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RESEARCH ARTICLE

Roads Impact the Distribution of Noxious Weeds More Than Restoration Treatments in a Lodgepole Pine Forest in Montana, U.S.A.

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Abstract

A century of fire suppression has created unnaturally dense stands in many western North American forests, and silviculture treatments are being increasingly used to reduce fuels to mitigate wildfire hazards and manage insect infestations. Thinning prescriptions have the potential to restore forests to a more historically sustainable state, but land managers need to be aware of the potential impacts of such treatments on invasion by exotic plants. However, the effects of these activities on the introduction and spread of invasive plants are not well understood. We evaluated noxious weed occurrence over a 9-year period (2001–2009) following thinning and burning treatments in a lodgepole pine forest in central Montana. Surveys were made in the treatment units and along roads for two shelterwood-with-reserve prescriptions, each with and without prescribed burning, burned only, and untreated controls. Five species listed as noxious weeds in Montana were recorded: spotted knapweed (*Centaurea stoebe*), oxeye daisy (*Leucanthemum vulgare*), Canada thistle (*Cirsium arvense*), common tansy (*Tanacetum vulgare*), and houndstongue (*Cynoglossum officinale*). With the exception of Canada thistle, noxious weeds were confined to roadsides and did not colonize silvicultural treatment areas. Roadside habitats contributed more to the distribution of noxious plant species than did silvicultural treatments in this relatively uninvaded forest, indicating the importance of weed control tactics along roads and underscoring the need to mitigate exotic plant dispersal by motorized vehicles. In addition, these findings suggest that roadways should be considered when evaluating the potential for invasion and spread of exotic plants following forest restoration treatments.

Key words: **burning, disturbance, exotic plants, forest management, invasive species, prescribed fire, silvicultural treatments, thinning.**

Introduction

Fire suppression and control policies of the twentieth century have altered the structure, composition, and ecology of many fire-adapted forests of North America (Keane et al. 2002; Hessburg et al. 2005). The resulting increase in homogeny and density of stands has elevated the vulnerability of forests to catastrophic wildfires and damaging insect outbreaks (Sampson 1997; McCullough et al. 1998; Parker et al. 2006; Woods et al. 2006). Restoration of western forests is now a management priority, and thinning treatments are being implemented at an accelerated rate. For example, the Healthy Forests Restoration Act (2003) authorized fuels reduction via thinning and prescribed burning on millions of hectares of forest land. However, thinning and burning treatments have the potential to facilitate invasion by exotic plants, which could thwart restoration efforts (D'Antonio & Meyerson 2002). Basic knowledge on exotic plant responses to restoration treatments is needed to soundly manage forests and successfully restore ecosystems.

The spread of exotic plants is a threat to health, sustainability, and productivity of many forests because they can negatively alter community structure and ecosystem processes (Levine et al. 2003; Moser et al. 2009). Strong invaders such as spotted knapweed (*Centaurea stoebe*) can reduce the diversity and abundance of native plants (Ortega & Pearson 2005), alter soil biota and chemistry (Weidenhamer & Callaway 2010), affect the physiology of co-occurring native plants (Kittelson et al. 2008), and even reduce reproductive success of native birds (Ortega et al. 2006). Restoration efforts that use thinning and burning have the potential to promote exotic plant invasion by creating disturbance which can increase resource availability (e.g. light and nitrogen) and decrease plant competition (McEvoy et al. 1993; D'Antonio & Meyerson 2002; Hunter & Omi 2006). Moreover, there is some evidence that fire suppression policies have actually helped exclude

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exotic plants, and that restoration efforts could enhance forest vulnerability to invasion (Keeley 2005).

Roads are another route by which restoration activities could encourage the establishment and spread of exotic plants. Thinning treatments frequently require the construction of roads and increased use of established roads. Exotic plant species frequently occur along roadsides; roads can act as conduits for their spread and invasion into neighboring habitats (Gelbard & Belnap 2003; Christen & Matlack 2009; Flory & Clay 2009). For example, seeds can be carried by animals and wind along roadways, or over long distances by motorized vehicles (Christen & Matlack 2009). If roads play a significant role in exotic plant recruitment and spread, then controlling roadside weeds before treatment could be important.

The United States Forest Service, Rocky Mountain Research Station is investigating the use of silvicultural prescriptions to restore the ecological structure and function of lodgepole pine forests in the northern Rockies (McCaughey et al. 2006; Woods et al. 2006). Although the adaptations of lodgepole pine to severe, stand-replacement fire have long been acknowledged, lodgepole pine forests also burn in low- to mixed-severity fire, often creating two-aged stands and variable mosaic fire patterns across the landscape. Although clearcutting and broadcast burning mimic the effects of stand-replacement fires, burning irregularly shaped cutting units containing patches of uncut “shelterwood” trees more effectively simulates the effects of historical fires (Hardy et al. 2006). However, the response of exotic species to this type of restoration treatment has not been documented in lodgepole pine forests. In a study of thinning and burning restoration treatments in ponderosa pine (*Pinus ponderosa* P. & C. Lawson) forests of western North America, abundance of transformer species (exotic plant species capable of altering environmental conditions) increased with increasing disturbance intensity, suggesting that less intense single-disturbance treatments (burn only, thin only) or incremental treatments may be preferred (Dodson & Fiedler 2006). In this study, we evaluated the effect of a two-aged silvicultural system termed “shelterwood-with-reserves” with two forms of leave tree retention (one leaving residual trees evenly distributed and the other leaving unharvested trees in groups), with and without prescribed burning in a lodgepole pine forest in central Montana, on invasion of weeds designated as noxious by the Montana Department of Agriculture (2006). We simultaneously monitored the presence of noxious weeds along the roads newly constructed for the restoration treatments and along the neighboring established forest roads. Our goal was to determine if these restoration treatments facilitate the establishment of noxious weeds, and if so, whether or not weed management should be incorporated to better restore forest health.

Methods

Study Area

Tenderfoot Creek Experimental Forest (TCEF) is situated in the Little Belt Mountains of central Montana, 120 km east of the Continental Divide at approximately lat 46°55′ N and long 110°52′ W (Fig. 1). TCEF is composed of 3,693 ha (9,125 acres) at elevations between 1,840 and 2,420 m (6,035–7,940 ft) and is dominated by lodgepole pine forest, which covers about 3,366 ha (8,317 acres), with interspersed floristically rich meadows. The watershed comprises seven subdrainages running north–south in a dendritic pattern (Barrett 1993). Schmidt and Friede (1996) detail the climate, geology, and soils of TCEF. Mincemoyer and Birdsall (2006) describe the plant communities, floristic affinities, and detail the flora of TCEF. Other tree species include subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), whitebark pine (*Pinus albicaulis* Engelm.), Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco), and quaking aspen (*Populus tremuloides* Michx.). Mincemoyer and Birdsall (2006) documented four species listed as noxious weeds by the Montana Department of Agriculture: spotted knapweed (*Centaurea stoebe* L.), oxeye daisy (*Leucanthemum vulgare* Lam.), Canada thistle (*Cirsium arvense* [L.] Scop.), and common tansy (*Tanacetum vulgare* L.); a single plant of a fifth noxious species, houndstongue (*Cynoglossum officinale* L.), was identified during this study.

Silvicultural Treatments

Silvicultural treatments were installed in the Spring Park Creek and Sun Creek watersheds of TCEF, and are described in detail by Hardy et al. (2006; Fig. 2). In brief, the treatments included evenly spaced and grouped shelterwood-with-reserve prescriptions of approximately 50% reduction in basal area applied on 16 units totaling 649 acres (eight units per treatment per watershed). The harvest system included felling by excavator-mounted “hot saws” and whole-tree skidding to centralized processing locations where trees were delimbed and decked for transport. All unutilized slash was piled and burned within each treatment unit. Half of the units were prescribed burned following harvest using a common burn prescription with an allowable overstory mortality of 50%. Actual fire-caused mortality was documented by Hardy et al. (2006). Each watershed also had an unlogged but burned treatment (Fig. 2). Unlogged, unburned areas in two adjacent TCEF watersheds served as controls. Application of treatments required the construction of approximately 4 km of roads, which was completed in 1999. Cutting treatments were conducted in 2000 and prescribed burning conducted in 2002 and 2003. The two watersheds had never been logged, and fire history data for the TCEF indicate that most of the treatment and control units last burned 130 years ago (Barrett 1993; Woods et al. 2006).

Noxious Weed Measurements

To monitor noxious weeds in the treatment and control units, we permanently marked a set of sampling points with metal pins according to a grid system. Grids were designed so that the sampling points were dispersed throughout the entire treatment unit by placing parallel rows of transects along

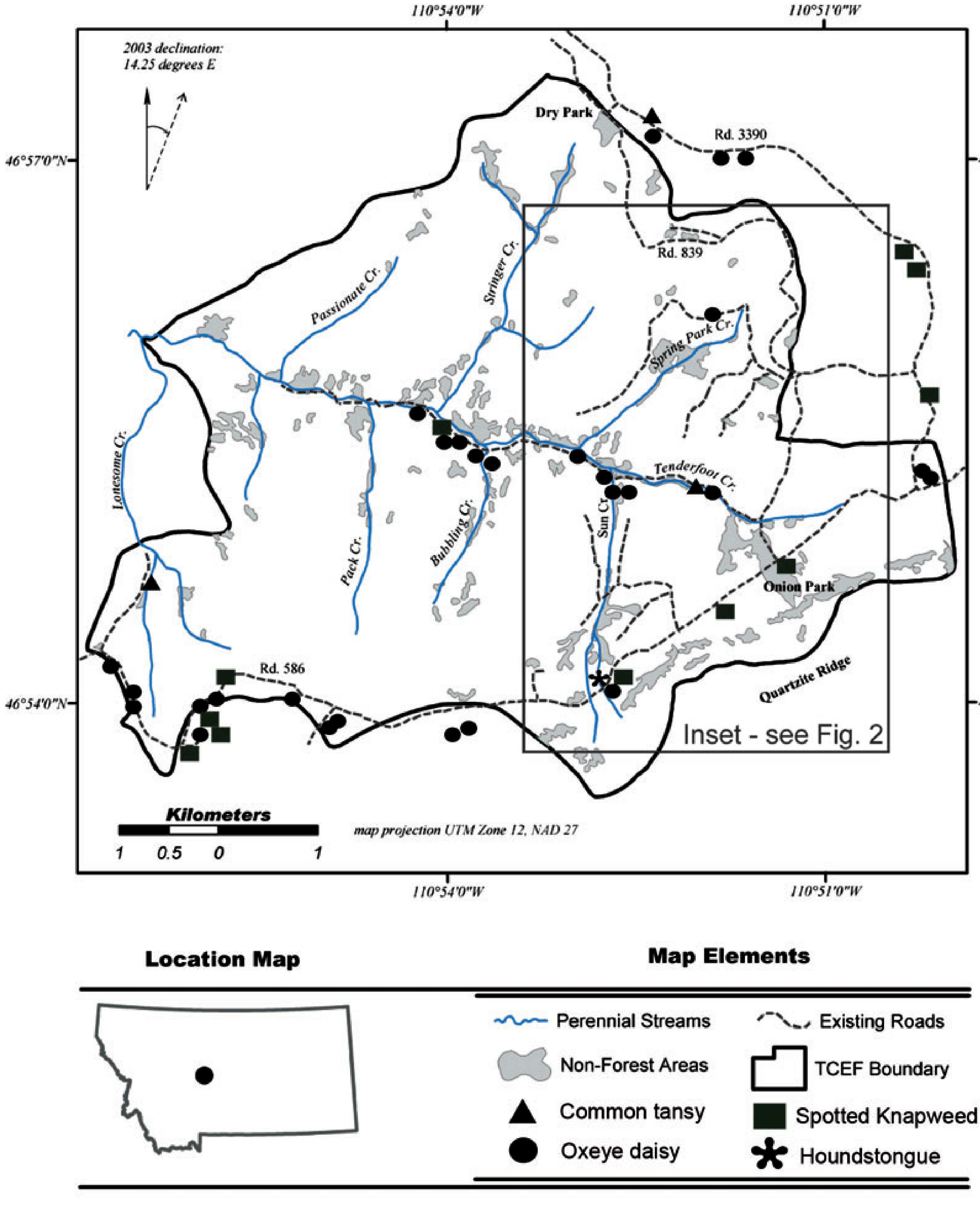

Figure 1. Map of TCEF, Montana, United States showing recorded distribution of the noxious weeds oxeye daisy, spotted knapweed, common tansy, and houndstongue.

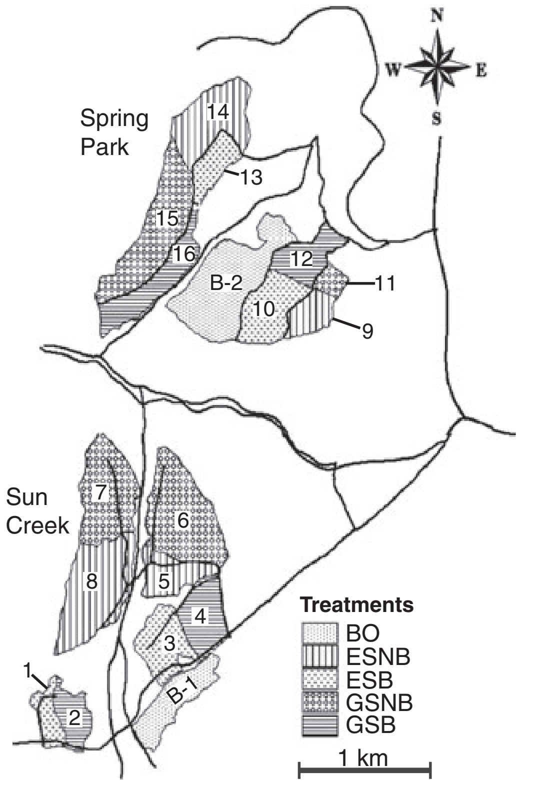

Figure 2. Detail of restoration treatment units within TCEF, Montana, United States (see inset from Fig. 1). The unit number or letter-number designation is given on or next to each unit. BO, prescribed burn only/no logging; ESB, evenly spaced shelterwood with burn; ESNB, evenly spaced shelterwood, no burn; GSB, grouped shelterwood with burn; and GSNB, grouped shelterwood, no burn.

a compass bearing with the sampling points evenly spaced along each transect. Distances between the transects and the sampling points varied depending on the size of the treatment unit and ranged between one and five chains (one chain = 20.12 m) apart. The number of sampling points varied for each treatment area and ranged from 17 to 51 (Table 1). Control units were designed in two adjacent unburned, unlogged watersheds (Stringer and Bubbling, see Fig. 1) each with two 1.5 km transects running along a compass bearing each with 25 sampling points evenly spaced three chains (approximately 60 m) apart. Between late August and late September of 2001, 2003–2005, and 2009, we examined understory vegetation within a 0.1-m^2 Daubenmire frame at each sampling point in the silvicultural treatment and control units and noted the percent cover of any weed designated noxious in Montana (Montana Department of Agriculture 2006). In addition, the treatment and control units were surveyed for noxious weed presence as we traveled between sampling points to determine if our sampling method was effectively detecting noxious weeds. In August of 2001, 2003–2005, and 2009, we also visually surveyed the permanent open access major forest roads and verges within and adjacent to the boundary of TCEF (roads 586, 839, and 3390), the permanent limited access Tenderfoot Creek Road, and the restricted access roads constructed for the restoration treatments (Sun Creek and Spring Park Creek Roads; Fig. 1) for noxious weeds. Thus, all the roads within the TCEF were surveyed. Because of the low presence of weeds, we did not designate specific road sampling points as this would likely have resulted in an underdetection of weed presence. Instead, with the exception of Canada thistle, we recorded all noxious weed occurrences and mapped the locations of the weeds using GPS points. Because the TCEF is relatively free of noxious weeds, all mapped individuals were mechanically controlled (hand pulled) to prevent establishment and spread. Populations of Canada thistle were widespread along the roads, and too numerous to be mapped or treated in this study.

Results

No noxious weeds were recorded at any of the sampling points within the silvicultural treatment or control units over the 9-year sampling period (Table 1)—9 years after logging and 6–7 years after burning. Although no noxious weeds were recorded at the sampling points, Canada thistle was observed within 13 of the 18 treatment units during our visual surveys, typically on burned slash piles, in unburned piles of logging slash, and in skid rows. During these visual surveys no other noxious weed species were found within the restoration treatment units. A single occurrence of oxeye daisy, recorded in 2009 on the restricted access Spring Park road, was the only instance of weed establishment on the roads constructed for the silvicultural treatments (Fig. 1). In contrast, noxious weeds (excluding Canada thistle that was common) were recorded 43 times along the open access forest roads within or adjacent to the boundary of TCEF (Fig. 1). Each of these records corresponds to a single individual or small group of plants. Of the 43 records, 28 were for oxeye daisy, 11 for spotted knapweed, 3 for common tansy, and 1 for houndstongue (Fig. 1 and Table 2).

Discussion

A number of studies have investigated the response of exotic plants to thinning and burning restoration treatments (see review by Sutherland & Nelson 2010), but few have considered the influence of roads on exotic plant species. Despite the fact that these treatments often require the construction of new roads and increased use of established roads—habitats known to support relatively high levels of weeds and to play a role in the spread and invasion of exotic plants (Forman & Alexander 1998; Parendes & Jones 2000; Gelbard & Belnap 2003). Almost all studies addressing the effects of silviculture treatments on exotic plants have found an increase in at least one exotic species following treatment (Sutherland & Nelson 2010), but whether roads played a role in these increases is unknown. However, roads can facilitate invasion into treated areas by acting as points of establishment for weed species and sources of weed propagules that increase the potential for

Table 1. Percent cover of noxious weeds at sampling points and presence/absence of Canada thistle within the silvicultural treatment and control units (Fig. 2) at TCEF, Montana, United States.

Drainage (Creek)	Unit	Treatment	Number of Points	Percentage of Noxious Weed Cover at Sampling Points					Canada Thistle in Unit
				2001	2003	2004	2005	2009	
Sun	1	ESB	17	0	0	0	0	0	Yes
Sun	2	GSB	21	0	0	0	0	0	Yes
Sun	3	ESB	28	0	0	0	0	0	No
Sun	4	GSB	28	0	0	0	0	0	No
Sun	5	ESNB	29	0	0	0	0	0	No
Sun	6	GSNB	38	0	0	0	0	0	Yes
Sun	7	GSNB	28	0	0	0	0	0	Yes
Sun	8	ESNB	45	0	0	0	0	0	Yes
Sun	B-1	BO	43	0	0	0	0	0	No
Spring Park	9	ESNB	27	0	0	0	0	0	No
Spring Park	10	ESB	28	0	0	0	0	0	Yes
Spring Park	11	GSNB	25	0	0	0	0	0	Yes
Spring Park	12	GSB	30	0	0	0	0	0	Yes
Spring Park	13	ESB	31	0	0	0	0	0	Yes
Spring Park	14	ESNB	40	0	0	0	0	0	Yes
Spring Park	15	GSNB	32	0	0	0	0	0	Yes
Spring Park	16	GSB	51	0	0	0	0	0	Yes
Spring Park	B-2	BO	39	0	0	0	0	0	Yes
Bubbling	East	Control	25	*	0	0	0	0	No
Bubbling	West	Control	25	*	0	0	0	0	No
Stringer	East	Control	25	*	*	0	0	0	No
Stringer	West	Control	25	*	0	0	0	0	No

BO, prescribed burn only/no logging; control, no logging, no burn; ESB, evenly spaced shelterwood with burn; ESNB, evenly spaced shelterwood, no burn; GSB, grouped shelterwood with burn; GSNB, grouped shelterwood, no burn.
* Data not collected.

Table 2. Number of observations of noxious weeds along roads over the 9-year sampling period at TCEF, Montana, United States.

Noxious Weed	Number of Occurrences				
	2001	2003	2004	2005	2009
Spotted knapweed	0	4	1	4	2
Oxeye daisy	6	10	6	3	3*
Common tansy	0	2	1	0	0
Houndstongue	0	0	0	0	1
	6	16	8	7	6

* Includes the single occurrence of any noxious weed along roads constructed to complete thinning and burning treatments.

spread outside of the road corridor (Gelbard & Belnap 2003; Fowler et al. 2008; Avon et al. 2010). In this study, we found that open access roads were a key habitat for establishment of noxious weed species in the TCEF. It is unclear if roadside populations of these weeds would encourage their spread into treated areas (we hand pulled all plants encountered), but their persistence along roadways should increase propagule pressure and the potential for invasion over time. These findings suggest that weed surveillance and management along roadways should be a part of efforts to restore forest ecosystems.

Following the treatments, Canada thistle was observed within 13 of the 18 treated units but was not found within any of the controls. Within the treatment units, Canada thistle was not found at any sampling point but was observed during travel between samples, primarily on post-harvest slash piles and skid rows, suggesting that weed management tactics should be focused on and around these most heavily disturbed sites. Slash management areas are known to be susceptible to exotic plant invasion (Scherer et al. 2000; Haskins & Gehring 2004), and weed control at these microsites could be an integral part of successful forest restoration and forest logging operations in general. In addition, because Canada thistle was abundant along roads in the TCEF, long-term control will also require managing roadside populations of this noxious weed.

Exotic plant invasion is dependent on a number of factors; key among these is propagule pressure of the exotic species (Sutherland & Nelson 2010). The overall low abundances of noxious weeds in the TCEF could in part explain the general absence of noxious weed invasion into thinned and burned treatments areas. Other studies have found similarly low levels of weedy plant invasion following thinning and burning treatments (Wayman & North 2007; Dodson et al. 2008; Nelson et al. 2008). Wayman and North (2007) reported no exotic plant invasion following thinning and burning treatments in a mixed-conifer California forest that contained only a single-known exotic plant species (*Rumex acetosella* L.). This non-native species was, however, found along roads and skid trails. This suggests that our findings might have broader significance for other forests in the early stages of invasion. In these cases, managing roadside weeds should afford the opportunity to limit invasive plant spread as a side effect of forest restoration, and perhaps to mitigate weed problems generally. Whether roads are of similar importance to the distribution of exotic plants in more invaded forests or for newly immigrated weeds in these forests are not understood, but should be investigated.

Implications for Practice

- Forest thinning and burning treatments have the potential to foster the invasion and spread of exotic plants which can thwart successful ecosystem restoration.
- In a relatively weed-free Montana forest, thinning and burning did not lead to increased numbers of noxious weeds, except for Canada thistle which invaded some areas. Instead, roads were a key factor influencing the distribution of noxious weeds.
- In this forest, managing weeds along roadways should provide effective, long-term insurance against the invasion, and spread of noxious weeds.
- Further study is needed to understand how roads and restoration treatments affect invasive plants—something that is likely to vary with the abundance and type of exotic plants present before treatment.
- Monitoring exotic plants should be a component of forest restoration. In particular, weed control along roadways and in heavily disturbed areas such as slash piles and skid rows, may be cost-effective and efficient tactics to limit exotic plant invasion.

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