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TRADE-OFF OF SEXUAL AND ASEXUAL RECRUITMENT IN A DOMINANT WEED *LIGULARIA VIRGAUREA* (MAXIM.) IN ALPINE GRASSLANDS (CHINA)

ABSTRACT: *Ligularia virgaurea* (Maxim.) is a typical naturally-occurring native noxious weed, widely distributed in alpine grasslands of the Tibetan Plateau, China. Three field sampling plots (30 m ´ 50 m) dominated by *L. virgaurea* were selected to study its population colonization mode and the relationship between sexual- and clonal-recruitment in alpine meadow of the Qinghai-Tibetan Plateau, NW China. Field investigations were conducted on its soil seed bank, seed rain and the individuals of new recruitment (seedlings and ramets) to study its sexual and asexual recruitment. And, 46 individuals which produced the seeds were selected randomly to study their relationship between seed production and ramet production. Results showed that there were more ramets (26.23 ramets m^{-2}) and less seedlings (6.70 seedlings m^{-2}) and a mean value of seed rain was close to 8.04 seeds m^{-2}, but the soil seed bank for this species was not found in study sites. Significantly negative correlations ($r = -0.416$, $P < 0.001$) between seed number per individual and ramet number per adult individual were found for *L. vrigaurea* in studied alpine grasslands. Our results revealed that clonal reproduction was the main population colonization mode. In addition, there was a significantly negative relationship between seed production and ramets for this species.

KEY WORDS: *Ligularia virgaurea*, ramet, seed, seedling, recruitment, alpine grassland.

1. INTRODUCTION

Ligularia virgaurea (Maxim.) is a perennial noxious weed with strong colonization and invasion ability in natural alpine grasslands of the Qinghai-Tibetan Plateau of China (Ma *et al.* 2005, Wang *et al.* 2008) and is mainly distributed in alpine grassland from 2700 to 4400 m. *L. virgaurea* can extend successfully and become an important component of the alpine plant communities in many habitats, and especially in heavily grazing-disturbed meadows. *L. virgaurea* is extremely harmful for grazing utilization, it is toxic to cattle and sheep, and thus selective grazing has led to a rapid increase in its abundance and it was becoming a great problem for local herdsmen.

The reproduction characteristic is one of the key life history traits with significant effects on fitness and colonization (Stearns 1992, Eriksson 1997, Ye *et al.* 2006). Many perennial plants can reproduce by both sexual and clonal means. The sexual and clonal reproductive modes have different function in their fitness characteristics (Bengtsson and Ceplitis 2000). *L. virgaurea* also colonize and expands population by both sexual- and asexual- reproduction (Wang *et al.* 2008), and is becoming dominant species in degraded or habitat-fragmented alpine grasslands of the Qinghai-Tibetan Plateau (Ma *et al.* 2006). Some studies were conducted to investigate its life history strategy and allelopathy effects on other species (Ma *et al.* 2005, 2006), which predicted that it has stronger colonization and invasion ability and it regenerates by means of both sexual (seed) and asexual (underground elongated rhizomes clone).

The trade-offs among components of reproduction in plants can be influenced by available resources and should reflect an alternative component of adaptation to the environment (Ronsheim and Bever 2000, van Kleunen *et al.* 2003). Plant can adjust their trade-off patterns of sexual and asexual reproduction to fit to the resources variation and trade-offs of reproductive strategy are an important evolutionary ways of plants for environment adaptation (Sutherland and Vickery Jr 1988, Bengtsson and Ceplitis 2000, Sun *et al.* 2001, Liu *et al.* 2009). However, among the published sources, most were conducted on sex allocation trade-off of plant reproduction (Bengtsson and Ceplitis 2000, Ronsheim and Bever 2000, Liu *et al.* 2009), few studies investigated the trade-offs of sexual and asexual recruitment. *L. virgaurea* is the wind-dispersal species and has favorable seed germination ability. However, little information is known on its colonization and invasion mechanism based on population recruitment and the relationship between sexual- and asexual-reproduction. It is essential to understand the role that seed reproduction and clonal growth play in maintaining population's recruitment of this species.

We conducted this field investigation to study: (1) the population colonization mode from reproductive characteristics for *L. virgaurea* in alpine meadow; (2) to assess whether there is a trade-off between sexual- and clonal-recruitment of this species.

2. MATERIAL AND METHODS

2.1. Study site

The sampling sites for *L. virgaurea* investigation were located in the eastern side of the Tibetan Plateau (33°45'N, 102°04'E, Maqu county, Gannan, Gansu Province) with an average altitude of over 3500 m a.s.l. The mean daily air temperature is 1.2°C, ranging from – 10°C in January to 11.7°C in July. Mean annual precipitation is 620 mm, mainly falling during the short, cool summer. The annual cloud-free solar radiation is about 2580 h. The vegetation is typical for alpine meadow and is dominated by clonal *Kobresia tibetica* (Maxim), *Kobresia kansuensis* (Kukenth),

Festuca ovina (Linn.), *Poa poophagorum* (Bor), *Roegneria nutans* (Keng), *Agrostis trinii* (Turcz.), *Saussurea hieracioides* (Hook.F.), *Anemone rivularis* (Buch.-Ham.), *Poa pratensis* (Linn.) and some other species (Wu *et al.* 2009). The average above ground biomass is 70–100 g dry mass per square meter. Typically, there are 20–30 vascular plant species and 800–1000 individual plants per square meter.

2.2. Sampling methods

We selected three similar sampling plots (30 m × 50 m) in alpine grassland dominated by *L. virgaurea* (Maxim.), and accompanied with *Kobresia pygmaea* (C.B. Clarke), *Elymus nutans* (Griseb.), *Stipa aliena* (Keng.), *Saussurea hioracioides* (Hook. f. View), *Poa pratensis* (L.), *Leontopodium leontopodioides* (Willd.) Beauv., *Anaphalis lacteal* (Maxim.), *Ranunculus tanguticus* (Maxim.), and *Euphorbia esula* (Linn.) and some other species. Five quadrates (50 cm × 50 cm) were set up along the diagonal line at each sampling plot. The coverage of *L. virgaurea* was about 40~50%. The soil seed bank sampling (in November 2007), seed rain collection (from June to November 2008) and recruitment pools (seedlings and ramets) investigation (during June 2008) were conducted by common methods (Kenkel *et al.* 1989). Soil seed bank was sampled using the concentration method (ter Heerdt *et al.* 1996). In each plot, 10 soil cores (5 cm diameter) of 20 cm depth were sampled along diagonal direction at regular intervals and all soil samples were put into the refrigerator (temperature 4°C) for two months. Sampling was carried out also during the end of November 2007 (after fall of mature seeds) in order to assess temporary sections of the seed bank (Baskin and Baskin 1998). Seed rain was collected using the methods of Booth and Larson (1998) from June to November 2008. In each sampling plot, ten seed traps (10 cm × 6 cm × 2 cm) were arranged in a 1.0 m grid (Aerts *et al.* 2006) at each plot. Seedlings were counted in each quadrate. All individuals of new recruitment were identified as seedlings from seeds or from asexual reproduction using excavating root method. 46 individuals which produced the seeds were selected randomly in three sampling plots to study their relationship between seed production and ramet production. The individuals from three sampling plots were repeated to reflect statistical sampling effect. All seeds of each individual were collected in succession from June to September 2008. Seeds of each fixed individual were collected and counted. Then ramet numbers for these fixed individuals were investigated along the rhizomes outspread direction by digging method.

Data of mean seed rain, seedlings and ramets in five quadrates of three sampling plots were regarded as repetitions. The correlation between the numbers of seeds and produced ramets was analyzed after data log-transferred. All data were analyzed with SPSS version 12.0 (SPSS Incorporated 2000) and tested for significance at $P<0.05$.

3. RESULTS

Results showed that *L. virgaurea* individual dispreads seeds with a mean 8.04 seeds m^{-2}. We found that there were the greater number of ramet recruitment (26.23 ramets m^{-2}) and the lesser number of seedling recruitment (6.70 seedlings m^{-2}; Fig. 1). But there was no soil seed bank for this species in our study samplings.

Population colonization mode of *L. vrigaurea* in alpine grassland was estimated as mostly depending on clonal-reproductive mode. The sexual-reproduction forming the seed rain is also presented but as the supplement to population colonization. The ramets (80%) showed significant dominance over seedlings (20%) among the individuals of *L. virgaurea* recruitment (Fig. 2).

A significantly negative correlation ($r = -0.416$, $P<0.001$) between average seed numbers per individual and average ramet numbers per adult individual were found for *L. vrigaurea* in studied alpine grassland (Fig. 3). *L. vrigaurea* produced more seeds with lesser ramets and lesser seeds with more ramets.

4. DISCUSSION

Ma *et al.* (2005) has reported that sexual reproduction plays an important role in plant population density in natural habitats. It may be the result of plants higher germination ability and seedling survival. But, our results showed that regeneration dynamics of *L. virgaurea* population is mainly dependent on asexual reproduction mode (ramet recruitment), and sexual-reproduction contributes a little to population colonization. It revealed that successful invasion and frequent colonization of *L. virgaurea* in alpine grassland was determined mainly by clonal-reproduction mode, and not by sexual-reproduction mode.

We found a significant trade-off between sexual- and asexual- reproduction of this species. It produced more seeds to enhance

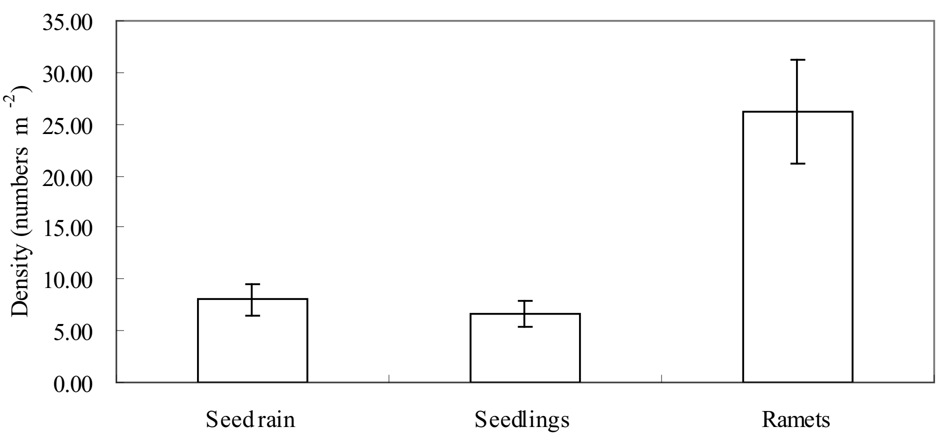

Fig. 1. Mean value (± SE) of seed rain numbers, seedling numbers and ramet numbers for *L. virgaurea* in studied alpine grassland. Seed rain in this study was taken as the number of seeds dispersed and collected in seed traps.

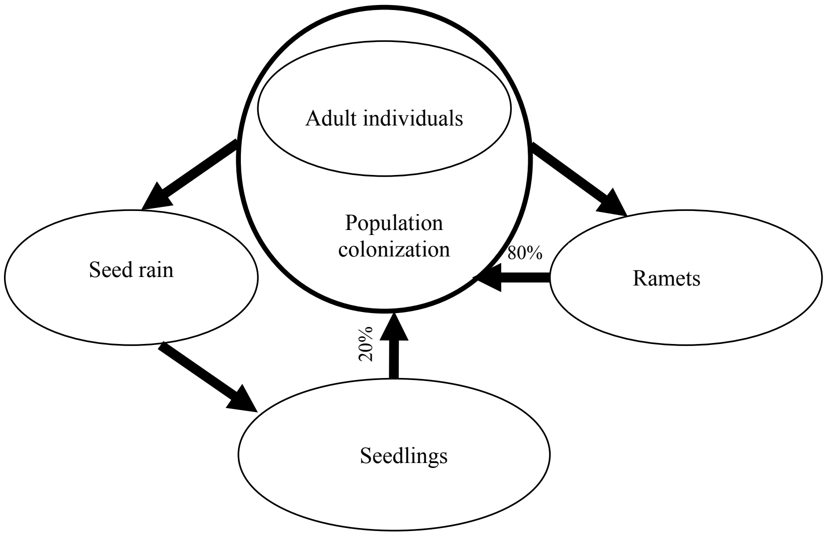

Fig. 2. Population colonization mode for *Ligularia virgaurea* in alpine grassland in this study. Ramets and seedlings give approximate contribution to population up to 80 and 20%, respectively. Seed rain was considered as the seed numbers dispersed and collected by seed traps.

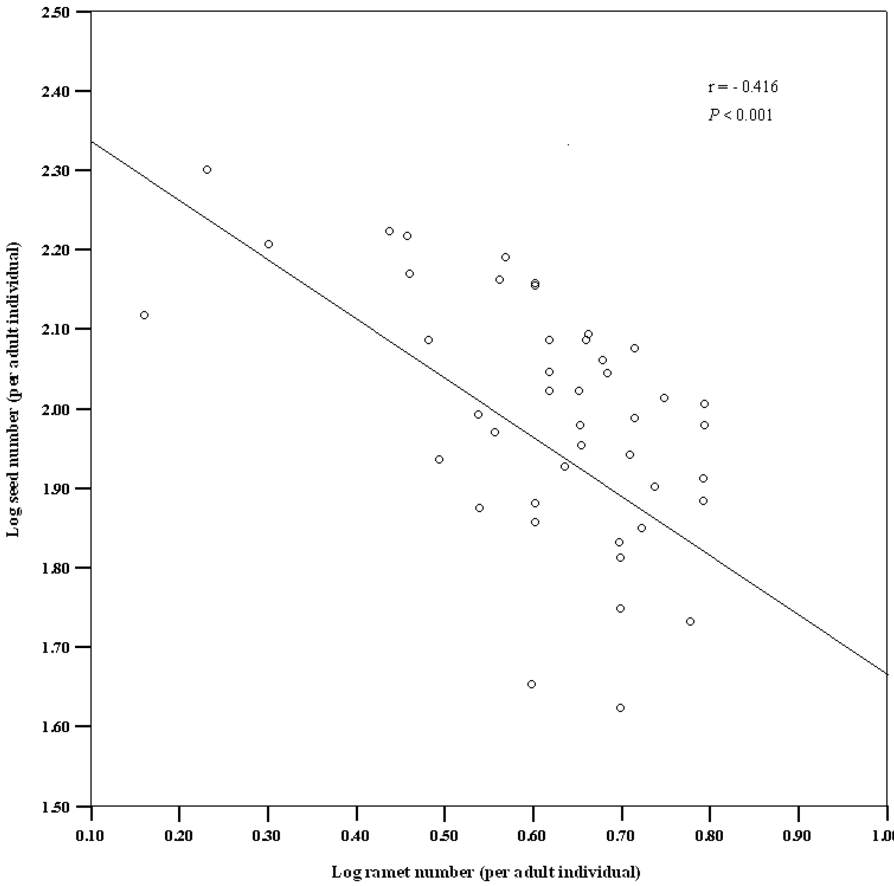

Fig. 3. Relationship (r = – 0.416, P <0.001) between the logarithm of the numbers of seeds and ramets produced by each adult plant of *Ligularia virgaurea*. 46 samples were examined. Seed numbers consist the total numbers of seeds produced in each sampling individual before dispersing.

its sexual-reproduction to expand the dispersal and invasion opportunity in community when resources were favorable. It can adjust the trade-off pattern of sexual and asexual recruitment to fit the alpine environment and resource competition in high-density community. Our results revealed that there was a trade-off between seed reproduction and ramet reproduction. It can be interpreted that the species keeps its successful recruitment by alternative reproductive modes (Maurer and Zedler 2002, Chu *et al.* 2006). Sexual reproduction *via* seeds is better way for founding new populations and maintaining gene diversity because of their small size and adaptation to dispersal (Eriksson 1997). While clonal reproduction *via* rhizomes or ramets is considered to be more successful for keeping the population density in stable habitats (Philbrick and Les 1996). Restricted resource allocation to different plant functional organization was mutually exclusive (Tilman 1998). More resources were allocated to clonal reproduction when sexual reproduction was restricted, because the more resource investment to one of the two reproduction modes will weaken the investment to the other reproduction mode in plant when resources were limited (Westley 1993, Liu *et al.* 2005). A pot experiment also has suggested a trade-off between vegetative growth and clonal reproduction under high light availability. It was found that plants of *L. virgaurea* would emphasize clonal reproduction under the full natural irradiance, while vegetative growth is undertaken under the shade conditions (Wang *et al.* 2008). Other studies also suggested that plant will proportionally allocate more biomass to clonal reproduction and produced lesser seeds in quantity, when resources became limiting factor for plant growth (Eriksson 1997, Li *et al.* 2005, Ye *et al.* 2006). Resources heterogeneity can affect reproduction and growth mode in plants (Lovett 1981, Eriksson 1992, Suzuki *et al.* 1999, Marushia and Holt 2006). Adaptation to resources heterogeneity was considered as a main interpretation for trade-off of plant sexual- and asexual- reproduction (van Kleunen and Fischer 2003). So, more researches on trade-off between sexual- and clonal- reproduction and their relative contributions to population dynamics should be conducted in future under habitats with heterogeneous resources.

Our results showed that there was no soil seed bank storage of *L. virgaurea* population and only a small quantity of seed rain, because most perennial species in grasslands have only transient seed banks. *L. virgaurea* population regeneration in degraded grasslands will create a certain microhabitat for some other species, because microsite heterogeneity in communities is potentially important for conspecific and interspecific seedling growth and survival (Chambers 1995, Marushia and Holt 2008). Weeds have been shown to enhance the survivorship and effectiveness of beneficial arthropods in agricultural landscapes (Landis *et al.* 2005), as they function as the cover species (Gliessman 1998).

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