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The distribution of transformer plant species, defined as harmful species that substantially modify ecosystems, was generally localized in Tallgrass Prairie National Preserve, Kansas (TPNP). Surveys for transformer species were conducted along line transects (n=301) in September 2006. Nine of 16 transformer plant species (81.8%) revealed significant positive associations with riparian forests or with cultivated land. These preferences are likely confounded in that the soils most suitable for cultivation lie in the vicinity of riparian forests. In contrast, a single transformer species revealed a significant positive association with roads. Agricultural areas and riparian forests appear to be more highly invaded than annually burned and grazed prairie in TPNP. Consequently, targeting early detection efforts in or near agricultural areas and riparian forests rather than the more extensive prairie will likely yield higher detection rates of transformer species.

INTRODUCTION

The term “invasive” applied to plant species often connotes a naturalized species that causes ecological or economic harm (Cronk and Fuller 1995). In this study, we adopt the term “transformer” for a potentially harmful plant species that substantially modifies ecosystems, while reserving “naturalized” for a plant species with viable populations that are introduced through human activities, and “invasive” for naturalized species that rapidly establish offspring at distances from parent plants (Richardson et al. 2000). Despite differences in terminology, plants which potentially cause ecological or economic harm constitute only a small percentage of naturalized plant species (Richardson et al. 2000, Mack et al. 2000). As a rule, economic concerns regarding transformer plant species are paramount in agricultural systems, while the impact on native species conservation is an overriding concern only in natural areas. In the Flint Hills, stretching from northern Kansas to northern Oklahoma, the line between agricultural economics and conservation blurs as working rangeland overlaps with the largest remaining contiguous untilled tallgrass prairie tracts in the U.S. (Knapp and Seastedt 1998).

Land management in the Flint Hills often consists of annual spring burning of bluestem-dominated (big: *Andropogon gerardii* Vitman and little: *Schizachyrium scoparium* [Michx.] Nash) prairie to support grazing of feeder cattle. In 2007, 50% and 25% of Flint Hills rangeland was leased for season-long and partial-season grazing, respectively (Anonymous 2007). Annual spring burning controls woody plants (Bragg and Hurlbert 1976) and potentially increases forage palatability and cattle weight gain (Anderson et al. 1970, Allen et al. 1976). Partial-season grazing includes intensive early stocking, which matches double stocking rates during the period of highest grass productivity from May through mid-July (Smith and Owensby 1978). The effects of fire and grazing in tallgrass prairie plant communities are well documented; fire and grazing affect below ground productivity (Rice et al. 1998), above ground standing crop and litter cover, nitrogen mineralization rates, productivity, microsite characteristics (e.g., soil moisture, light), species diversity (Collins and Steinauer 1998), and naturalized plant species richness (Smith and Knapp 1999).

Disturbances may facilitate invasive plant establishment in rangelands through reduced competition or increased microsite heterogeneity (Hobbs and Huenneke 1992, Masters and Sheley 2001). For example, the abundance of naturalized Kentucky bluegrass L. (*Poa pratensis* L.), field brome (*Bromus japonicus* L.), common pepperweed (*Lepidium densiflorum* Schrad), and naturalized species richness was higher in buffalo wallows compared to grazed prairie (Trager et al. 2004; nomenclature follows NRCS, USDA Plants (NRCS 2008)). Quist et al. (2003) correlated military training intensity in grasslands at Fort Riley, Kansas with higher smooth brome (*Bromus inermis* Leyss.) and Korean clover (*Kummerowia stipulcaea* [Maxim.] Makino) abundance. In contrast, annual spring burning in Flint Hills rangelands apparently minimizes colonization of naturalized plant species. Smith and Knapp (1999) found that naturalized plant cover was virtually non-existent in annually burned Flint Hills grasslands, compared to >20% in long-unburned grassland. Grazing, however, increased naturalized species richness in burned and unburned treatments. Cover of Kentucky bluegrass totaled ~3% in annually burned prairie compared to almost 15% in unburned prairie (Towne and Owensby 1984). The effect of disturbances on plant community invasibility clearly varies with disturbance type.

In this study, we assessed the abundance and distribution of transformer plant species at Tallgrass Prairie National Preserve (TPNP). Specifically, we sought to determine: (1) the abundance of transformer plant species at TPNP, (2) the distribution of transformer species relative to vegetation cover and disturbance factors, and (3) the implications for detection and control of such potentially harmful plant species.

Materials and Methods

Study area – Tallgrass Prairie National Preserve (TPNP) is located near Strong City in Chase County, Kansas. The vegetation of the preserve consists of tallgrass prairie associated with the characteristic benches and concave slopes of the Flint Hills. Dominant grasses include big and little bluestem. Riparian forests, accounting for the only significant assemblage of trees in TPNP, line Fox and Palmer creeks. The lowland areas along these creeks were previously cultivated (Anonymous 2004). Agricultural areas adjacent to Palmer Creek, in the northern portion of TPNP, however, were abandoned prior to 1900 and have since reverted to prairie (Barnard, unpublished). Areas previously in agriculture as recently as 1994 in the vicinity of Fox Creek were converted to smooth brome (ca. 200 ha) and pastured or hayed, while a smaller area (<10 ha) was restored to native C_4 grasses. Cattle grazing and fire management have likely occurred since the mid-1800s, with large-scale ranching beginning in the 1870s. At the time of the study and in the years previous, intensive early stocking with annual spring burning was the most commonly used grazing system in TPNP. Since 2002, grazing intensity varied across pastures and among years in TPNP.

Field methods – In September 2006, we searched for 79 plant species designated as transformer species, according to a review of numerous national and regional watch lists, in surveys conducted along contiguous belt transects (Young et al. 2007). The transects were 3 m-wide and either 400 m long (n=274), or clipped at the park boundary (n=27) (Figure 1). We created the line transects in a GIS (ArcGIS 9.2) and loaded these features on a GPS unit for field use. Kentucky bluegrass and Canada bluegrass (*Poa compressa* L.) were not surveyed because of the difficulty of detecting localized occurrences. For comparison with invasive plants that were widespread in TPNP, but not designated as transformer species, we also documented the distribution

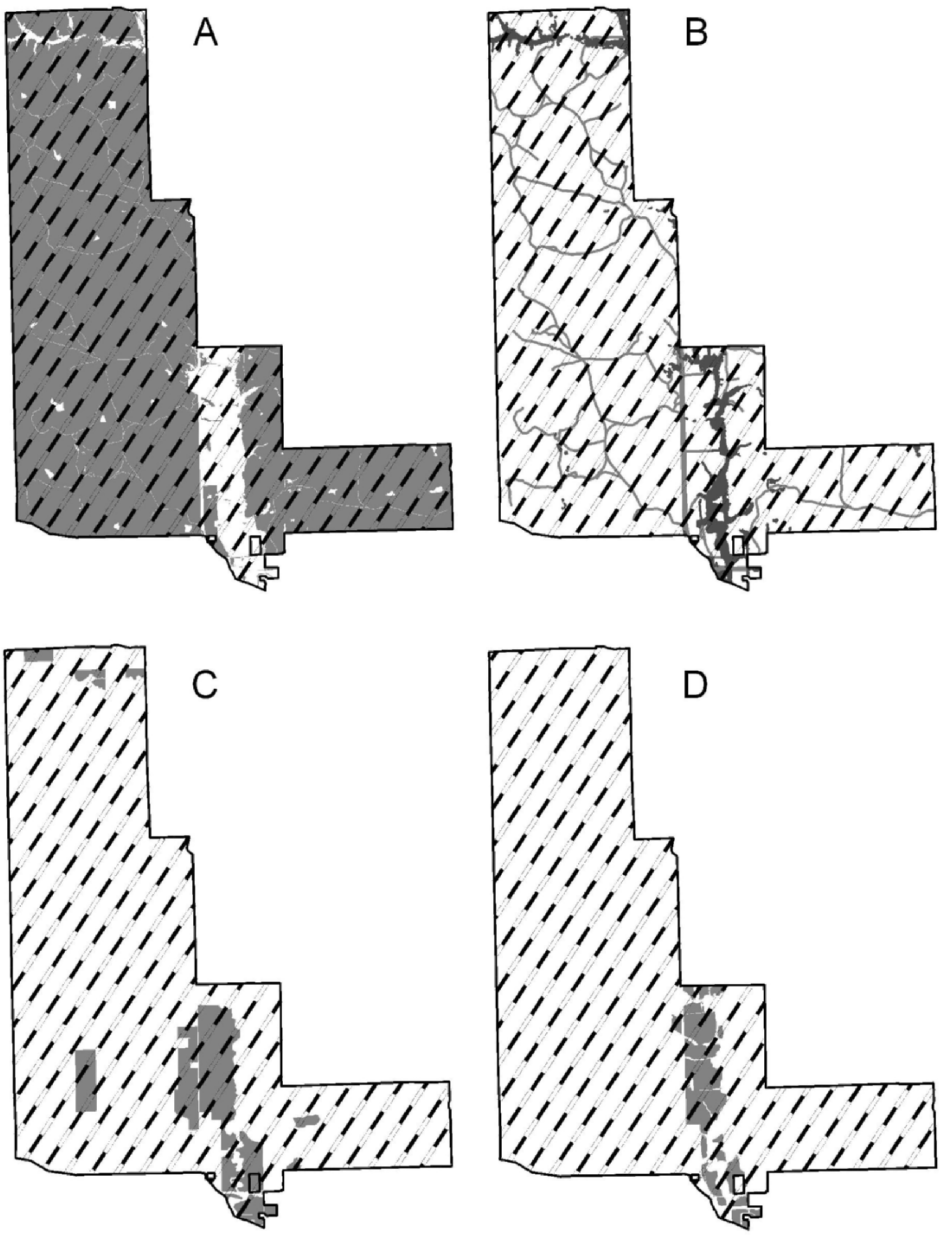

Figure 1. The distribution of 400-m sample transects (alternating filled and empty lines) in relation to cover type and land disturbance at Tallgrass Prairie National Preserve (TPNP). The following land cover types at TPNP are represented in gray: A) prairie cover, B) riparian forest cover, C) cultivated land as of 1895, and D) modified grassland. Roads are shown as light gray lines in inset B. Scale = 1:90,000.

of the naturalized annual grass, bald brome (*Bromus racemosus* L.), and the native weed, buffalobur nightshade (*Solanum rostratum* Dunal). Our taxonomic concept of bald brome includes *Bromus commutatus* Schrad.; other authorities separate these species (Yatskievych 1999).

Analytical methods – We evaluated the association between plant species distribution and two types of variables in a GIS: plant cover (riparian forest and prairie) and land disturbance (land in cultivation as of 1895, recently modified grassland, and roads) (Figure 1). We obtained the 1895 land use data from a National Park Service-developed rectified layer based on a linen map of Spring Hill and Deer Park Farms. Oats, millet, corn, alfalfa, and pasture accounted for 94.7% of the area classified as cultivated on this map. We developed all other layers using heads-up digitizing (ArcGIS 9.2, ESRI 2006) of 2001 and 2006 color infrared imagery. Modified grassland consisted of former agricultural areas planted to smooth brome (>90%) or restored native warm season grasses (see Study Area). In 1895, a total of 407.8 ha in TPNP was in cultivation, while 209.3 ha of modified grassland was identified using recent imagery with 163.5 ha of cultivated land and modified grassland overlapping. The roads layer consisted of preserve roads and Highway 177. For each transformer plant species identified, we overlaid occupied transects with habitat variable layers to determine the number of transects that intersected each variable. A chi-square test of independence (Daniel 1990) was used to compare observed plant species distributions relative to the distribution of each habitat variable. Statistical significance was set at $P = 0.05$. SPSS 14.0 for Windows was used for all analyses (SPSS 2005).

Results

Eleven transformer plant species were found across the 301 transects in Tallgrass Prairie National Preserve (TPNP) (Table 1). Smooth brome (*Bromus inermis* Leyss.) was the most common, occurring on 21 transects. Eight species were present on ≤ 5 transects. In spite of the small sample sizes, it was possible to obtain statistically significant results for almost all habitat associations, in at least one direction (i.e., positive or negative). Because the distribution of transects was highly skewed for most plant cover and land disturbance factors, and the number of transformer plant species occurrences for most species were small, it was often not possible to obtain significant negative associations for riparian forest or cultivated land or modified grassland, or positive associations for prairie. Thus, the absence of a “significant” result may simply indicate a lack of statistical power, rather than a true lack of association. Nine of the eleven (81.8%) transformer plant species in TPNP revealed significant positive associations with riparian forest (Table 1). Four of these nine species also revealed significant negative associations with prairie. Nine of the eleven (81.8%) transformer plant species revealed significant positive associations with cultivated land in 1895, while five of these species revealed significant positive associations with recently modified grassland. A single transformer plant species, yellow sweetclover (*Melilotus officinalis* L. (Lam.)), was associated with preserve roads, although sample size was very small.

Overall, 47 of the 59 occurrences (80%) of all transformer species were found within the 46 transects intersecting riparian forests, while 46 of the 59 occurrences (78%) of all transformer species were found within the 44 transects intersecting cultivated land as of 1895. These transects represent only 16% and 15%, respectively, of the total 301 transects surveyed. Twenty-four transects intersected both riparian forest and cultivated land as of 1895.

Bald brome and buffalobur nightshade contrasted in their associations with plant cover type and broader distributions compared to the transformer plant species. Bald brome revealed significant positive associations with riparian forest, cultivated land as 1895, modified grassland, and roads. Buffalobur nightshade revealed no significant associations with any habitat variables, although power to detect certain associations was low due to the skewed distribution of habitat factors, as described above.

Because numerous chi-square tests were conducted simultaneously (n = 65), the probability of making a Type I error is no longer 0.05. Although determining the actual Type I error rate for comparisons in this situation is difficult, by definition we would expect that one out of every 20 comparisons would be spuriously significant, if there were in fact no real differences (i.e., no preferences for certain habitat types) (Sokal and Rohlf 1995). We observed 32 significant chi-square test results, and this 49% rate of significant results is an order of magnitude higher than the 5% rate we would expect by chance alone. Overall, about half of the comparisons resulted in a significant association relative to a given habitat type.

Discussion

TPNP supports relatively localized occurrences of few transformer plant species. These transformer species occurred most often in or near riparian forests and cultivated land. The legacy of historical agriculture appears to have more strongly influenced transformer plant species distribution than disturbances associated with recently modified grasslands, despite significant overlap in those areas. This cluster of associations is not surprising, because lands near TPNP that were cultivated for pasture or row crops and subsequently modified as C_3-dominated grassland are generally located adjacent to riparian forests in the silty clay loams of the Smolan and Tully series and the silt loams of the Reading series (Neill 1974).

While agriculture practices influenced invasive plant distribution, annual spring burning, grazing, and roads did not appear to strongly affect invasive plant distribution. Four transformer species revealed significant negative associations with prairie, although statistical power was too low in most cases to detect any significant positive associations. Thus, while there is no evidence that annual burning and grazing have facilitated widespread invasion, positive associations between some of the transformer species and such disturbances cannot be entirely ruled out. In this study, we found only yellow sweetclover and bald brome to be positively associated with preserve roads. This matched our observation that road sides and cattle gathering points in TPNP support numerous native and naturalized weeds, but few transformer species (Young, pers. obs.).

Given the possibility for transects to be classified under multiple variables at the 400-m scale of this study, we deduced the probable location of transformer plant species associated with riparian forest and cultivated land based on known habitat preferences and field observations. Johnsongrass (*Sorghum halepense* (L.) Pers., a Kansas noxious weed), Japanese hedgeparsley (*Torilis japonica* (Houtt.) DC.), spotted knapweed (*Centaurea stoebe* L. ssp. *micranthos* (Gugler) Hayek, a Kansas high priority watch list weed), and yellow sweetclover were likely found in open pasture or fields (Barkley 1986). The invasive herb, garlic mustard (*Alliaria petiolata* (M. Bieb) Cavara & Grande), occurred in the riparian forests in TPNP. Its invasive tendency in Eastern forests (Peterson et al. 2003) suggests that this plant may become more widespread in the riparian forests in TPNP. All transformer tree species identified in the study—white mulberry (*Morus alba* L.), Callery pear (*Pyrus calleryana* Decne.), and black locust (*Robinia pseuduacacia* L.)—colonized riparian forests in TPNP.

While relatively few transformer plant species occupy TPNP, the lack of significant associations for the noxious bull thistle (*Cirsium vulgare* (Savi) Ten.) suggests that the upland range in TPNP experiences some propagule

Table 1. Occurrences of species in line transects intersecting (+) and not intersecting (-)riparian forests, prairie, cultivated land (circa 1895), modified grassland (2006), and roads at Tallgrass Prairie National Preserve. Numbers below counts are chi-square values (df = 1 for all), and *P*-values; values in bold represent significant differences at α = 0.05.

	Riparian Forest		Prairie		Cultivated Land (1895)		Modified Grassland		Roads	
	+	-	+	-	+	-	+	-	+	-
Distribution of transects (n=301)	46	255	295	6	44	257	26	275	100	201
TRANSFORMER PLANT SPECIES										
Alliaria petiolota (n=5)	5	0	4	1	5	0	4	1	3	2
Garlic mustard	**25.42, <0.0001**		**7.13, 0.008**		**26.66, <0.0001**		**28.32, <0.0001**		1.58, 0.21	
Arctium minus (n=3)	2	1	3	0	1	2	0	3	2	1
Lesser burdock	**5.90, 0.015**		0.06, 0.80		0.83, 0.36		0.28, 0.59		1.49, 0.22	
Bromus inermis (n=21)	16	5	17	4	17	4	20	1	10	11
Smooth brome	**46.84, <0.0001**		**18.97, <0.0001**		**56.25 <0.0001**		**120.23, <0.0001**		1.81, 0.18	
Centaurea stoebe ssp. *micranthos* (n=1)	1	0	1	0	1	0	0	1	1	0
Spotted knapweed	**5.44, 0.019**		0.02, 0.89		**5.73, 0.017**		0.10, 0.76		*	
Cirsium vulgare (n=3)	1	2	3	0	1	2	0	3	1	2
Bull thistle	0.74, 0.39		0.06, 0.81		0.83, 0.36		0.28, 0.59		0.00, 0.99	
Melilotus officinalis (n=2)	1	1	2	0	2	0	2	0	2	0
Yellow sweetclover	1.83, 0.18		0.04, 0.84		**11.25, 0.0008**		**19.77, <0.0001**		**3.97, 0.046**	
Morus alba (n=3)	2	1	3	0	2	1	1	2	2	1
White mulberry	**0.59, 0.015**		0.06, 0.80		**6.27, 0.012**		2.24, 0.13		1.49, 0.22	

Pyrus calleryana (n=1)	1	0	1	0	1	0	0	1	1	0
Callery pear	**5.44, 0.020**		0.02, 0.89		**5.73, 0.017**		0.10, 0.76		*	
Robinia pseudoacacia (n=1)	1	0	1	0	1	0	0	1	1	0
Black locust	**5.44, 0.020**		0.02, 0.89		**5.73, 0.017**		0.10, 0.76		*	
Sorghum halepense (n=12)	10	2	9	3	10	2	11	1	6	6
Johnsongrass	**36.38, <0.0001**		**21.87, <0.0001**		**38.17, <0.0001**		**76.32, <0.0001**		1.45, 0.23	
Torilis japonica (n=7)	7	0	6	1	5	2	3	4	4	3
Japanese hedgeparsley	**34.46, <0.0001**		**4.65, 0.031**		**16.50, <0.0001**		**9.39, 0.002**		1.75, 0.19	
RUDERAL PLANT SPECIES										
Bromus racemosus (n=42)	20	22	39	3	16	26	13	29	18	14
Bald brome	**24.80, <0.0001**		3.82, 0.051		**14.08, 0.0002**		**18.21, <0.0001**		**6.70, 0.0096**	
Solanum rostratum (n=68)	7	61	68	0	11	57	3	65	29	38
Buffalobur nightshade	1.12, 0.29		1.38, 0.24		0.11, 0.74		1.37, 0.24		2.44, 0.12	

* not possible to achieve statistical significance at $\alpha = 0.05$.

pressure from transformer plant species. Similarly, the widespread distribution of buffalobur nightshade suggests that, once established, plant species with invasive life-history traits may become widely distributed. We note that these species may be associated with other disturbances, such as cattle trails and gas wells and lines, that were not included in this study. Sericea lespedeza (*Lespedeza cuneata* (Dum. Cours.) G. Don) and Caucasian bluestem *(Bothriochloa bladhii* (Retz.) S.T. Blake) are transformer species noted as invasive in the Flint Hills. While not encountered on our survey transects, both plant species have colonized TPNP. Approximately 0.08 ha of sericea lespedeza and 0.5 ha of Caucasian bluestem have been treated on the preserve. As with smooth brome, ease of establishment, productivity, and drought tolerance led to the use of these plants for erosion control and forage production in the Flint Hills. The historical and intentional introduction of these plants over large acreages in the Flint Hills may provide a seed source to support future introductions. Observations at Fort Riley, Kansas, a site with high levels of mechanical disturbance, showed that once established, sericea lespedeza spread rapidly over a six-year period (Althoff et al. 2006).

Based on this study, targeting monitoring to agricultural areas and riparian forests is likely to yield the highest transformer plant detection rates, while lower detection rates may be expected in the managed grassland. The presence of transformer species in TPNP, however, and the potential for increased regional propagule pressure following intentional planting of transformer species, point to the importance of continued detection monitoring. Plant detection at early invasion stages provides the greatest possibility for long-term successful control of these plants in TPNP (Hobbs and Humphries 1995, Masters and Sheley 2001).

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