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Edge type defines alien plant species invasions along *Pinus contorta* burned, highway and clearcut forest edges

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Abstract

Forest edges have been long recognized as the first landscape elements to be invaded by alien plant species in forest ecosystems. However, little is known about the role of forest edge type in invasive species patterns. In the Northern Rocky Mountains of the United States, disturbance-caused forest edges are a common feature in the landscape with anthropogenic (e.g. roadside, clearcut) and natural (e.g. burned, windthrown) edge types. In this paper we examine patterns of alien species invasion and native community structure across three forest edge types in *Pinus contorta* forests including contrasts between undeveloped landscapes in Yellowstone National Park (YNP), and developed (roaded and logged) portions of the adjacent Gallatin National Forest (GNF). Six sets of transects were located in each of five study sites, including clearcut, burn and highway edge types. When burn and highways edges were compared between GNF and YNP, landscape matrix did not have a significant effect on either alien species richness or cover. In both landscapes, highway edges had higher alien species richness and cover than burn edges. For burn and highway edges, alien species richness and cover were significantly related to edge type, distance from edge and the interaction between both variables. In Gallatin NF, alien species were concentrated along highway edges, while burn and clearcut edges are significantly less invaded. Overall, alien species richness was negatively correlated with native species richness in plots with at least one alien species ($R^2 = 0.30$, $p < 0.001$). We were able to explain from 23 to 68% of the variation in alien species richness from simple measures of vegetation structure within each of the edge types. Our study suggests that at least for high elevation conifer ecosystems such as West Yellowstone, alien plant invasion into interior forest is significantly enhanced by disturbance edges only along roadsides. Further studies are needed to determine causal mechanisms that explain the high degree of invisibility of roadside edges. Our results highlight the need for careful planning and management of roads, as they may become a primary conduit of alien plant invasions.

Keywords: Forest invasion; Edge effects; Yellowstone National Park; *Pinus contorta*; Exotic species

1. Introduction

While much work has been done on understanding how alien invasive species interact with native species at the individual plant or patch scale, increasing evidence suggests that landscape structure and land-use are also key elements influencing alien species invasion processes across a range of spatial scales (Hobbs, 2000; With, 2002; Pauchard and Alaback, 2004; Pauchard and Shea, 2006). At the landscape scale, forest edges are recognized as a potential starting point for invasions of alien plant species into less disturbed environments (Saunders et al., 1991; Brothers and Spingarn, 1992; Cadenasso and Pickett, 2001; Honnay et al., 2002). Invasive species often are unable to percolate deeply into forested environments (Honnay et al., 2002; Watkins et al., 2003; Pauchard and Alaback, 2004). While many of these species have high light, nutrient or energy requirements that are best met in edge environments, it is unclear what role native species and ecosystem structure plays in affecting ''invasibility'' in forest habitats (Gilbert and Lechowicz, 2005; Stohlgren and Barnett, 2003).

Most of the evidence of edge effects in forests on native and alien species comes from clearcut logged and agricultural edges (e.g. Chen et al., 1991; Honnay et al., 2002; Murcia, 1995; Euskirchen et al., 2001). Other natural and anthropogenic edges types such as forest road edges or burn forest edges would be expected to show distinct edge responses due to their unique structure and landscape context, yet few studies have directly

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compared edge types (Mullen et al., 2003; Watkins et al., 2003). The influence of edge type is particularly important in the case of alien species invasions where landscape dispersal processes may influence stand scale phenomena (With, 2002). While changes in physical environment along edges have direct implications to growth, competition and population dynamics of many native species, there is growing evidence that for alien species propagule pressure may be an equally important factor (Matlack, 1993; Young and Mitchell, 1994; Cadenasso et al., 1997; Cadenasso and Pickett, 2001; D'Antonio et al., 2001; Honnay et al., 2002).

Edge types (e.g., roads, clearcuts, burned forests) provide natural experiments not only to compare invasion processes in relation to distance from the edge, but also to examine other factors such as landscape matrix influences (sensu Lindenmayer and Franklin, 2002). Since edge types are generally associated with unique matrix conditions and thereby specific alien species propagule pressure, comparing edge effects of several types of edges within contrasting landscape matrices may be useful to examine the role of landscape phenomena on alien species invasions.

In the Northern Rocky Mountains of the United States, disturbance-caused forest edges are a common feature in the landscape. Roadside and clearcut forest edges are the dominant anthropogenic edge types (Reed et al., 1996), while edges of burned forests are the dominant edge type in protected areas (Turner et al., 1997; Parmenter et al., 2003). *Pinus contorta* forests in the vicinity of West Yellowstone, Montana provide a unique opportunity to study the influence of edge type and landscape matrix on invasion processes. A relatively small and homogeneous forested area contains highways, burned forests and clearcut forest edges. In addition, these edges occur on both human-disturbed (logged and high density roads) landscapes of Gallatin National Forest (GNF) and in undeveloped landscapes of Yellowstone National Park (YNP) (low density roads and burn edges only). All these edge types can be found in the Madison Plateau area on one habitat type with similar soil, elevation and topographic conditions (Despain, 1990).

In this paper we examine differences in patterns of alien species invasion and native communitiy structure among three forest edge types (burned forests, clearcuts and highways) in the Madison Plateau of West Yellowstone to determine: (1) are there differences in patterns of alien plant invasions along edges between the landscape matrices of GNF and YNP?, (2) are there differences in alien species between edge types (highway, burn, clearcut) within the developed landscape matrix of GNF? and finally (3) what structural attributes of the vegetation are most closely associated with alien species invasion within each edge type?

2. Methods

2.1. Study sites

The study area is located in the West Side of Yellowstone National Park and adjacent Gallatin National Forest (44°48′N, 111°12′W and 44°37′N, 111°00′W). The area represents a strong contrast between land use history inside and outside of the park, but the entire study area has a similar elevation, soil type and habitat type (Despain, 1990). Soils are dominated by Typic Cryochrepts with obsidian sand alluvial parent material (USDA Forest Service, Gallatin NF, unpublished). These soils are coarse textured, well drained, and have low organic matter content.

Climate is continental and montane, and is strongly influenced by its high elevation (2000 m) and protected valley topography. Precipitation in the area averages 550 mm/year, with peaks in December–January, and June. During the winter, snow accumulation averages 100 cm. Snow cover usually persists from November to April. Mean temperature ranges from a low of −11.1 °C during January to a high of 15.2 °C in July (Western Regional Climate Center, 2001). Frosts are common throughout the year.

P. contorta forests and *Artemisia tridentata* shrublands are dominant vegetation types. Forests are classified as *P. contorta*/*Purshia tridentata* habitat type for most of the area (Pfister et al., 1977). These forests have a low productivity, with mature tree heights around 20 m (Pfister et al., 1977; Despain, 1990). Understory species include *P. tridentata*, *Lupinus* spp., *Antennaria microphylla*, *Oryzopsis exigua* and *Sitanion hystrix*. Forests are open and tree seedling establishment is limited by drought (Despain, 1990; Stohlgren and Bachard, 1997). This habitat type has been found only in West Yellowstone and it is associated with alluvial soils (Pfister et al., 1977).

Disturbances in the area include fire, windthrow, logging and road development (Parmenter et al., 2003). Fire is the main natural disturbance, but is infrequent due to low rates of fuel accumulation and the rarity of extended droughts (Turner et al., 1997, 2003; Schoennagel et al., 2003). Fire average return intervals range from 400 to 600 years, but frequency may increase in more productive sites (Romme and Despain, 1989; Turner et al., 1994). GNF has been subjected to significant logging pressure, with clear-cutting and selective cutting as the major extractive techniques (Susan LaMont, USDA Forest Service, Gallatin National Forest, Personal communication 2000). Logging effected approximately 800 ha/year from the 1970s to the 1990s, with peaks in the early 1970s and mid 1980s (Gallatin National Forest, unpublished). Road development associated with logging has fragmented the area. Grazing, logging and transportation have facilitated the introduction of aggressive weeds into the area of West Yellowstone (Stohlgren et al., 1999; Olliff et al., 2001; Whipple, 2001). Among the most invasive are *Centaurea maculosa*, *Linaria vulgaris*, *Linaria dalmatica*, *Melolitus officinalis*, *Cirsium arvense* and *Verbascum thapsus* (Olliff et al., 2001; Whipple, 2001). The harsh, high elevation climate restricts the intensity of weed invasion, especially those adapted to more temperate agricultural conditions (Forcella and Harvey, 1983; Sax and Brown, 2000). Nevertheless, human disturbed areas (e.g. roads, clearcuts) have been already modified by plant invaders. Furthermore, weeds are progressively colonizing riparian habitats and other pristine environments (Pauchard et al., 2003).