

Landscape Factors Influencing the Abundance and Dominance of the Invasive Plant *Potentilla recta*

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Abstract

Little is known about the relative importance of environmental, biotic, historical, and spatial factors that influence invasive plant abundance, dominance, and distribution across landscapes. We identified factors that influence the abundance and dominance of *Potentilla recta* L. (sulfur cinquefoil) in bunchgrass grasslands of northeastern Oregon to better understand the conditions under which it becomes a major component of plant communities. We estimated *P. recta* stem density and dominance from field measurements across the landscape and used classification and regression tree analyses to assess the importance of environmental, biotic, spatial, and historical factors in explaining *P. recta* presence, stem density, and dominance. Plots were sampled within a systematic grid with 250-m spacing within our 6.5-km² study landscape. At each sample point we recorded *P. recta* presence, stem density, and dominance as well as 11 biological, environmental, spatial, and historical variables. *P. recta* was widely distributed, with stem densities in occupied plots averaging 5.8 stems · m⁻² and dominance values ranging from 1% to 52%. Percent cover of bare ground was the most important variable to predict the presence of *P. recta*, though the model fit was poor, likely because the entire study area is suitable for *P. recta* establishment. A strong relationship between *P. recta* dominance and habitat type ($r^2 = 67.5\%$) was found, with dominance greatest in old fields on relatively flat slopes (mean dominance of 34.1%). Dominance estimates were $\leq 1\%$ in plots located in forest, shrub, and grassland habitats. Factors that make old fields susceptible to dominance remain unknown, though microsite conditions that increase *P. recta* seedling survival rates and limited native propagule availability due to previous cultivation may be involved. Since old fields are found throughout the region, are highly susceptible to *P. recta* invasion, and represent a source of seeds, containment and restoration activities should focus on these areas.

Resumen

Poco se sabe acerca de la importancia relativa de los factores ambientales, bióticos, históricos y espaciales que influyen en la abundancia, dominancia y distribución a través del paisaje de las plantas invasoras. Identificamos factores que influyen en la abundancia y dominancia de *Potentilla recta* L. (“Sulfur cinquefoil”) en los pastizales amacollados del nordeste de Oregon, para entender mejor las condiciones bajo las cuales llega a ser uno de los componentes principales de las comunidades vegetales. Estimamos la densidad de tallos y dominancia de *P. recta* a partir de mediciones de campo a través del paisaje y usamos análisis de árbol de Clasificación y Regresión para evaluar la importancia de los factores ambientales, bióticos, espaciales e históricos en explicar la presencia, densidad de tallos y dominancia del *P. recta*. Las parcelas fueron muestreadas dentro de una cuadrícula con una separación de 250-m entre puntos y dentro de nuestra área de estudio de 6.5 km². En cada punto de muestro registramos la presencia, densidad de tallos y dominancia de *P. recta*, así como otras 11 variables biológicas, ambientales, espaciales e históricas. El *P. recta* estuvo ampliamente distribuido, con un promedio de densidad de tallos de 5.8 tallos m⁻² y los valores de dominancia variaron de 1% a 52%. El porcentaje de suelo desnudo fue la variable más importante para predecir la presencia de *P. recta*, aunque el ajuste del modelo fue pobre, probablemente porque toda el área de estudio es apropiada para el establecimiento de *P. recta*. Se encontró una estrecha relación entre la dominancia de *P. recta* y el tipo de hábitat ($r^2 = 67.5$), con la mayor dominancia en los campos viejos en pendientes relativamente planas (dominancia promedio de 34.1%). Las estimaciones de dominancia en las parcelas localizadas en hábitat de bosque, matorral y zacatal fueron $\leq 1\%$. Los factores que hacen a los campos viejos susceptibles para ser dominados por esta especie son aun desconocidos, aunque las condiciones de micrositio que incrementan la tasa de supervivencia de las plántulas de *P. recta* y la limitada disponibilidad de propágulos de especies nativas debido a las prácticas previas de cultivo del campo, pueden estar involucrados. Dado que los campos viejos se encuentran en toda la región son altamente susceptibles a la invasión de *P. recta* y representan una fuente de semilla, por lo que las actividades de contención y restauración deben enfocarse en estas áreas.

Key Words: invasive plants, noxious weeds, Oregon, Blue Mountains, landscape ecology, bunchgrass rangelands

INTRODUCTION

In the past several decades, the impact of exotic, invasive plants on ecological patterns and processes has been recognized, and invasive species are considered a significant threat to biodiversity and the composition, structure, and function of local

Research was funded by the USDA Forest Service, Pacific Northwest Research Station, and the Center for Invasive Plant Management.

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Manuscript received 26 February 2006; manuscript accepted 2 March 2007.

and regional ecosystems (D'Antonio and Vitousek 1992; Vitousek et al. 1996; Mack et al. 2000). Invasive, exotic species pose a significant economic and ecological problem to western forests and rangelands, and it has been estimated that exotic species in western rangelands cost \$1 billion per year in forage losses and \$5 billion per year to control (Pimentel et al. 2000). As a result, the causes and consequences of exotic plant invasions in rangelands have received considerable attention from scientists, and invasive plant management is now a central component of many land managers' activities.

In some ecosystems, exotic species reach such high abundances (density, biomass, cover) that they become community dominants. These situations pose the greatest threat to native ecosystems because dominant species set the environmental context for the persistence and abundance of other species (Huston 1994; Keddy 2001; Denslow and Hughes 2004). Despite the attention exotic plant invasions have received in recent years, little is known about the relative importance of environmental, biotic, historical, and spatial factors that influence landscape-level patterns of exotic plant abundance, dominance, and distribution (Parks et al. 2005). This lack of understanding of the invasion process hinders the development of efficient, cost-effective approaches to invasive plant management. Environmental and biological information also can be useful in the development of predictive models of invasive plant spread to better inform invasive plant management programs. Anticipating the establishment and spread of invasive plant species is important, as invasions are often easiest to control early in the invasion process. Moreover, invasive plant management is expensive and time consuming, and information to prioritize management actions is highly desirable (Andersen et al. 2004; Endress et al. 2006). Unfortunately, few studies have taken an integrated approach to predict and contain invasive plant species in the forests and rangelands of the interior Pacific Northwest (but see Shafii et al. 2003, 2004; Radosovich et al. 2005).

Estimates of invasive plant success in particular habitats are usually based on presence/absence, absolute cover, or biomass data. Recently, it has been suggested that dominance, or the relative cover or biomass of a species, may be a better measurement to estimate and characterize plant invasions and their potential impact on plant communities (Lundholm and Larson 2004). Measurements of absolute cover or biomass often underestimate the degree to which an invasive plant species is abundant relative to native species, particularly when total foliar cover is considerably lower than 100%, as is the case in arid and semiarid ecosystems (Lundholm and Larson 2004). In addition, many invasive plant species found in the interior Pacific Northwest have broad ecological amplitude and are able to establish, even at very low abundances, in a wide range of habitats (Parks et al. 2005). For species with broad ecological amplitude, the conditions whereby it can dominate a plant community should be identified. Knowing the likelihood of dominance is useful because it assists in the prioritization of management actions, including inventory, monitoring, eradication, control, and restoration activities.

Potentilla recta is a relatively recent introduction to the interior Pacific Northwest, and many new infestations have reached environmentally severe sizes and densities (Rice 1999). It is native to Eurasia and was introduced into North America

prior to 1900. The species has since spread across the continent. The plant reproduces only by seed. In northeastern Oregon, *P. recta* can live to 10 years of age (Perkins et al. 2006). Adult plants are prolific seed producers with up to 6 000 seeds produced per plant per year (Dwire et al. 2006). In eastern North America, it is a minor agricultural weed, but in the drier climates of the West, *P. recta* forms dense populations in several native plant communities (Rice 1999). Zouher (2003) found that *P. recta* established and persisted in 53 and 32 different land cover types identified by the Society for Range Management and the Society for American Foresters, respectively. These land cover types range from bluebunch wheatgrass grasslands to white spruce-aspen forests. While numerous plant communities are at risk to invasion by *P. recta*, little is known about the relative risk of different plant communities.

In this study, we identify factors that influence landscape-level patterns of abundance and dominance of *P. recta* L. (sulfur cinquefoil) in the low-elevation rangelands of northeastern Oregon to better understand the conditions under which it becomes a major component of plant communities. Specifically, our objectives were to: 1) estimate stem density and dominance of *P. recta*; and 2) assess the importance of environmental, biotic, spatial, and historical factors in explaining presence, stem density, and dominance of the species.

MATERIALS AND METHODS

Study Site

Our research is focused on the low-elevation (< 2000 m) rangelands of the Blue Mountains ecoregion of northeastern Oregon and southeastern Washington. Perennial bunchgrass communities dominate the area, but the region also contains forest stands of ponderosa pine (*Pinus ponderosa* P. & C. Lawson) and Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco var. *menziesii*). Bunchgrass communities in the region have undergone considerable change in the past 150 years. These grasslands are typically dominated by perennial bunchgrass species including *Pseudoroegneria spicata* (Pursh) A. Löve, *Poa secunda* J. Presl, and *Festuca idahoensis* Elmer. Cultivation, grazing, altered fire regimes, and the introduction of exotic plant species have resulted in their transition to grasslands dominated by exotic grass and forb species (Johnson and Swanson 2005; Parks et al. 2005). Bunchgrass rangelands are considered one of the most altered ecosystems in the interior Pacific Northwest (Bunting et al. 2002) and contain the greatest number of exotic species of all ecosystems in Oregon (Parks et al. 2005). Many bunchgrass communities are now dominated by a mix of exotic species including several annual grasses (*Bromus tectorum* L., *Taeniatherum caput-medusae* L. [Nevski], *Ventenata dubia* [Leers] Coss. & Durieu) and a number forbs (*Centaurea* spp., *Linaria* spp., *P. recta*) (Parks et al. 2005).

Our research was conducted in Wenaha State Wildlife Area near Troy, Oregon. Elevation ranges from 900 to 1 150 m, and annual precipitation averages 430 mm · y⁻¹ (Western Regional Climate Center, Reno, NV). Most precipitation occurs from October through May with the warm, drier summer months characterized by periodic thunderstorms. The area is representative of the low-elevation rangelands of the Blue Mountain

ecoregion in terms of habitats and land use history. The area is characterized by a matrix of open coniferous forest (*P. ponderosa*, *P. menziesii* var. *menziesii*), abandoned agricultural fields (dominated by *Poa bulbosa* L., *Bromus inermis* Leyss., and *Poa pretensis* L.), and perennial bunchgrass (*P. spicata*, *P. secunda*, *F. idahoensis*) plant communities. As with many areas of the region, intense land use began with the expansion of cattle and sheep ranching and the conversion of bunchgrass rangeland to agricultural fields and as part of the US Homestead Act of 1865 (Jordan 1954; Galbraith and Anderson 1971; Carrey et al. 1979). The rugged landscape, arid environment, and the difficulty in meeting livelihood needs resulted in abandonment of most agricultural fields (Jordan 1954; Carrey et al. 1979). Currently, the predominant land use activities are cattle grazing and big game hunting (elk [*Cervus elaphus*] and mule deer [*Odocoileus hemionus*]).

Sampling Design

A systematic grid was established with 250-m spacing within a 6.5-km² area along Eden Bench, part of the Wenaha State Wildlife Area, using Geographic Information Systems (GIS) technologies (ESRI ArcGIS 8.3). During July 2003, each sample point in the grid was found using real-time differential global positioning systems (Trimble Pathfinder ProXRS; Trimble 2002), and at each sample point, we delineated a 22.7-m-diameter circular plot (405 m²). This plot size was chosen for use in a companion photodetection study for *P. recta* (Naylor et al. 2005). The presence of *P. recta*, slope, aspect, and tree canopy cover (visual estimate using the following percent cover categories: 0, 1, 1–5, 5–25, 25–50, 50–75, 75–95, 95–99, 100) were estimated for each plot ($n = 80$). Plots were also classified into 1 of 5 habitat categories, which included grassland (grass dominated areas with < 5% tree canopy cover and < 25% shrub cover), shrubland (< 5% tree canopy cover and > 25% shrub cover), open forest (5%–50% tree canopy cover), forest ($\geq 50\%$ tree canopy cover), and abandoned agricultural fields (“old fields”).

Within each 405-m² plot, twelve 1-m² quadrats were established for intensive sampling. The 1-m² plots were spatially arranged throughout the plot in the following pattern: plots were established 3 m and 9 m from the plot center in each the cardinal directions (N, S, E, W) and 6 m from the plot center in NE, SE, NW, and SW directions. At each quadrat, percent canopy cover was recorded for *P. recta*, total vegetation (< 1 m in height), and vegetation by general life form categories (i.e., forbs, graminoids, shrubs). Percent cover for bare ground and rock cover were also recorded. Cover was visually estimated using the following percent cover classes: 0, < 1, 1–5, 5–15, 15–25, 25–35, 35–45, 45–55, 55–65, 65–75, 75–85, 85–95, > 95. If *P. recta* was present, the total number of stems in each quadrat was recorded. Dominance (relative cover) was calculated by dividing the percent cover of *P. recta* of a quadrat by the total vegetation cover of that quadrat.

Geographic Information Systems

In addition to collecting data in the field, several landscape variables were also calculated using GIS software (ESRI ArcGIS 8.3). These calculations included distance (m) to the nearest water source (stream, pond, spring, and so on), distance (m) to

the nearest road, elevation, and soil type. Water sources and roads were digitized from 1:6 000 scale georectified natural color aerial photographs (Naylor et al. 2005) and grayscale digital orthographic quadrangles (USDA Forest Service 2001). Distance measurements to the nearest water source or road feature were calculated using ArcGIS 8.3. These variables were of interest because the abundance of several exotic rangeland weeds is positively related to either roads or riparian areas (Parks et al. 2005). Soil data were from the NRCS Soil Survey Geographic (SSURGO) database for Wallowa County Area, Oregon (USDA, NRCS 2005) and were classified to the soil great group taxonomic level, which differentiates soils based on the development of pedogenic horizons, soil moisture, and base status. In this study, 4 soil great groups were identified: haploxerolls, argixerolls, haploxeralfs, and soils comprised of both argixerolls and haploxerolls.

Analysis

Classification and regression tree analyses (CART) were conducted to identify the most important variables explaining *P. recta* presence, stem density, and dominance. CART models are ideally suited to identify ecological patterns and processes, including factors that influence the abundance and distribution of species (De'ath and Fabricius 2000; Wiles and Brodahl 2004; Taverna et al. 2005). CART models are nonparametric models that explain variation of a single response variable (e.g., *P. recta* density) by recursive partitioning of the data set into more homogeneous data subsets, using combinations of explanatory variables (Urban 2002). Explanatory variables may be categorical and/or continuous. CART estimates model fit by calculating r^2 ; when the response variable is categorical (e.g., *P. recta* presence), model quality is estimated by its misclassification rate. CART analysis represents a relatively new and powerful alternative to traditional statistical techniques, including analysis of variance and linear, multiple, and logistic regression analyses, where it is difficult to analyze nonlinear relationships, high-order interactions, missing values, or data that are highly skewed or multimodal (De'ath and Fabricius 2000; Urban 2002; Taverna et al. 2005).

Three CART analyses (CART version 5.0; Salford Systems 2002) were performed using 79 of the 80, 405-m² circular plots for 3 different independent variables: *P. recta* presence, stem density, and dominance. One plot was dropped from the analyses because of a GPS malfunction that resulted in loss of the data. Each of the 79 remaining plots was classified for presence or absence of *P. recta* based on field sampling. Plot estimates of *P. recta* dominance and stem density were determined by calculating the mean values of those 2 variables from the 12, 1-m² plots. For 18 of the 79 plots, *P. recta* was found but was not abundant enough to occur in any of the 12, 1-m² sampling quadrats. In these cases, we assigned a dominance value of 0.1% and stem density value of 0.01 stems \cdot m⁻². A strong positive correlation between dominance and stem density ($r = 0.85$, $P < 0.0001$) was found, and for that reason the CART analysis for stem density is not presented.

Explanatory variables entered into the models are found in Table 1. The CART trees were constructed automatically using the Gini Method with a minimum parent node of 10

Table 1. Variables used in classification and regression tree analyses to identify factors influencing *Potentilla recta* presence and dominance near Troy, Oregon.

Variable	Type	Source
Response variables		
<i>P. recta</i> presence	Categorical	Field measurement in 405-m ² plots
<i>P. recta</i> dominance	Numeric	Mean field measurement of 12, 1-m ² plots
Explanatory variables		
Soil type	Categorical	Soil Survey database (USDA, NRCS 2005)
Aspect	Categorical	Field measurement in 405-m ² plots
Slope	Numeric	Field measurement in 405-m ² plots
Elevation	Numeric	10-m Digital Elevation Model (USDA 2000)
Habitat	Categorical	Field measurement in 405-m ² plots
Tree canopy cover	Numeric	Field measurement in 405-m ² plots
Shrub cover	Numeric	Mean field measurement of 12, 1-m ² plots
Rock cover	Numeric	Mean field measurement of 12, 1-m ² plots
Bare ground cover	Numeric	Mean field measurement of 12, 1-m ² plots
Distance to water	Numeric	Spatial Join in ESRI ArcGIS 8.3
Distance to road	Numeric	Spatial Join in ESRI ArcGIS 8.3

observations (Salford Systems 2002). The success of the CART analyses were assessed by 10-fold cross validation using the 1-SE rule (De'ath and Fabricius 2000; Salford Systems 2002). Cross validation was conducted to select the classification tree sizes and estimate error rates for trees of a given size. When the response variable is a continuous, numeric variable (e.g., *P. recta* dominance), CART estimates the model fit by calculating r^2 ; when the response variable is categorical (e.g., *P. recta* presence), the quality of the model is estimated by its misclassification rate. The misclassification rate is the proportion of observations that have been misclassified (e.g., a plot where the model suggests *P. recta* should be absent but the species is actually present).

RESULTS

P. recta was found in 59 of the 79 sampled plots (74.7%), although canopy cover, stem density, and dominance varied considerably among plots. Mean percent cover of *P. recta* in occupied plots was 3.5% (SD = 7.6; median = 2.0) with a maximum value of 34%. Stem density in occupied plots averaged 5.8 stems · m⁻² (SD = 9.9; median = 2.6) with a maximum value of 87 stems · m⁻². *P. recta* dominance ranged from 1% to 52% with a mean dominance of 6.5% (SD = 13.0; median = 5.2%).

The classification tree indicated that bare ground was the most important variable predicting the presence of *P. recta* (Fig. 1). Plots with ≥ 18% cover of bare ground were more likely to have *P. recta* (89%) than plots with < 18% bare ground (53%). Nearly 98% of the plots with bare ground ranging from 18% to 48% contained *P. recta*. Cross validation revealed that only 61% of observed plots were correctly classified, and the model explained 34.3% of the variance. Other explanatory variables in this analysis (e.g., shrub cover, soil type, aspect, and so on; Table 1) did not

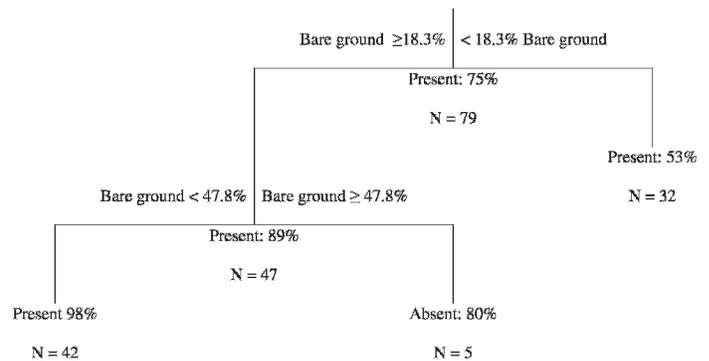


Figure 1. Classification tree for the presence/absence of *Potentilla recta* in the Wenaha State Wildlife Management Area near Troy, Oregon. Each split is labeled (classified) according to whether *P. recta* is predominantly present or absent, the percentage of observations in that class, the number of observations, and the proportion of variance explained by the split. The misclassification rate for *P. recta* presence is based on 10-fold cross validation of the data was 39%.

explain a sufficient amount of variation to be retained in the final CART tree.

The CART model developed to identify factors for *P. recta* dominance differed from the presence/absence model and indicated that habitat type was most important predictor of *P. recta* dominance (Fig. 2). Dominance was greatest in old fields (mean dominance of 18.7%), while it was much lower for plots located in forest (0.2%), open forest (0.5%), shrub (0.8%), and grassland (1.0%) habitats (Fig. 3). A 1-way analysis of variance (ANOVA; Welch's ANOVA for samples with unequal variances using PROC GLM; SAS Institute Inc. 2000) found that these differences were significant (df = 4, 75,

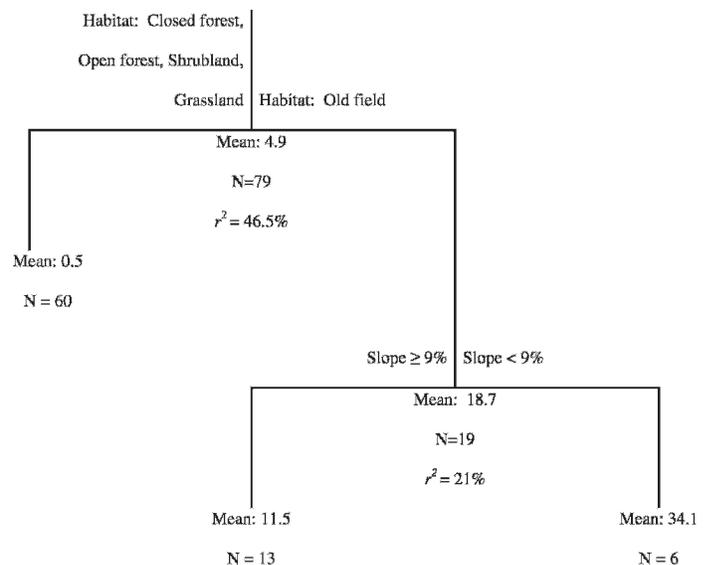


Figure 2. Regression tree analysis for dominance of *Potentilla recta* in the Wenaha State Wildlife Management Area near Troy, Oregon. The 2 splits (nonterminal nodes) are labeled with the explanatory variable (e.g., slope, habitat), the values that determined the splits, as well as the mean dominance (mean %), number of observations (N), and proportion of variance explained by the split (r^2). Each node is labeled with the mean *P. recta* dominance (%) and the number of observations in each group. The tree explained (r^2) 67.5% of the total variance.

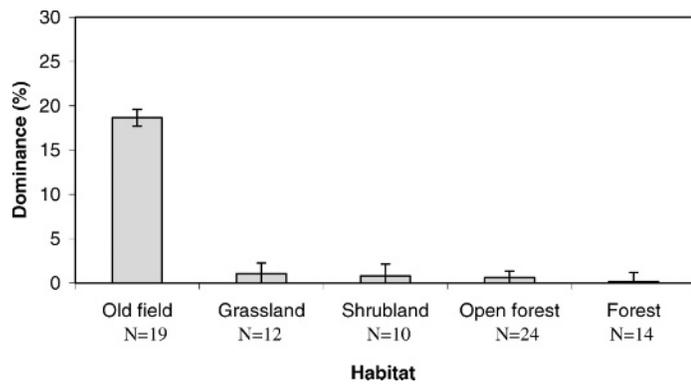


Figure 3. Mean dominance (± 1 SE) of *Potentilla recta* among different habitat types in the Wenaha State Wildlife Management Area near Troy, Oregon. Dominance values were significantly different among habitat types ($P = 0.0013$).

$F = 6.12$, $P = 0.0013$). This analysis further split old fields into 2 groups based on slope. Old fields on low slopes ($< 9\%$) had the greatest *P. recta* dominance values, averaging 34.1%, as compared to dominance value of 11.5% for old fields with slopes $> 9\%$. Regardless of habitat type, dominance decreased as slope increased (Fig. 4; $r^2 = 0.166$, $P = 0.0003$). Cross validation of the CART tree revealed that the model explained 67.5% of the data variance. Because of the strong correlation between dominance and stem density, old fields also had the highest mean density of *P. recta* ($19.2 \text{ stems} \cdot \text{m}^{-2}$), compared to other habitats, where mean stem densities were less than $1 \text{ stem} \cdot \text{m}^{-2}$. These differences were also significant (Welch's 1-way ANOVA; $df = 4$, $75 F = 4.18$, $P = 0.011$).

DISCUSSION

P. recta is widely distributed throughout our study landscape, and dominance is most strongly related to past land use. Mean dominance of *P. recta* in old fields is more than 37 times greater than in other habitats. The CART model for explaining *P. recta* presence was poor, with a high rate of misclassification. The poor fit of this model is likely due to the fact that all the habitats along Eden Bench are generally suitable to *P. recta* establishment.

Results from this study suggest that dominance by *P. recta* may be less attributable to competition than has been previously supposed; rather, *P. recta* dominance is the product of the synergism between *P. recta* invasion, disturbance, and land use/land cover change. Thus, rather than driving the transformation of native bunchgrass communities, *P. recta* may be a "passenger" of more fundamental environmental changes that limit native flora, such as reduced dispersal of native species due to cultivation and habitat fragmentation. Similar patterns have been found in other ecosystems (e.g., Seabloom et al. 2003; Corbin and D'Antonio 2004; Didham et al. 2005; MacDougall and Turkington 2005). For example, past land use was the strongest predictor of the abundance and distribution of 3 invasive species in secondary forests in the eastern United States (Lundgren et al. 2004). Similarly, the density of 3 invasive plants in Spain was greatest in abandoned fields or in woodlands that were former agricultural areas (Vilà et al.

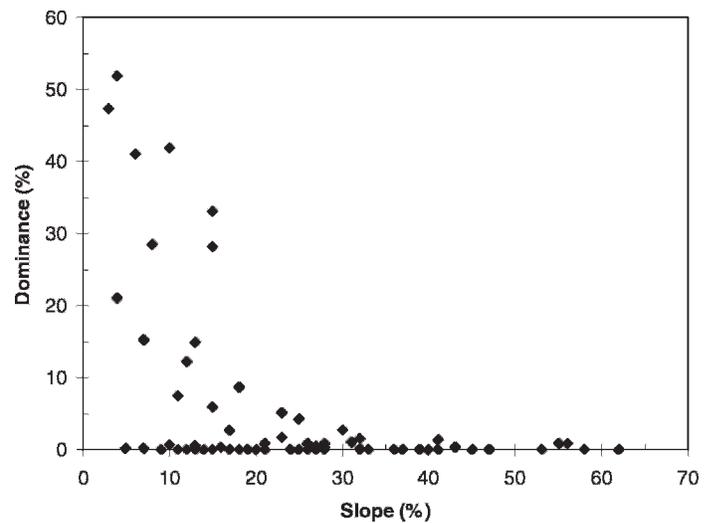


Figure 4. Dominance of *Potentilla recta* (relative *P. recta* cover) vs. slope from 79 plots sampled in the Wenaha Wildlife Management Area in northeastern Oregon. Dominance was calculated as the percent cover of *P. recta*/percent total vegetation cover.

2003; Domènech et al. 2005). The relationship between land use history and exotic plant dominance should not be particularly surprising since past land use has been shown to affect a wide range of ecological patterns and processes and in many cases has a greater influence on plant abundance and plant community structure and composition than biophysical factors (Motzkin et al. 1996; Foster et al. 1998; de Blois et al. 2001). However, this relationship has not received much attention in western North America rangelands despite the considerable amount of area cultivated, even briefly, as part of the western migration of settlers. Abandoned agricultural fields dominate most of the flat bench areas in the low-elevation landscape of the Blue Mountain ecoregion, and these areas contain the greatest number of listed exotic weed species for all plant communities in the state of Oregon (Parks et al. 2005). Future research should focus on the mechanisms that influence invasive plant dominance and rangeland community dynamics in areas exposed to intense land use and under what conditions particular land use activities have the greatest impact on exotic plant establishment and dominance. Such studies could provide valuable insight into landscape patterns of invasive plant spread, abundance, and dominance.

While this study showed clear differences in dominance among habitats, the underlying factors that make previously cultivated areas susceptible to dominance remain unclear. In some cases, *P. recta* can establish readily the first year following cultivation (Perkins et al. 2006), and seedling densities can be high in abandoned fields (Tuitele-Lewis 2004). Generally, seedling mortality of *P. recta* is often $> 95\%$ (Tuitele-Lewis 2004). However, microsite factors, such as increased soil moisture, may increase *P. recta* seedling establishment in abandoned fields. Relatively flat areas, such as the abandoned fields in this study, generally have deeper soils with higher moisture content than sloped areas. If soils in old fields maintain higher soil moisture levels later in the summer in the top several centimeters of soil than areas not previously cultivated, seedling survival rates could increase,

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- resulting in increased establishment and subsequent *P. recta* dominance. Soil moisture differences may also explain the negative relationship between slope and *P. recta* dominance. Another factor that may allow *P. recta* to dominate previously cultivated sites is a limited seed bank that reduces establishment and competition from other species. Limited native propagule availability has been hypothesized as a factor influencing exotic plant abundance and dominance at the community level in other grassland and savannah systems (e.g., Seabloom et al. 2003; MacDougall and Turkington 2005; Hobbs et al. 2006), though it has been rarely evaluated.
- While *P. recta* densities were low in grassland and forest habitats, it is unclear if future densities will remain low or increase to those found in the old fields. It is unlikely that low densities in forest and grasslands are due to low propagule supply because *P. recta* is a prolific seed producer (Dwire et al. 2006), is widely distributed throughout the area (e.g., found in 75% of our plots), and is extremely dense in many areas with a maximum stem density recorded at 157 stems \cdot m⁻² (Naylor et al. 2005). However, our results suggest that these habitats are more resistant to invasion than old fields. The underlying reasons for this resistance are unknown, though these may also be microhabitat related (e.g., increased shade in forest and low soil moisture along bunchgrass communities found on slopes).
- ### MANAGEMENT IMPLICATIONS
- Since old fields are found throughout the low-elevation rangelands of the Blue Mountain ecoregion, are highly susceptible to *P. recta* invasion, and represent fixed locations that produce a considerable source of seed for further invasion into less disturbed areas, containment and restoration activities should focus on these areas. Restoration is important because recolonization by native species appears limited, and herbicide and prescribed fire applications alone do not prevent recolonization by *P. recta* (Lesica and Martin 2003). Thus, many common weed control techniques (e.g., herbicide application, tillage, mowing) are likely to offer only short-term reductions in invasive plant abundance. Low abundances of *P. recta* were found in other habitats, but it is uncertain if these populations will expand in the future. In northeastern Oregon, many perennial bunchgrass grasslands and ponderosa pine stands contain *P. recta*, but not at dominance or stem densities levels found in old fields. Monitoring and managing populations in these areas would be a useful strategy to prevent and contain *P. recta* expansion in the intermountain West.
- ### ACKNOWLEDGMENTS
- Research was funded by the Center for Invasive Plant Management and a Joint-Venture Agreement between Oregon State University and the Pacific Northwest Research Station. Authors thank Rick Madigan and the Oregon Department of Fish and Wildlife for their support. Anne Bartuszevige, Manuela Huso, and 2 anonymous reviewers provided helpful for comments and suggestions on previous versions of this manuscript.
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