Bullying the Bullies: The Selective Control of an Exotic, Invasive Annual (*Rapistrum rugosum*) by Oversowing with a Competitive Native Species (*Gaillardia pulchella*)

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Abstract

Mechanical, biological, and chemical attempts to control invasive plants can be expensive, ecologically damaging, and frequently unsuccessful. This study proposes using the intrinsic biological attributes of the threatened plant community by artificially increasing the density of competitive native species to selectively suppress the growth of the invasive. Evidence from agricultural weed control suggests that oversowing infested areas with species with biological traits similar to those of the invasive species not only reduces productivity of the invasive species but also may eliminate environmental damage associated with standard control techniques. Annual bastard cabbage (*Rapistrum rugosum*), a Eurasian exotic, is an invader of native plant communities in the continental United States. Control with herbicides has been problematic due to high mortality of adjacent native species and subsequent perpetuation of a disturbed state that facilitates further regeneration of *R. rugosum* from the seed bank. In a randomized field experiment, sowing native Indian blanket (*Gaillardia pulchella*) over established seedling colonies of *R. rugosum* resulted in significant reduction of *R. rugosum* productivity ($F = 3.43$; $p < 0.05$). The highest sowing rate of *G. pulchella* resulted in a 72% reduction in aboveground productivity of *R. rugosum* that translated to an estimated 83% decrease in seed set, without significant suppression of adjacent native species. It is proposed that enriching threatened or infested plant communities with selected native species with matching phenologies and competitive characteristics has advantages over conventional control methods in that (1) it reduces the threat to nontarget organisms; (2) once installed, the species could self-regenerate; and (3) it does not perpetuate a disturbed (early-successional) state that might aggravate the problem. This may serve as an alternative technique to protect and restore native plant communities.

Key words: competition, *Gaillardia pulchella*, invasive, native species, *Rapistrum rugosum*.

Introduction

Invasive plants can cause a variety of problems in native plant communities: excluding native species; altering habitat, hydrology, and nutrient cycling; and significantly impacting plant and animal diversity (Vitousek 1986; Huston et al. 1994; Packard & Mutel 1997; Hall et al. 2000). Development and implementation of safe, effective eradication or control agents requires considerable time and resources, and such programs are frequently unsuccessful (Dahlsten 1986). Furthermore, without careful selection and implementation, many chemical, mechanical, and biological control methods can themselves be detrimental to nontarget species and ecosystem health, which may accelerate the process of invasion (Packard & Mutel 1997; Sheley & Krueger-Mangold 2003). Over recent years, the increase in awareness of the problems associated with the use of herbicide as a "silver bullet" approach to invasive species control, combined with concerns over environmental health, has caused a shift of focus toward alternative, ecologically based, longer-term solutions (Hall et al. 2000; Sheley & Krueger-Mangold 2003). However, research efforts have mainly focused on extrinsic (mechanical, chemical, and biological) control methods. This study proposes using intrinsic biological attributes of selected native plant species within the threatened community to competitively suppress or exclude the invasive species.

Although it is difficult to make useful generalizations about the biology of invasive species, various models have been proposed, involving dispersal ability, population biology, spatial dynamics of invasion (Rejmanek 1996; Peterson & Vieglas 2001), lack of natural "enemies" (Huston 1994), and characteristics of the invaded ecosystem (Radosevich et al. 2003). An invasive plant that successfully establishes in a "stable" plant community demonstrates that it is able to outcompete its new neighbors for one or more resources. However, Elton (1958) hypothesized that plant communities with higher diversity might be more likely to resist invasion due to niche saturation and higher incidence of interspecific competition

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(Naeem et al. 2000) (but see Palmer & Maurer 1997; Huston 2004). The successful establishment of an invasive species in a plant community does not imply that all the native species in that community are unable to compete with the exotic. Rather, it may be that any native competitors may be locally absent. It is not uncommon for native plant communities, particularly those which are early successional, to have unoccupied microsites due to seed limitation (Turnbull et al. 2000). Therefore, the success of a potential competitive (i.e., invasive) species may simply be dependent on the seed limitation of an equivalent or superior native competitor (Turnbull et al. 2000). These scenarios permit the possibility that one or more species within the invaded system may still have the potential to be able to successfully compete with the invader but happen to be locally absent or at low densities. Once identified, the density of these competitively aggressive species could be artificially increased to enrich the threatened natural community and suppress the invader's spread.

Elevating seed densities to control undesirable plants by increasing interspecific competition is a technique used frequently in agriculture, particularly when a selective herbicide is not available (Jasieniuk et al. 2001; Roberts et al. 2001). Numerous studies demonstrate that the manipulation of seeding rates of a competitive crop can suppress weed production and erode the weed seed bank (Blackshaw et al. 2000*a*, 2000*b*; Nice et al. 2001; Roberts et al. 2001; Boydston & Vaughn 2002). The competitive abilities of a tertiary crop for weed suppression in cropping systems, a so called "living mulch," have also been examined in agricultural systems (see Hartwig & Ammon 2002 and Kobayashi et al. 2003, for reviews), and more recently in restoration efforts (Perry & Galatowitsch 2003). In an invaded plant community in the Great Basin, field and transplant studies of the relationships between the exotic grass (*Bromus tectorum* L.) and the perennial native grass (*Elymus elymoides* Raf.) suggest competitive displacement of the exotic by the native grass (Booth et al. 2003). Seed addition of perennial grasses has also been successfully used to control Russian knapweed (*Acroptilon repens* L.) when used in combination with initial herbicide application (Bottoms & Whitson 1998; Benz et al. 1999; Bottoms et al. 2001; Whitson 2001). In a California grassland, the addition of seed established long-term viable native species populations, despite the presence of exotic species (Seabloom et al. 2003). Seabloom et al. (2003) suggest that the dominance of the invasive species is a consequence of open microsites due to seed limitation of the native components rather than relative competitive abilities of the invaders. If this is true, then such augmentation of the native seed bank may potentially retard, arrest, or reverse exotic invasion.

This project tests the hypothesis that oversowing an annual invasive species, Annual bastard cabbage (*Rapistrum rugosum* (L.) All.), in the early stages of growth with a phenologically synchronous, competitive, "combatant" native species, Indian blanket (*Gaillardia pulchella* Foug.), can reduce the productivity and seed production of the invasive species without the detrimental ecological side effects normally associated with other control methods.

Methods

Target Species

Rapistrum rugosum is an annual herb from Eurasia that has sporadically naturalized in North America and in other parts of the world (Brown 1878; Lemke & Worthington 1991). In central Texas, this species inhabits disturbed and nondisturbed areas such as agricultural fields, roadsides, forests, and riparian features, and appears to be expanding its range into the Edwards Plateau to the west and the Rio Grande valley in the southern regions of the state (Lemke & Worthington 1991). Its rapid infestation along Texas' roadsides has become a high-profile problem due to its perceived replacement of the native spring wildflowers, which in the public eye are a prominent characteristic of Texas landscapes (Fig. 1). *Rapistrum rugosum* has been consequently listed as a noxious weed (USDA 2002). Usually germinating in the fall and overwintering as a basal rosette, it initiates flowering relatively early in the spring (occasionally late spring, fall, and winter), frequently forming dense, largely monospecific patches, which may persist for several seasons. Although not restricted to Brassicaceae, patch persistence has been attributed to high pollination rates and short dispersal distances, in addition to the presence of allelochemicals (Auerbach & Shmida 1987). Early flowering and patch formation and persistence have been shown to increase pollination and reduce herbivory (Auerbach & Shmida 1987), and such traits are not uncommon in many annual and perennial forbs species (Dieleman & Mortensen 1999; Eber & Brandl 2003).

Figure 1. A continuous colony of *Rapistrum rugosum* dominates an established roadside plant community of native grasses and forbs.

The competitive ability of many crucifers is further enhanced due to high resistance to herbivory and species phenology; for example, *R. rugosum* grows and flowers at the beginning of spring before the peak of herbivorous insect populations. High growth rates, tall stature ($\overline{X}$ height around 20–80 cm [Auerbach & Shmida 1987; Lemke & Worthington 1991; Diggs et al. 1999]), copious seed production, and large rosette diameter (10–50 cm) of *R. rugosum* can facilitate the competitive exclusion of phenologically synchronous native species. Therefore, effective control of *R. rugosum* is of increasing concern for native plant conservationists, roadside vegetation managers, ranchers, and farmers.

Unfortunately, as is true for other invasive crucifer species, control is fraught with difficulties. There is no known effective biocontrol (Hashem et al. 2001), and selective herbicides used in agriculture have been shown to become ineffective after several generations (Adkins et al. 1997; Hashem et al. 2001). Although short-term control of *R. rugosum* in roadside plant communities can be achieved through the use of a broad-spectrum herbicide, consequent pulses of germination from the existing seed bank into an early-successional site can maintain or even enhance the population. Furthermore, herbicidal treatment may have a compounding effect of sustaining these treated sites in an ecologically disturbed state, thereby facilitating further infestation from the remaining dormant seed bank.

Study Site

Experiments were conducted on a 300-m-long rural roadside site, near Austin, Texas (lat 30° 11′N, long 97° 52′W; elevation 247 m; mean annual rainfall 810 mm). The embankment had a 20% southeast-facing slope, with soils derived from existing clayey, mixed thermic, lithic argiustolls of the Speck series (10–50 cm deep) (USDA 1974). Climate is subhumid, subtropical, with bimodal rainfall pattern peaking in spring and fall. Rainfall during the study period (October 2000–May 2001) was 616 mm (30-year mean for the same period was 476 mm).

Experimental Design

The common native annual species, *Gaillardia pulchella*, was selected for oversowing due to its life history, which is approximately synchronous with *R. rugosum* (i.e., fall/winter germination followed by spring flowering), and its ecological characteristic as a competitive generalist forming dense, expansive colonies in a wide range of habitats (Heywood & Levin 1985; Diggs et al. 1999). Field observations also indicated that despite the common occurrence of both *R. rugosum* and *G. pulchella* along roadsides, they rarely coexisted, possibly due to an antagonistic effect. To more objectively assess this relationship, percent cover values of species occurring in a roadside community containing both *R. rugosum* and *G. pulchella* were recorded in 1-m^2 quadrats ($n = 21$) placed at 3-m intervals along a 60-m transect in close proximity to the sowing study. These values were reciprocally transformed and Pearson's product–moment correlation coefficients (Zar 1999) calculated between species.

In October 2000, three densities (0, 2, and 10 g/m^2; $n = 30$) of *G. pulchella* seeds were hand-sown in 0.25-m^2 plots randomly arranged along a 300-m transect running parallel to the roadside shoulder. This transect ran through a plant community, which included a more or less homogeneous, continuous colony of recently germinated seedlings of *R. rugosum*. The following late spring (May 2001), the plots were harvested, plants oven-dried, and weighed, and stems (individuals) for each species counted separately. Dry weight data were log-transformed for statistical analysis. Effects of treatments on stem density were examined with Kruskal–Wallis one-way analysis of variance (ANOVA) on ranks, and treatment on aboveground dry mass analyzed using one-way ANOVA with Tukey honestly significant differences test ($p \leq 0.05$). An estimate of the relationship between plant dry weight and seed production of *R. rugosum* was determined by weighing individual plants ($n = 30$) across a range of sizes, and weighing and counting total number of seeds.

Results

Four species dominated the experimental plots, *Rapistrum rugosum* (invasive), *Gaillardia pulchella* (native), Horsemint (*Monarda citriodora* Cerv. ex Lag.) (native), and Bluebonnet (*Lupinus texensis* Hook.) (native). Counts of individuals revealed no difference between treatments for any species (Table 1). However, seeding rate had a significant inverse relationship with total shoot mass of *R. rugosum* ($F = 3.43$; $p < 0.05$) but had no significant effect on the other native species (Fig. 2). *Lupinus texensis* indicated an inverse trend, *M. citriodora* a positive relationship, and *G. pulchella* a weak "humpback" relationship, with maximum production at the medium density of oversowing (Fig. 2).

Rapistrum rugosum whole-plant dry mass had a positive, quadratic relation to total seed capsule weight ($R^2 = 0.922$; $p < 0.001$) (Fig. 3), which, in turn, had a positive, linear relationship with total seed number ($R^2 = 0.924$; $p < 0.05$, data not shown).

Table 1. The effect of oversowing *Gaillardia pulchella* seeds on stem (individual) density ($\overline{X}$ ± SE) of *Rapistrum rugosum* and three dominant native species.

G. pulchella Seed Rate (g/m^2)	*Stem Density (per m^2)*			
	R. rugosum	*G. pulchella*	*Lupinus texensis*	*Monarda citriodora*
0	50.8 (±8.2)	25.6 (±4.1)	15.6 (±1.7)	15.2 (±2.8)
2	34.8 (±3.9)	29.2 (±7.1)	11.2 (±2.5)	23.6 (±4.4)
10	49.2 (±9.1)	21.6 (±4.4)	15.6 (±3.0)	23.6 (±7.5)

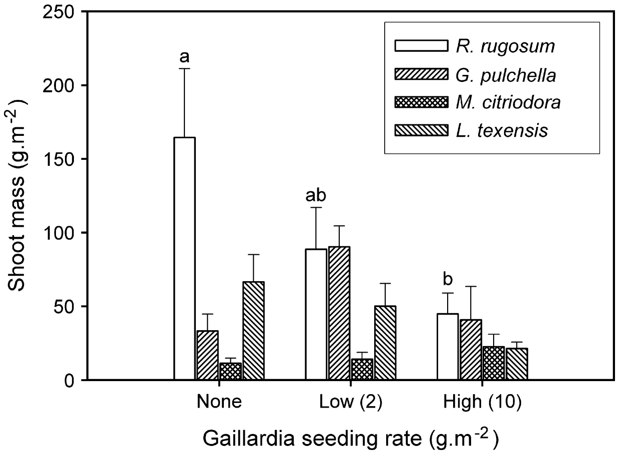

Figure 2. The effect of oversowing seeds at three different rates on the production of *Rapistrum rugosum, Gaillardia pulchella*, *Monarda citriodora*, and *Lupinus texensis*. Bars with different letters are significantly different at 0.05 level.

The survey of an existing roadside community infested with *R. rugosum* revealed a total of 18 species, of which, 8 occurred less than five times and were removed from the analysis. Correlation analysis indicated that both *G. pulchella* and *Bromus japonicus* (an invasive exotic) demonstrated a significant negative coefficient with *R. rugosum* (Table 2).

Discussion

Although this study does not allow insight into the underlying mechanism of the apparent antagonistic effect of oversowing one species with another, it indicates that *Gaillardia pulchella* may have competitively suppressed the productivity of the non-native, target species. Moreover, *G. pulchella* had a less suppressive effect on the two other dominant native species present. Intraspecific competition may have caused a marked decrease in *G. pulchella* productivity at the highest rate of seed density. These data suggest that native seed oversowing may potentially selectively suppress the growth of the non-native target species. Although the resultant interspecific competition by oversowing with highly competitive native species may also suppress "compatriot" native species populations, the trend indicated in this study by *Lupinus texensis* suggests that any negative effect might be damped because of long-term coexistence and adaptation (Callaway & Aschehoug 2000).

The highest sowing rate of *G. pulchella* used in this study resulted in a 72% reduction in aboveground dry mass. This translates to an estimated 83% decrease in seed set due to the quadratic relationship of plant mass to seed mass (Fig. 3). This may have positive implications for the reduction of the targeted invasive species. However, this study did not allow examination of long-term effect on the target species, and any impact of this technique might be subsequently damped or canceled the following season by a preexisting seed bank. Similarly, however, the native seed bank may also be elevated as a consequence of native seed addition (*G. pulchella* is a prolific seeder), which might influence the plant community in the subsequent seasons. Evidently, the long-term effectiveness of this approach requires further examination.

Although this study demonstrated an interspecific density effect, the mechanism was not established, and a similar outcome might not occur under different environmental circumstances. Interspecific competition can occur both above- and belowground, where ecological niches overlap through exploitation of one or more resource (Tilman & Wedin 1991). However, the multidimensional characteristics of a species niche imply that change in one variable (e.g., seasonality of rainfall) may result in a different outcome. The nature of the competitive relationship of these two species therefore requires further experimental investigation, where each pair of species (native species vs. *Rapistrum rugosum*) is grown at a range of plant densities and under a selection of different abiotic conditions.

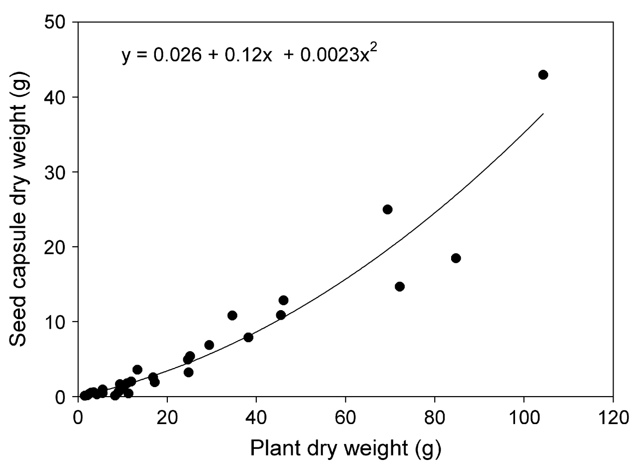

Figure 3. The relationship of whole-plant dry weight of *Rapistrum rugosum* to seed capsule weight (g).

Oversowing Species Selection

Assuming that edaphic and disturbance conditions were homogenous, the negative correlation of the target species with *G. pulchella* in a native plant community infested with *R. rugosum* (Table 2) is an indication of potential suitability of this species for further investigation. The additional information that *G. pulchella* has phenology similar to *R. rugosum*, is a habitat generalist, produces abundant seed, and is common and commercially available made *G. pulchella* a good candidate for field testing.

Evidence from weed science suggests that crop species can be used to suppress weed productivity at affordable loss of crop yield at certain densities. However, this does

Table 2. Correlation matrix (Pearson's coefficient) for cover (reciprocally transformed) of eight species and bare ground along a *Rapistrum rugosum*–infested community along a roadside.

	Bare Ground	*Bromus japonicus*	*Centaurea melitensis*	*Gaillardia pulchella*	*Nasella leucotricha*	*Plantago rhodosperma*	*R. rugosum*	*Sonchus sp.*	*Thelesperma filifolium*
Bromus japonicus	−0.329								
Centaurea melitensis	−0.562*	0.091							
Gaillardia pulchella	−0.258	0.354	−0.218						
Nasella leucotricha	−0.484	−0.282	−0.342	0.279					
Plantago rhodosperma	0.147	−0.347	−0.522**	−0.456**	0.116				
R. rugosum	0.209	−0.593*	0.402	−0.575**	−0.226	−0.066			
Sonchus sp.	−0.601**	−0.145	0.056	−0.213	−0.707	−0.401	0.070		
Thelesperma filifolium	−0.015	0.364	−0.271	0.350	0.491	−0.403	−0.360	−0.173	
Torillis arvensis	0.484	0.289	−0.108	−0.139	0.632	−0.194	−0.481*	−0.474**	−0.304

*$p < 0.1$; **$p < 0.05$.

not necessarily reflect the crop's competitive ability but rather the effect of "crowding-out" the target species. To maximize the efficiency of the process of oversowing to combat invasives in a native plant community, it would be preferable to identify more than one competitive species, from the spectrum of native species available. Natural plant communities comprise a range of species with different requirements and competitive characteristics, any one of which may be a superior competitor to a potential invasive species. However, the identification of the most promising candidate species for oversowing presents a challenge. Selection of these combatant species, if they exist at all, will depend on the land manger's ability to identify those that exhibit traits similar to that of the target species (e.g., phenology, growth habit), are common (suggesting more generalistic biological traits), occur naturally in relatively high densities, and, for practical purposes, are commercially available or easily harvested. Quantitative phytosociological analysis, for example, nonmetric, multidimensional scaling, or detrended correspondence analysis (Kent & Coker 1992), might be an additional aid in this selection process where the invasive species has already become established in the native plant communities. Although relative location within an ordination or correlation matrix does not necessarily infer direct antagonism/attraction between two species (there may be other underlying historic, edaphic, or biological variables), it may highlight potential candidate species for further investigation.

Implications for Restoration and Conservation

This study examined the use of oversowing with annual native forbs in an early-successional (frequently mowed) grassland, where native seed limitation may be a contributing factor (Turnbull et al. 2000). In plant communities that are later successional, heavily infested, or have high canopy cover, the implementation of this technique with other conventional techniques such as herbicide application, prescribed fire, mowing, seed drilling may be needed to increase the probability of success (e.g., Bottoms et al. 2001; Whitson 2001). In other physiognomic plant communities, such as forests and shrublands, where large-scale mechanisms drive regeneration, this technique may require further modification. Plant communities that have been dramatically altered, either chemically, biologically, or mechanistically by plant invasion, may not readily respond to this technique and will require further study. Many invasive species succeed because their life history traits are significantly different from those of the member species of the invaded community. In these cases, a candidate for oversowing in the native community may not even exist.

There may be potential dangers associated with this method if used at a large-scale. The establishment of dominance of the combatant species, albeit a native one, may have negative consequences for some members of the native plant community, which may be less robust in terms of competitive abilities or low abundances. Similarly, the selection of allelopathic species for oversowing may cause long-term problems for the native community. Clearly, species selection and sowing densities need careful consideration and trial before the technique is installed on a large-scale.

Despite the potential problems, I propose that this approach poses fewer risks compared to conventional (including biological) techniques, and has several advantages because

- The "active ingredient" is (or was) already present in the plant community.
- The technique poses little threat to nontarget organisms.
- It does not perpetuate a disturbed (early-successional) state, which can aggravate the problem.
- Once established, a viable population of the selected native combatant species may self-perpetuate in successive seasons, thereby applying continual competitive pressure on the target species and buffering against further invasion.
- It has relatively low environmental impact.
- It is potentially relatively inexpensive.

The results of this study and the proposed application advantages of this technique call for further investigation of this method. Although it is not anticipated that this method will necessarily completely eradicate an invasive species in natural systems, these data suggest that oversowing with native plants could reduce invasive populations to the point where they could be eradicated using conventional treatments.

Acknowledgments

I would like to thank staff and volunteers of the Lady Bird Johnson Wildflower Center, in particular Daniel Dietz, Marcia Hermann, Guy Thompson Jr., and Jill Springall, for their valuable assistance in the field, and Steve Windhager for review of the draft manuscript. I also thank the coordinating editor, James Aronson, and two anonymous reviewers for their comments. I also appreciate the generous support from the Houston Endowment, The Brown Foundation, Inc., The George & Mary Josephine Hamman Foundation, The Margaret Cullinan Wray Charitable Lead Annuity Trust, and the Magnolia Charitable Trust whose funding support made this research possible.

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