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Developing minimal-input techniques for invasive plant management: perimeter treatments enlarge native grass patches

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Note

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Abstract

There is a continual need for invasive plant science to develop approaches for cost-effectively benefiting native over nonnative species in dynamic management and biophysical contexts, including within predominantly nonnative plant landscapes containing only small patches of native plants. Our objective was to test the effectiveness of a minimal-input strategy for enlarging native species patches within a nonnative plant matrix. In Pecos National Historical Park, New Mexico, USA, we identified 40 native perennial grass patches within a matrix of the nonnative annual forb kochia [*Bassia scoparia* (L.) A.J. Scott]. We mechanically cut *B. scoparia* in a 2-m-wide ring surrounding the perimeters of half the native grass patches (with the other half as uncut controls) and measured change in native grass patch size (relative to pretreatment) for 3 yr. Native grass patches around which *B. scoparia* was cut grew quickly the first posttreatment year and by the third year had increased in size four times more than control patches. Treated native grass patches expanded by an average of 25 m^2, from 4 m^2 in October 2015 before treatment to 29 m^2 in October 2018. The experiment occurred during a dry period, conditions that should favor *B. scoparia* and contraction of the native grasses, suggesting that the observed increase in native grasses occurred despite suboptimal climatic conditions. Strategically treating around native patches to enlarge them over time showed promise as a minimal-input technique for increasing the proportion of the landscape dominated by native plants.

Introduction

Questions of how and where to prioritize treating nonnative plants within landscapes are fundamental to invasive plant management and key research priorities (Davies and Sheley 2011; Ransom et al. 2012). Within landscapes containing a matrix of native species with small, discontinuous patches of nonnative plants, treatments for nonnative plants are often prioritized based on criteria such as size of nonnative patches and feasibility of removal, invasiveness of nonnative species, or resource values threatened by nonnative plant invasion (Rew et al. 2007). However, many contemporary landscapes instead have the inverse patch structure, in which landscapes contain a matrix of nonnative plants and only small, discontinuous patches of native species (Gilbert and Levine 2013). In these cases, treatments are usually prioritized among sites, which are then treated in their entirety or in systematically distributed sections (Abella 2014).

Given limited resources for management, an alternative to treating entire sites could be a minimal-input approach that prioritizes treatments around the perimeters of native species patches to potentially enlarge them over time within the nonnative plant matrix. Little research exists directly examining the potential efficacy of this approach, and related literature suggests both possible hindrances to the approach and ideas as to why it could be effective. For example, hindrances could include limited native species propagules, legacy effects of nonnative plant presence, and environmental limitations to native plant recruitment such as dry conditions possibly exacerbated in small native patches (Corbin and D'Antonio 2012; Cutway 2017; Pearson et al. 2016). In contrast, other ideas, such as the importance of gap-phase recruitment in competitive stands and opening regeneration niches, predict that creating growing space around native patches should enlarge them (Davies and Sheley 2011; Zimmerman et al. 2018). Additionally, for native species in patchy refugia, extinction risk can be lowered by increasing the size and connectivity of native species patches (Gilbert and Levine 2013).

We assessed the efficacy of a minimal-input technique for increasing native species within a nonnative plant matrix by strategically treating around the perimeters of native grass patches in

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Management Implications

Many contemporary landscapes contain small patches of native species within a matrix of nonnative plants, necessitating decisions for how to most effectively deploy limited resources for invasive plant management. A potential way to prioritize treatments for maximum benefit on such landscapes is to strategically treat around the native patches to enlarge them over time, but this strategy has been little evaluated. We tested this strategy within a monotypic matrix of the nonnative annual forb *Bassia scoparia* (kochia) with scattered patches of native perennial grasses. Mechanically cutting *B. scoparia* within a 2-m buffer surrounding native grass patches rapidly enlarged native patches the first growing season. The positive response continued through the third and final year of the experiment, when treated native patches were seven times larger than before treatment. The expansion of native patches occurred despite dry conditions likely suboptimal for perennial grass growth. Results suggest that within landscapes dominated by nonnative plants with small native grass patches, prioritizing treatments around native patches can quickly enlarge them and be a minimal-input strategy benefiting native species.

a dual context of archaeological and natural resource conservation. Managing for native vegetation compatible with archaeological resource preservation is challenging in diverse locations globally, such as around Iron Age earthworks in Europe (Jones 1998). In the United States, native vegetation is frequently needed in national historical parks for maintaining authenticity of cultural resources such as battlefields, stabilizing earth- and stoneworks constructed by Native Americans, and protecting artifacts held in soil (Thorne 1990). Generally, for stabilizing soil-held archaeological features or material surrounding stone structures, relatively shallow- and laterally rooted, short-statured species are optimal for protecting soil while allowing access to archaeological features for maintenance and viewing (Jones 2000). With their laterally extensive, fibrous root systems and low aboveground height, native perennial shortgrasses are often ideal for stabilizing archaeological sites (Jones 2000). On an archaeological site containing small native grass patches in a matrix of nonnative forb monoculture (kochia [*Bassia scoparia* (L.) A.J. Scott]), we tested a hypothesis that treating nonnative forbs around perimeters of native grass patches would enlarge native patches.

Materials and Methods

Focal Nonnative Species

Native to Europe and western Asia, *B. scoparia* is an annual forb equipped with traits for invasiveness, especially in arid/semiarid regions outside the species' native range. Since its introduction as an ornamental to North America during the 1800s, *B. scoparia* has become one of the most widespread nonnatives in western North America, invading agricultural fields, pastures, rangelands, roadsides, and a variety of disturbed sites in semiarid grasslands and woodlands (Friesen et al. 2009). *Bassia scoparia* employs C_4 photosynthesis, is capable of deeply rooting to 5 m, and has high water-use efficiency, enabling competitive ability on dry, hot soil (Friesen et al. 2009; Phillips and Launchbaugh 1958). *Bassia scoparia* frequently forms monocultures, with one study recording 380,000 freshly germinated seedlings m^{-2} (Dille et al. 2017). Most *B. scoparia* seeds exhibit minimal innate dormancy and readily germinate under suitable conditions, although the species can form soil seedbanks persisting across years (Zorner et al. 1984). A seed burial experiment in the Great Plains reported that most *B. scoparia* seeds in soil were short-lived (1% remaining at 3 yr), but that some germination occurred 10 yr after burial (Burnside et al. 1996). *Bassia scoparia* can be controlled with herbicides, but the species' increasing resistance to herbicide can hinder effectiveness (Kumar et al. 2019).

Study Area

We performed the experiment in the 2700-ha Pecos National Historical Park, 40 km southeast of the city of Santa Fe in north-central New Mexico, USA. The park, administered by the U.S. National Park Service since 1965, is managed for human visitation while conserving natural and cultural features, including Pecos Pueblo structures representative of 700-yr-old Native American architecture and Spanish Colonial mission churches constructed from 1625 to 1717. The park is a transitional area where three biogeographic regions meet: the southern Rocky Mountains to the north, the Great Plains to the east, and the Basin and Range Province to the southwest (Johnson 1969). The semiarid climate, recorded at an elevation of 2,116 m at the park headquarters, has averaged the following from 1916 through 2018: −9/8 C January daily low/high temperature, 12/30 C July daily low/high temperature, and 41 cm yr^{-1} of precipitation, including 69 cm of snowfall. Livestock grazing has been excluded since 1935 where we conducted the experiment.

The study site (35.54°N, 105.69°W) within the park was a 2-ha area encircled by the Pueblo and Mission Ruins Visitor Trail, encompassing the cultural resources of stone and rubble mound structural remains of Pueblo Native American cultures; a historical missionary church; and cultural material held in soil, including pottery fragments, faunal bone, and stone tools. Possibly related to a long history of anthropogenic use, the site was minimally vegetated by woody plants in the late 1800s and early 1900s, as shown in historical photographs and descriptions when initial archaeological investigations began (Kidder 1958). Based on historical descriptions and contemporary distributions of vegetation types at similar elevations in less-disturbed areas, *Pinus–Juniperus* woodland with openings of shortgrass grassland may represent the natural vegetation type at the site. While exactly how or when *B. scoparia* invaded the site is unclear, it is thought to have invaded the site before the mid-1900s. In 2015 when we began the experiment, the site contained a near monoculture of *B. scoparia* surrounding the archaeological features and often growing in or on top of them in the case of collapsed stone, adobe brick mounds, and soil-held features. Small patches (0.1 m^2 to several square meters) of native perennial grasses were interspersed within the *B. scoparia* matrix.

Experimental Design, Treatments, and Data Collection

In October 2015, before treatment, we identified 40 native perennial grass patches to serve as experimental units distributed throughout the matrix of *B. scoparia*. We defined native perennial grass patches as containing one or more genets of the same species covering at least 0.1 m^2 and separated by at least 4 m (with the intervening matrix area being *B. scoparia* monoculture) from another patch of the same or different grass species. There were 10 patches each (equally subdivided by treatment) of four focal native perennial grass species (their nomenclature, traits, and average cover are provided in Table 1). We randomly assigned a *B. scoparia* cutting treatment to half ($n = 20$) the patches, while

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Table 1. Names, traits, and average cover of native perennial grasses in 12.6-m^2 circular plots (2-m radius) centered within native grass patches around which the nonnative annual forb *Bassia scoparia* was mechanically cut ($n = 20$) or not cut ($n = 20$) in Pecos National Historical Park, New Mexico, USA.[a]

Scientific name	Common name	Description	Uncut	Cut
Focal species			-------- % cover[b] ----------	
Bouteloua gracilis (Willd. ex Kunth) Lag. ex Griffiths	Blue grama	C_4 bunchgrass	1.2 ± 0.9	0.2 ± 0.1
Bouteloua hirsuta Lag.	Hairy grama	C_4 bunchgrass	1.5 ± 0.6	8.6 ± 3.1
Elymus elymoides (Raf.) Swezey	Squirreltail	C_3 bunchgrass	0.3 ± 0.1	0.1 ± 0.1
Pascopyrum smithii (Rydb.) Á. Löve	Western wheatgrass	C_3 rhizomatous	28.6 ± 6.5	35.8 ± 6.2
Additional species				
Achnatherum robustum (Vasey) Barkworth	Sleepygrass	C_3 bunchgrass	0.0 ± 0.0	0.1 ± 0.1
Bouteloua dactyloides (Nutt.) J. T. Columbus	Buffalograss	C_4 rhizomatous	0.4 ± 0.4	0.0 ± 0.0
Muhlenbergia repens (J. Presl) Hitchc.	Creeping muhly	C_4 rhizomatous	1.4 ± 0.9	3.7 ± 3.1
Sporobolus cryptandrus (Torr.) A. Gray	Sand dropseed	C_4 bunchgrass	0.3 ± 0.2	0.0 ± 0.0

[a]Grasses are divided into focal species present in patches when the experiment began in 2015 and additional species occurring within the patches later in the experiment. Average cover is for the final measurement in October 2018, 28 mo after the first *B. scoparia* cutting treatment.
[b]Mean ± standard error of the mean. For comparison, *B. scoparia* cover in October 2018 averaged 17.6 ± 4.4 (uncut) and 13.7 ± 4.2 (cut).

the other half ($n = 20$) did not receive a *B. scoparia* cutting treatment. To implement the cutting treatment, we used mechanical, handheld brush cutters (Stihl, Waiblingen, Germany; Echo, Lake Zurich, IL, USA). For a 2-m distance into the *B. scoparia* matrix out from the perimeter of each assigned native grass patch and completely encircling the grass patch, we cut all *B. scoparia* plants at ground level (and laid cut stems on the ground in place) in June 2016 and again in July 2017. The cutting was timed to include nearly all *B. scoparia* germination that had occurred in spring, to maximize the number of plants treated, while taking place before *B. scoparia* had produced seed, to minimize seed production. Although cut *B. scoparia* individuals could resprout and seedlings could emerge in growing seasons after cutting, cover of *B. scoparia* within cut patches averaged 23% lower than in uncut patches at the end of the experiment in October 2018 (Table 1). Cutting *B. scoparia* also enabled native grasses to experience growing periods when height of *B. scoparia* was reduced to near ground level, potentially providing competitive advantages previously shown important for native grass species of our experiment to have for competitiveness with nonnative forbs (Allen 1982).

We measured native perennial grass patch size (area in m^2) six times in a 3-yr period for cut and uncut patches. We measured patch size before (October 2015) and after treatment (July 2016, June and October 2017, and May and October 2018) up to 28 mo after the first *B. scoparia* cutting treatment. Grass patches approximated circles, so we recorded patch size as the area of a circle by measuring and averaging at least four radii from a patch's center to outer perimeter. Throughout the experiment, we kept the original patch as measured at that location before treatment as the unit for analysis, which could subsequently change in size or species composition after treatment. In some cases, for example, an originally single-species native grass patch could subsequently contain intermingled native grass species after treatment (Table 1). Because of this turnover in species composition, we did not compare perennial grass species and instead measured change in size of perennial grass patches at the original pretreatment location regardless of species composition.

Statistical Analysis

The change in native perennial grass patch sizes (m^2) for each of five posttreatment measurement times, relative to pretreatment sizes, was the response variable for statistical analysis. We were interested in differences between treatments for each measurement time independently, so we performed analyses within each measurement period. This approach kept focus on differences between treatments at each measurement time, rather than on exploring seasonal fluctuations. For each of the five posttreatment measurement times, we used two-sample Welch's *t*-tests to compare mean change from the pretreatment baseline in native perennial grass patch size between *B. scoparia*-cut and uncut patches. Welch's *t*-tests accommodate unequal variances between treatments, important in our experiment because the data set followed a common pattern wherein variances increased proportionally with means. We controlled for type I statistical errors across the five tests using the Benjamini-Hochberg procedure to optimize limiting the false discovery rate while maintaining power (Benjamini and Hochberg 1995). We set a conservative critical value of 0.05 for the false-positive rate.

Native grass patches varied in size before treatment. To explore whether responses hinged on initial patch sizes, we used Pearson's correlation to quantify relationships between pretreatment and October 2018 native grass patch size. We ran correlation analysis with and without the two largest patches (which were two to three times larger than the next largest patch) included. We excluded these two patches from the final correlation analysis to avoid disproportionate influence on relationships among the 38 other patches.

Results and Discussion

Change in Native Grass Patch Size

Mechanically cutting the nonnative forb *B. scoparia* around the perimeters of native perennial grass patches stimulated expansion of native grasses (Figure 1). Compared with patches where *B. scoparia* was not cut, native grass patches where surrounding *B. scoparia* was cut grew larger relative to pretreatment for all five posttreatment measurement times during the 3-yr experiment (Figure 2). By October 2018, native grass patches around which *B. scoparia* was cut averaged 28.8 ± 10.8 m^2 (±SEM) in size. This was four times larger than the 6.6 ± 1.8 m^2 for native patches around which *B. scoparia* was not cut. There was little relationship between the initial (October 2015) and posttreatment (October 2018) size of native grass patches ($r^2 = 0.01$ and 0.09 for *B. scoparia* cut and uncut patches, respectively).

Overcoming Likely Unfavorable Weather Conditions

The experiment occurred during a generally dry period. A dry early summer (May to June, 47% of average precipitation) and July through October (67%) warm-season growth period occurred in

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Figure 1. Example of a native perennial grass patch (in this example, *Bouteloua gracilis* with some *Elymus elymoides* intermixed), surrounded by near monoculture of the nonnative annual forb *Bassia scoparia*, in an experiment testing effects of cutting *B. scoparia* surrounding native grass patches, Pecos National Historical Park, New Mexico, USA. The photo was taken in October 2017, 16 mo after initial *B. scoparia* cutting. The native grass patch increased from a pretreatment size of 0.1 m^2 (October 2015) to 50 m^2 in October 2017 (photo by LPC).

2016 during the first year of the experiment (Santa Fe, NM, weather station, 40 km northwest of the study site at a similar elevation of 2,049 m, 67 m lower than the study site). The second year, 2017, had a dry May to June (33%) and average July through October (100%). Most of the last year of the experiment was exceptionally dry, with only 26% of average winter/spring precipitation from November 2017 through April 2018 and only 40% in May to June 2018. The dry conditions could relate to why native grass patches contracted in May 2018 compared with October 2017 in both the *B. scoparia* cut and uncut treatments, although native grass patches were still larger where *B. scoparia* was cut. This dry period was followed by a wet July through October (144%) preceding the final measurement in October 2018, the only growing season during the experiment that was wetter than average.

Published literature suggests that the major increase in native grass patches after *B. scoparia* cutting might have been even greater had conditions been moister. Research spanning a century in semiarid grasslands, including with species in our study, revealed that native perennial grass cover is highly sensitive to precipitation within a growing season and across multiple years (Rondeau et al. 2013; Weaver and Albertson 1943; Witwicki et al. 2016). One experiment, for example, found that blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths] cover declined by a third when moisture was experimentally reduced by 25% (Evans et al. 2011). Ruderal forbs, including *B. scoparia*, increased under the experimental drying during the concomitant contraction in native perennial grasses (Evans et al. 2011). These observations suggest that treatments in our experiment were able to overcome generally dry conditions that should have favored increases in *B. scoparia* and decreases in native grasses. The idea that alleviating competition from nonnative plants can increase the resistance and resilience of native plants to drought or other climatic events is an emerging research topic in invasive plant management (Abella 2014; Monaco et al. 2017).

Persistent Patch Increases under Transient Species Composition

Native grass patches expanded while experiencing high turnover in species composition, an ecological process likely explained in part by previous autecology research. In a study of mixed-species prairies, for example, *B. gracilis* genets had maximum life spans of 35 to 38 yr, average life spans of only 3 to 4 yr, and fewer than half survived more than a year (Fair et al. 1999; Lauenroth and Adler 2008). Squirreltail [*Elymus elymoides* (Raf.) Swezey] was even shorter-lived, with an average life span of 1 yr (and maximum of 5 yr), and only 30% of genets persisted more than a year (Lauenroth and Adler 2008). In western wheatgrass [*Pascopyrum smithii* (Rydb.) Á. Löve], production of annual tillers (including modular units becoming new individuals) creates variability in the spatial configuration of genets and patches with multiple genets from one year to the next (Ott and Hartnett 2015). Native grasses not among the initial focal species of patches in our experiment but that colonized one or more patches after treatment also were transient, such as buffalograss [*Bouteloua dactyloides* (Nutt.) J. T. Columbus], with genet longevity averaging only 2 yr (Lauenroth and Adler 2008). Transience in species in any given patch was why we analyzed native grass patches irrespective of their species composition. Further research tracking changes in individual species, perhaps using demographic techniques, may aid in identifying whether particular native grass species respond most vigorously to nonnative plant removal across a range of conditions.

Regeneration Components

Autecology literature for the native grass species offers insight into potential regeneration processes contributing to observed expansions of grass patches. Although all the grasses can reproduce vegetatively, recruitment could also have occurred via seed. In a long-term study in the Great Plains, *B. gracilis* seedling recruitment was frequent, occurring in 35 of 38 (91%) years (Fair et al. 1999). All four focal native grass species can form persistent soil seedbanks (Abella et al. 2007; Pérez et al. 1998). While seeds are mainly dispersed near adults, at least some of the species on occasion can experience seed dispersal over tens of meters (Marlette and Anderson 1986). This distance would suffice to have seed exchange among perimeters of many of the grass patches in our experiment. Patch expansion could also have resulted from rapid clonal growth. For example, Webb (1941) reported fast vegetative expansion of *B. dactyloides*: plants produced tillers at 1-mo-old, flowers appeared at age 2.5 mo, roots exceeded 1.4-m long before 4-mo-old, and stolons grew up to 2 cm day^{-1} in length. On a devegetated site where *B. dactyloides* was experimentally planted at a spacing of 0.7 m, the species formed a solid sod cover within 4 mo (Webb 1941). In Wind Cave National Park, South Dakota, *P. smithii* maintained 18 m of rhizome length per square meter of soil and produced new tillers in both spring and autumn from these rhizomes, enabling the species to rapidly colonize open area (Ott and Hartnett 2015). The rapid expansion of native grasses into growing space created by cutting *B. scoparia* could thus have resulted from a combination of the diverse colonization options the native grasses possess. While our goal was to test minimal-input strategies (i.e., limiting the area required for treatment and avoiding resource-intensive seeding or planting of natives), partitioning observed native grass expansions into regeneration components in future research might aid identifying whether strategic augmentation of propagules could enhance the grass response.

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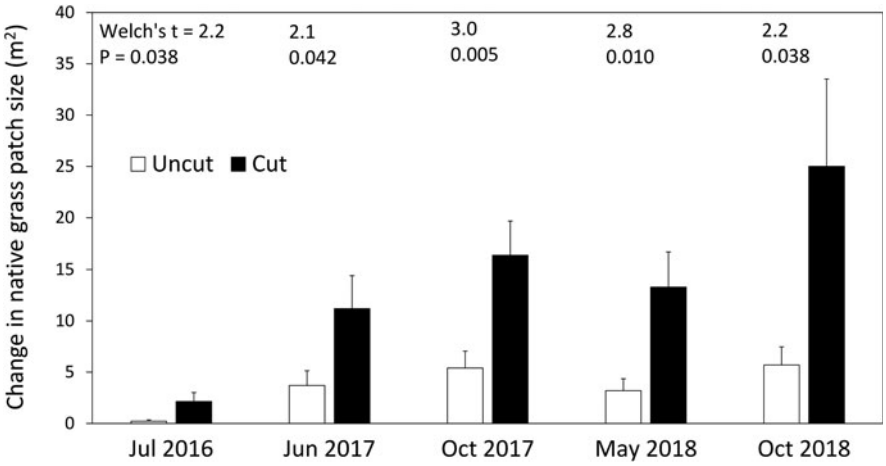


Figure 2. Relative to pretreatment (October 2015), change in mean size of native perennial grass patches around which the nonnative annual forb *Bassia scoparia* was mechanically cut or was not cut in Pecos National Historical Park, New Mexico, USA. Error bars represent 1 standard error of the mean. Type 1 error–protected Welch's *t*-tests compare cut and uncut means within each posttreatment time.

Time Frame and Treatment Sustainability

Although the 3-yr experiment encompassed multiple generations of the annual *B. scoparia* and exceeded the average genet life expectancy of focal native grass species (Lauenroth and Adler 2008), examining potential further trends in *B. scoparia* dynamics, native grass persistence, and competitive suppression of *B. scoparia* by expanding native grasses may help identify the longer-term sustainability and cost-effectiveness of the treatment strategy. Without seed inputs, the 2-yr cutting treatments should have depleted the *B. scoparia* seedbank around native grass patches by at least 95% (Dille et al. 2017; Zorner et al. 1984). However, some *B. scoparia* seed inputs likely occurred because of the inherent spatial arrangement of treatments around grass patches with intervening *B. scoparia* monoculture. Whether established native grasses could persistently competitively suppress *B. scoparia* is uncertain but possible based on theory of priority effects and invasion resistance of communities (Allen and Meyer 2014). Competitive dynamics might partly hinge on the fluctuating species composition of native grass patches, which could strengthen or reduce community invasibility. While limiting similarity theory proposes that communities composed of species most similar to *B. scoparia* should best resist invasion (i.e., not necessarily the perennial grasses), the fluctuating composition of grasses differing in growth seasonality and morphology that cycled among patches could provide continuous competition to *B. scoparia* (Abella et al. 2011; Allen and Meyer 2014).

The approach of treating nonnative plants around perimeters of native patches showed promise as a minimal-input strategy for increasing native species over time within landscapes dominated by a matrix of nonnative plants. While enlarged native grass patches persisted for at least 3 yr, including across dry years, further exploring how frequently or long the minimal-input treatments might be needed to sustain the native species increases is warranted.

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