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Predicting the Occurrence of Downy Brome (*Bromus tectorum*) in Central Oregon

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Where the nonnative annual grass downy brome proliferates, it has changed ecosystem processes, such as nutrient, energy, and water cycles; successional pathways; and fire regimes. The objective of this study was to develop a model that predicts the presence of downy brome in Central Oregon and to test whether high presence correlates with greater cover. Understory data from the U.S. Department of Agriculture (USDA) Forest Service's Current Vegetation Survey (CVS) database for the Deschutes National Forest, the Ochoco National Forest, and the Crooked River National Grassland were compiled, and the presence of downy brome was determined for 1,092 systematically located plots. Logistic regression techniques were used to develop models for predicting downy brome populations. For the landscape including the eastside of the Cascade Mountains to the northwestern edge of the Great Basin, the following were selected as the best predictors of downy brome: low average March precipitation, warm minimum May temperature, few total trees per acre, many western junipers per acre, and a short distance to nearest road. The concordance index = 0.92. Using the equation from logistic regression, a probability for downy brome infestation was calculated for each CVS plot. The plots were assigned to a plant association group (PAG), and the average probability was calculated for the PAGs in which the CVS plots were located. This method could be duplicated in other areas where vegetation inventories take place.

Nomenclature: Downy brome, *Bromus tectorum* L.; western juniper, *Juniperus occidentalis* Hook. var. *occidentalis*.

Key words: Downy brome, cheatgrass, Central Oregon, logistic model, Current Vegetation Survey.

Downy brome (*Bromus tectorum* L.), also known as *cheatgrass*, has a long history as a weed in the United States, arriving in the northeast perhaps as early as 1790 and later becoming highly invasive in dry rangelands of the western states in the 1900s (Novak and Mack 2001). More recently, downy brome has been documented in drier, low- to mid-elevation forests of the western United States (Keeley and McGinnis 2007; Kerns et al. 2006; McGlone et al. 2009). Invasive grasses, and downy brome in particular, have altered ecosystem processes, such as nutrient, energy, and water cycles; successional pathways; and fire regimes (D'Antonio and Vitousek 1992). Downy brome invasion often increases fire frequency by increasing fine-fuel continuity, thus, facilitating fire spread over large land areas (Brooks et al. 2004; Bunting et al. 2002; Whisenant 1990).

Downy brome invasibility appears to be closely related to temperature at higher elevations and soil water availability at lower elevations (Chambers et al. 2007). Downy brome seed has a high germination rate (Rice and Dyer 2001), and under optimum conditions, that rate can be as high as 99.5% (Hulbert 1955). Low soil moisture reduces downy brome seedling emergence more at warmer sites than it does at cooler sites, and Thill et al. (1979) found the optimum temperature for emergence was 15 to 20 C at 0 MPa soil water potential (Ψ). Burnside et al. (1996) found that downy brome seed remained viable after 9 yr in western Nebraska when buried 20 cm beneath the soil surface. Although many researchers report a short period of seed viability (Chepil 1946; Hulbert 1955; Thill et al. 1979), Billings (1994) reported 95 to 100% germination from seed stored in paper sacks for up to 11.5 yr.

Once introduced to the seed bank, even in low levels, downy brome presents a high risk of invasion after disturbance. Bates et al. (2005) found that all herbaceous vegetation increased after the removal of western juniper (*Juniperus occidentalis* Hook. var. *occidentalis*) in a relatively undisturbed, sagebrush–steppe plant community in the northern Great Basin, but downy brome and perennial grasses dominated after the sixth year in areas where the litter from cut trees remained. Downy brome declined considerably 13 yr after the removal of western juniper (Bates et al. 2005), perhaps because of competition with

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Management Implications

Currently, there is interest in how downy brome might change fire return intervals throughout the West and whether prescribed fire will help or cause further problems by favoring downy brome infestations. Of special interest is the question of how to manage dry western rangelands and forests in the face of climate change with the recent push by the U.S. Federal Government to recognize climate change and manage forests for future climates. Land managers must consider how large-scale disturbances may reset plant association groups as climate changes. Areas with healthy native plant populations can keep downy brome populations minimized; however, if the native plants are wiped out by a large-scale disturbance and the climate is slightly warmer and drier than it had been historically, downy brome could easily spread and then alter fire regimes that maintain the downy brome population. Keeping downy brome out of an area is far easier than trying to eradicate it once it becomes established.

This article presents a statistical model that land managers can use to predict the presence of downy brome in Central Oregon. For example, land managers in Central Oregon who know the values of average March precipitation, minimum May temperature, total trees per acre, western junipers per acre, and distance to the nearest road can calculate the probability of downy brome presence. For land managers in the Deschutes National Forest, Ochoco National Forest, and Crooked River National Grassland, a map has been generated showing the probability of finding downy brome. Land managers in other areas can use the methods in this article to create a statistical model, using standard inventories, such as Current Vegetation Survey or Forest Inventory and Analysis. The probability of downy brome presence can be used to make informed decisions about fuels treatments and other management actions.

native perennial grasses that increased gradually in cover and density or because nitrogen had been immobilized by early seral species. Chambers et al. (2007) also found invasibility was lowest where perennial understory vegetation remained relatively high, even following a disturbance such as fire.

Several studies have modeled the spread of downy brome, usually to predict how its range might be affected by potential climate change (Anacker et al. 2010; Bradley 2009; Bradford and Lauenroth 2006; Bradley and Mustard 2005; Chong et al. 2006; Evangelista et al. 2008). Precipitation and temperature were often tested as central components of the models. Bradley (2009) found that low summer, annual, and spring precipitation followed by warm winter temperatures were the best predictors of downy brome presence. In the Lake Tahoe Basin, Anacker et al. (2010) found downy brome increased with dry winters, warmer temperatures, shorter distance to urban areas, shorter distance to major roads, and lower tree cover. However, Bradford and Lauenroth (2006) found that wet winters created moist spring soil conditions and produced higher probabilities of spring downy brome establishment in the Great Basin sagebrush steppe and Patagonian steppe. This conflict between results, wet vs. dry winter, may have more to do with the variability of environments in the areas studied, where Bradford and Lauenroth (2006) focused on dry shrubland locations and Bradley (2009) and Anacker et al. (2010) considered a much wider range of environments. Other reasons for differing results may have to do with greater genetic plasticity of annuals and site differences, such as soil texture, slope, and aspect.

Other studies have modeled downy brome occurrence without the focus on precipitation or temperature. Using a maximum entropy method, Evangelista et al. (2008) found that solar insolation was the most important contributor, followed by slope and overland distance to water. Soil wetness index was the only variable selected using logistic regression, from several geographic variables (Evangelista et al. 2008). Of the several nonnative invasive plants that Chong et al. (2006) studied, downy brome was found to be the most difficult species to predict because, they theorized, it occurred in a wide range of habitats. They found that greater soil phosphorus, the percentage of total biological soil-crust cover, and the percentage of bare ground were the best predictors of downy brome occurrence. Universal Transverse Mercator–north and elevation had negative effects, whereas herbaceous species richness had positive effects, but these three variables had only indirect effects on downy brome occurrence (Chong et al. 2006).

The question of how to manage western rangelands and dry forests in the face of climate change has been a discussion point for many land managers, especially with the recent policy by the U.S. Federal Government to manage forests for future potential climates (Pew Center 2010). Because downy brome has been documented in low- to mid-elevation forests in the West, where frequent fires occur, climate change could begin to favor downy brome. Not only would frequent disturbance from fire in a warmer and drier climate increase downy brome cover in some ecosystems, but rising CO_2 could increase downy brome productivity and fuel load (Smith et al. 1987, Ziska et al. 2005). The purpose of this study was to predict where downy brome is likely to be present in Central Oregon at a scale at which land managers work, in the face of climate change.

Materials and Methods

Study Area. Our study area was the Deschutes National Forest, Ochoco National Forest, and Crooked River National Grassland in Central Oregon (Figure 1). The eastside of the Cascade Mountain Range formed the western border of the study area, where March precipitation was about 27 cm and occurred mostly as snow, and minimum May temperatures averaged −3.6 C. The northwest corner of the Great Basin formed the eastern border of the study area, where March precipitation was lower (about 2.2 cm), and minimum May temperatures

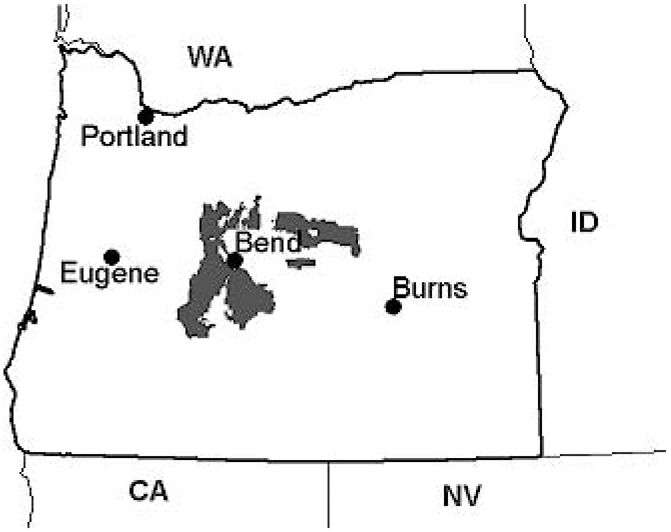

Figure 1. Map of Oregon, showing the study area: Deschutes National Forest, Ochoco National Forest, and the Crooked River National Grassland.

were higher (about 4.2 C). The geology of the area was influenced by relatively frequent and recent volcanic activity, especially the eruption of Mount Mazama (now Crater Lake) about 7,700 yr ago (Bacon and Lanphere 2006). In general, soils were derived from medium- to coarse-textured, air-fall volcanic ash or basaltic residuum. Depths ranged from shallow to very deep, and rock content was relatively low. The Cascade Range creates a rain shadow east of the mountains, causing the climate in our study area to have steep temperature and precipitation gradients, ranging from cold and moist in the mountains to xeric in the Northern Great Basin.

Similar assemblages of plants tend to grow together, depending on many factors, including climate, landforms, and geomorphic processes. We used plant assemblages defined by the USDA Forest Service geographic information system (GIS) layer, ''Plant Association'' (http://www.fs.fed.us/r6/data-library/gis/deschutes/index.shtml), and further lumped them into the ''Plant Association Groups'' (PAGs) defined by Forest Plant Associations of the Oregon East Cascades (Simpson 2007). The PAGs at the lower elevations of our study area (on average, less than 1,400 m in elevation) were (1) western juniper steppe, dominated by *J. occidentalis*, little sagebrush (*Artemisia arbuscula* Nutt.), and scabland sagebrush [*Artemisia rigida* (Nutt.) Gray]; (2) western juniper woodland, dominated by *J. occidentalis*, basin big sagebrush (*Artemisia tridentata* Nutt. ssp. *tridentata*), Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young), antelope bitterbrush [*Purshia tridentata* (Pursh) DC.], and curl-leaf mountain mahogany (*Cercocarpus ledifolius* Nutt.); and (3) ponderosa pine dry, dominated by ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson), bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) A. Löve], Idaho fescue (*Festuca idahoensis* Elmer), antelope bitterbrush (*Purshia tridentata*), big sagebrush (*Artemisia tridentata*), greenleaf manzanita (*Arctostaphylos patula* Greene), and *C. ledifolius* or snowbrush (*Ceanothus velutinus* Hook.). At higher elevations (on average, greater than 1,400 m), the PAGs most often found were (1) scabland shrub, dominated by Sandberg bluegrass (*Poa secunda* J. Presl) and *A. rigida* or *A. arbuscula*; (2) grassland, dominated by *Pseudoroegneria spicata*, *F. idahoensis*, and *Poa secunda*; (3) xeric shrub, dominated by *A. arbuscula*, *F. idahoensis*, *A. tridentata*, and *Purshia tridentata*; (4) mesic shrub, dominated by mountain big sagebrush [*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle] and Geyer's sedge (*Carex geyeri* Boott); (5) meadow/riparian, dominated by quaking aspen (*Populus tremuloides* Michx.), willow (*Salix* spp.), thinleaf alder [*Alnus incana* (L.) Moench ssp. *tenuifolia* (Nutt.) Breitung], white false hellebore (*Veratrum album* L.), and widefruit sedge (*Carex angustata* Boott) or Sitka sedge [*Carex aquatilis* Wahlenb. var. *dives* (T. Holm) Kük.]; (6) ponderosa pine moist, dominated by *P. ponderosa* and *Carex* spp., with some *C. ledifolius* or common snowberry [*Symphoricarpos albus* (L.) Blake]; (7) lodgepole dry and lodgepole wet, dominated by lodgepole pine (*Pinus contorta* var. *murrayana*); (8) mixed conifer dry and mixed conifer wet, dominated by Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], Shasta red fir (*Abies magnifica* A. Murray bis var. *shastensis* Lemmon), grand fir [*Abies grandis* (Douglas ex D. Don) Lindl.], and white fir [*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.], or Engelmann spruce (*Picea engelmannii* Perry ex Engelm.); and (9) mountain hemlock dry, dominated by mountain hemlock [*Tsuga mertensiana* (Bong.) Carrière].

Inventory Data. We used plot data from the Current Vegetation Survey (CVS), performed by the USDA Forest Service (Max et al. 1996). The CVS field data were collected from 1993 to 2006; we used the most recent data if plots were revisited. Plot locations were systematic on a grid of 5.47 km (3.4 mi). Tree measurements and counts were recorded in five subplots with 15.6-m (51.1-ft) radii for all species. Ocular estimates of understory indicator species were recorded in five subplots with 7.3-m (24-ft) radii. Not all understory species were measured because the CVS mission was to inventory forests, with an emphasis on trees, making it difficult to get a complete picture of vegetation dynamics. For more information on CVS data collection procedures, see Johnson (1997). Slope, elevation, distance to nearest road, total trees per acre, *J. occidentalis* per acre, *P. ponderosa* per acre, *P. contorta* per acre, and *P. menziesii* per acre were used as quantitative independent variables. Aspect was converted to a categorical variable.

We used all plots that lay on the Deschutes and Ochoco National Forests, and the Crooked River National

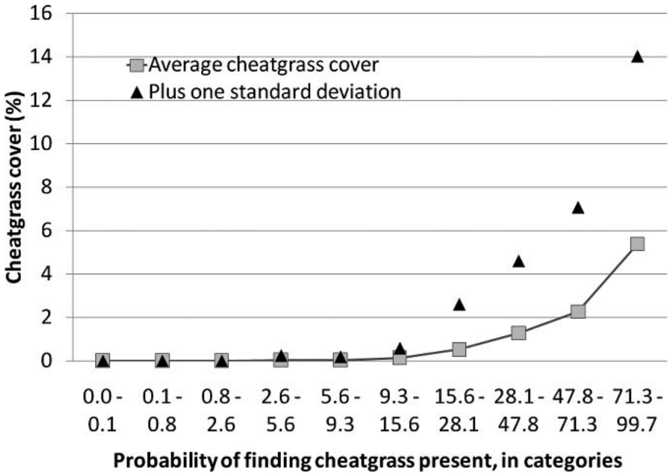

Figure 2. Probability of the presence of downy brome in 10 categories of 109 plots each, showing the average percentage of cover by downy brome in each category.

Grassland from master databases (data on file), which totaled 1,092 locations. We brought the plot coordinates into ArcGIS spatial analyst software (ESRI, 380 New York Street, Redlands, CA 92373-8100) and used the locations to extract climate data, based on raster climate data for 1971 to 2000 (The Climate Source 2010), for each plot. The average maximum temperature, average minimum temperature, and average precipitation for the months of January, February, March, April, May, October, November, and December were used. The plot coordinates were also used to calculate the distance to the nearest road using the USDA Forest Service GIS road layer for all major and minor roads (http://www.fs.fed.us/r6/data-library/gis/deschutes/index.shtml). Soil drainage index (DI), a value ranging from 0 (solid rock) to 99 (open water) (Hole 1978), was also extracted from a data layer compiled from several organizations with various levels of accuracy. We did not use this soils data because, in a preliminary analysis, DI was not significant, although more standardized and accurate measures of DI may prove to be significant in the future.

Statistical Analysis. Logistic regression in SAS statistical software (SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513-2414; SAS Institute Inc. 2007) was used to predict the occurrence of downy brome in Central Oregon plots. Downy brome presence or absence was recorded for each plot, as a binomial variable in a casewise analysis. Downy brome occurred in 23.2% of the CVS plots. A stepwise selection method was used in which nonsignificant variables ($P > 0.05$) were eliminated. The selected model was reduced further after testing for collinearity (tolerance > 0.4).

In a casewise analysis, it is difficult to estimate the goodness of fit; however, SAS (2007) gives a concordance index (*c*), which ranges from 0.5 to 1, where 0.5 corresponds to the model randomly predicting the response and 1 corresponds to the model perfectly discriminating the response. We used this concordance index to assess goodness of fit. A Spearman correlation coefficient was also calculated to determine the relationship between the probability of downy brome occurrence calculated for each of the plots and the percentage of cover values recorded by the CVS field crews. We validated this model using a separate data set from an earlier, unrelated study on *Purshia tridentata* response to fuels treatments. After the analysis, we grouped the plots by PAGs. We also used ArcGIS to create a map of the study area showing the probability of finding downy brome.

Results and Discussion

Our model selection techniques chose the following variables as the best predictors of downy brome presence, where p is the probability that downy brome is present:

$$\begin{aligned} Log[P/(1-p)] = &-0.0274 - 0.0015 \\ &\times [\textit{distance to the nearest road}(\mathrm{m})] \\ &-0.0034 \times (\textit{total trees per acre}) \\ &+0.0202 \times (\textit{total juniper per acre}) \\ &+1.0116 \times [\textit{average minimum May temperature}(\mathrm{C})] \\ &-0.2146 \times [\textit{average March precipitation}(\mathrm{cm})] \end{aligned} \quad [1]$$

In this model, $c = 0.92$, which indicates a fairly strong ability to predict the presence of downy brome.

Merely predicting the occurrence of a single downy brome plant would not help land managers avoid an infestation. Although the data were not normally distributed and the results of the Spearman correlation should be interpreted cautiously, there was a correlation between percentage of cover by downy brome and the probability of finding downy brome at a site ($r = 0.61$, $P \leq 0.0001$, $n = 1{,}092$). Where there is a high probability of finding downy brome, there seems to be higher downy brome cover. A graph showing downy brome cover in 10 categories of probability of occurrence illustrates how the percentage of cover increases (Figure 2).

Areas in Central Oregon with a drier March, warmer May, greater number of western juniper per acre, fewer total trees per acre, and a shorter distance to a road increases the probability of finding downy brome, although cover by downy brome varies by site. Each of these variables influences the probability of finding downy brome, so having a much drier than average March does not necessarily mean there will be a high probability of downy brome if the other variables do not favor downy brome presence. Average May precipitation and minimum

Table 1. Predictions of downy brome presence (1) and absence (0) for the 176 validation plots, calculated using the model in this article with a 50% cutoff, compared with field observations from the validation plots.

Frequency	Predictions from model		
Observations	0	1	Totals
0 (absent)	125	8	133
1 (present)	20	23	43
Totals	145	31	176

June temperatures were also significant, but they were collinear with average March precipitation and minimum May temperatures, so they were removed from the model. Average May precipitation and minimum June temperatures were removed because models containing them resulted in a lower concordance index ($c = 0.91$).

We validated the model by using all plots from a study on understory vegetation, conducted between 1998 and 2000 on the Deschutes National Forest. Botanists recorded understory vegetation on plots treated with prescribed burn, wildfire, or mowing and untreated controls selected posttreatment. The 176 plots were selected to represent sites minimally disturbed by human activity within the treated and untreated areas. Tree species and number of trees per acre were also recorded. March precipitation, minimum May temperatures, and distance to nearest road were calculated from global positioning system plot points in ArcGIS for validation of the model in this article. Downy brome occurred in 24.4% of the 176 validation plots. Table 1 shows predictions using the model reported in this article, and the observation of downy brome presence from the 176 validation plots, using greater than 0.5 (50% probability) as a cutoff at which downy brome was likely to be found.

The model accurately predicted absence of downy brome in 125 out of 133 plots that had no downy brome (94% of the time), predicted the presence of downy brome in 23 out of 43 plots that had no downy brome (53% of the time), and was correct in 148 out of 176 cases (84% of the time). These plots represent gray areas, where cheatgrass could become a problem and where it already exists (i.e., ponderosa pine and lodgepole pine forests up to the edge of the shrub-steppe), and not the full study area's range (i.e., high elevation). The validation plots were subjectively placed in minimally disturbed sites, unlike the CVS plots, which were systematically placed and could land in highly disturbed sites. This may be why the model did not predict downy brome presence accurately in those plots. We noticed that validation plots in which the model predicted no downy brome, but downy brome presence was recorded, occurred in canyons and other sheltered but often visited locations, such as Hole-in-the-Ground in the Deschutes National Forest.

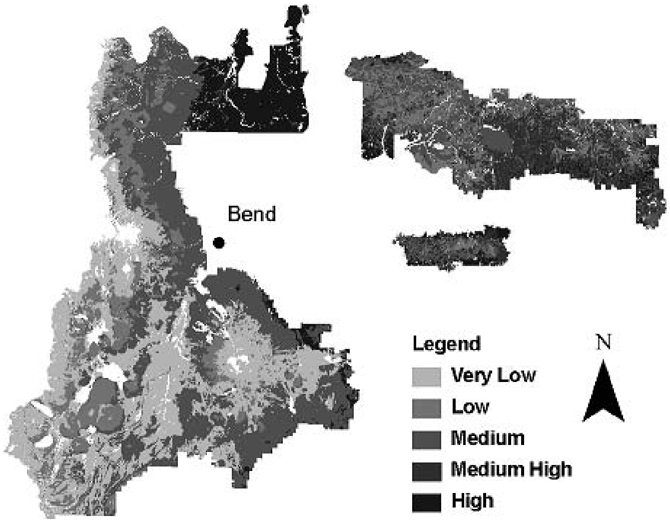

Figure 3. The probability of finding downy brome in plant association group (PAG) polygons, within the Deschutes National Forest, Ochoco National Forest, and the Crooked River National Grassland.

Plant Association Groups. To simplify the results for personnel in the field, we grouped the CVS plots by PAG. The probability of downy brome for each plot was calculated, using the model equation (Equation 1). Table 2 compiles the ratio of infested plots to total plots by PAG (actual infestation) and compares it to averages of probability of downy brome and each of the model's variables by PAG.

Based on our selected model, juniper steppe and juniper woodland PAGs have a high probability of containing downy brome (greater than 69%). Our model also predicts that plots in mesic shrub, lodgepole pine wet, lodgepole pine dry, and mountain hemlock PAGs have very low probabilities of downy brome (less than 6%). The probabilities for each PAG were joined to the USDA Forest Service GIS PAG layers (Figure 3).

The assignment to plant association and the further lumping into PAGs created more variability in the variables used to predict downy brome, which may explain one surprising result. There was more downy brome occurring in, and predicted for, the ponderosa pine moist PAG than there were for the ponderosa pine dry PAG. The biggest difference between the two PAGs was that the moist group was warmer in May, had a greater number of *J. occidentalis*, and was only slightly wetter in March. This suggests that these mapped plant associations or the groups they were placed in need slight adjustments.

In some PAGs, the predicted occurrence of downy brome is lower than the actual occurrence because there are

Table 2. Probability of the presence of downy brome and the variables used to calculate that probability, summarized by PAG (mean ± 1 SD).[a]

PAG	Average march precip	Average min may temp	Average distance to road	TPA juniper	TPA all tree species	Total plots in PAG	Actual infestation per total	Average probability of occurrence
	cm	C	m	No.				
W juniper steppe	4.37 ± 1.03	1.90 ± 0.70	291.3 ± 248.1	35.5 ± 25.7	65.8 ± 46.9	15	1.00	0.69 ± 0.04
W juniper woodland	2.95 ± 0.66	2.64 ± 0.80	231.9 ± 237.0	44.6 ± 56.4	53.7 ± 62.6	75	0.84	0.86 ± 0.02
Scabland shrub	6.02 ± 1.85	0.91 ± 0.64	201.7 ± 177.6	21.5 ± 43.0	65.7 ± 97.1	29	0.52	0.40 ± 0.04
Ponderosa pine moist	5.56 ± 2.02	1.10 ± 1.10	102.4 ± 72.4	15.0 ± 26.6	236.0 ± 164.6	33	0.52	0.37 ± 0.04
Grassland	6.65 ± 2.66	1.27 ± 1.23	599.5 ± 710.3	24.0 ± 41.3	128.9 ± 130.7	6	0.50	0.36 ± 0.14
Xeric shrub	3.42 ± 1.48	0.23 ± 1.52	473.0 ± 587.7	5.4 ± 19.4	20.7 ± 40.8	13	0.39	0.31 ± 0.07
Mixed conifer dry	7.52 ± 3.60	0.69 ± 1.01	264.1 ± 504.6	8.10 ± 21.3	337.6 ± 22.7	229	0.27	0.23 ± 0.02
Ponderosa pine dry	4.96 ± 1.77	0.22 ± 1.21	130.4 ± 129.8	6.7 ± 2.46	257.9 ± 286.5	277	0.21	0.23 ± 0.01
Mixed conifer wet	9.41 ± 3.48	0.72 ± 1.07	195.9 ± 304.6	0.6 ± 5.9	410.9 ± 310.7	132	0.09	0.14 ± 0.02
Lodgepole dry	7.80 ± 4.09	−0.53 ± 0.60	357.6 ± 601.0	0	575.3 ± 496.3	190	0.02	0.04 ± 0.00
Meadow/riparian	8.25 ± 5.95	0.88 ± 0.93	324.4 ± 489.3	2.6 ± 9.0	244.8 ± 284.8	12	0.00	0.23 ± 0.07
Mesic shrub	8.68 ± 0.50	0.33 ± 0.60	652.6 ± 655.3	0	107.4 ± 134.4	4	0.00	0.06 ± 0.02
Lodgepole wet	9.25 ± 5.12	−0.13 ± 0.32	218.1 ± 209.1	0	814.3 ± 631.2	17	0.00	0.02 ± 0.01
Mountain hemlock dry	18.6 ± 3.98	−1.52 ± 0.93	2111.7 ± 1530.7	0	520.3 ± 299.6	60	0.00	0.001 ± 0.00

[a] Abbreviations: PAG, plant association group; precip, precipitation; temp, temperature; TPA, trees per acre; W, western.

other factors not considered in the equation used to predict downy brome occurrence. For example, the meadow/riparian PAG has a much higher average predicted value, when compared with the ratio of infested to total plots, because soil moisture data were not considered in creating the model. The meadow/riparian plots probably lie in areas in which Climate Source mapped a dry March and a warm May, but downy brome is not found there because subsurface moisture makes the site too wet. Although the PAGs simplify the search for downy brome, they are less accurate than the logistic regression equation, which can calculate probabilities wherever March precipitation, May temperatures, western juniper per acre, total trees per acre, and distance to roads are known.

Variables Explored. Downy brome grows in many of the climates and PAGs found in our study area, where winter and spring are relatively wet and summers are hot and dry. It is a winter annual plant that typically germinates in the fall and produces seeds in the spring when soils are still moist but are warming up, using soil moisture early in the growing season when other plants remain dormant or grow slowly (Harris 1967; Hulbert 1955). Before the summer arrives, downy brome has completed its growth cycle and has set seed. If perennial native species are established, however, downy brome density remains low (Cox and Anderson, 2004). Downy brome responds adversely to shade and, therefore, does not do as well where precipitation is high enough to support forests or crowding competition. Downy brome grown in full sunlight produced more biomass, tillers, and leaves and allocated a larger proportion of their total production to roots than did plants grown in 60% and 90% of sunlight (Pierson et al. 1990).

Downy brome has long been associated with disturbances, such as fire and roads, and our model selected distance to nearest road as a good predictor of downy brome presence. Anacker et al. (2010) found that distance to major roads from a national road atlas was significant in predicting downy brome presence. Getz and Baker (2008) also found that downy brome invasion was significantly greater near roads as well as at burn edges. They speculated that vehicles and cattle transported downy brome seed, which had a high presence along the roads in their study area. Downy brome does poorly in compacted soils (Kyle et al. 2007) but perhaps gains a foothold in the disturbed areas near roads. Paved and unpaved roads in the National Forests often provide clearings with full sun that are frequented by vehicles that could transport weed seeds.

Early in the analysis, the number of lodgepole pines per acre entered the equation with a low P value ($P = 0.0001$) but was collinear with total trees per acre ($P < 0.0001$) and was, therefore, removed. Where there were higher numbers of lodgepole pines per acre, the probability of downy brome was lower, which corresponds to what we see in the field. Climax lodgepole pine grows in the colder areas of our study with deep gravel-sized pumice soils that have poor heat-retention properties, are moisture limited and nitrogen poor (Cochran et al. 1967, Geist and Cochran 1990). We have observed that downy brome appears more often in the finer pumiceous ash soils and tends to disappear as gravel-sized substrates increase.

Western juniper was positively associated with downy brome in our logistic regression equation. Downy brome competes with western juniper for limited nitrogen and soil moisture in the sagebrush steppe of the high desert, but both species have adapted to this environment and are able to coexist. In a study of the impact of western juniper invasion on understory vegetation of sagebrush steppe in northeastern California, Coultrap et al. (2008) found that downy brome cover and total grass cover were greater on study sites where eastern juniper was removed than it was on untreated sites. Bates et al. (2005), measured temporary increases in downy brome biomass and cover in areas where western juniper was cut. Downy brome biomass and cover declined in the cut areas, however, as native understory vegetation increased.

The logistic regression model presented in this article predicts that downy brome would generally be found in the drier and warmer areas of our study area. Where mountain hemlock, lodgepole, and mesic shrub PAGs are found in higher elevations, minimum temperatures during spring are often below freezing. Sheley and Larsen (1994) reported that frost heaving reduced winter seedling populations of downy brome by 53%, although all downy brome seedlings that survived the frost heaving period made it to seed set. Bates et al. (2006), experimented with the timing of precipitation using a series of shelters in an area dominated by Wyoming big sagebrush and perennial bunch grasses. Downy brome did well in the shelters, including a sheltered control, but did poorly in the unsheltered control. They speculated that downy brome was positively influenced by warmer temperatures under the shelters and noted that frost heaving was observed in the unsheltered treatment but not under the shelters.

Application. As in the article by Chambers et al. (2007), where the question of what makes Great Basin sagebrush ecosystems invasible by downy brome was posed, we wonder whether the mid-elevation conifer forests will become susceptible to downy brome invasion with climate change. Downy brome can inhibit the establishment of other native plants (Humphrey and Schupp 2004; Melgoza et al. 1990). There is evidence that downy brome is becoming problematic in other mid-elevation forests in the western United States, particularly in ponderosa pine–dominated forests (Keeley and McGinnis 2007; Kerns et al. 2006; McGlone et al. 2009).

The results of this study show that downy brome is not just a problem for dry shrublands and juniper woodlands.

Its encroachment in dry, mid-elevation forests is also a concern in areas where climate is becoming warmer and drier (Allen and Breshears 1998; van Mantgem and Stephenson 2007; Walther et al. 2002). Where ponderosa pine, Douglas-fir, grand fir, and western redcedar forests remain intact in future climate change scenarios, downy brome will probably only occur in ephemeral populations (Pierson and Mack 1990). However, where climate shifts enough so that regeneration of these forest types is not supported because of recurrent disturbance and less available water, the ephemeral downy brome populations could become persistent.

Land managers currently prescribe thinning, burning, or mowing treatments in Central Oregon to meet a range of objectives, including reducing hazardous fuel accumulation that could lead to wildfire, protecting sage grouse (*Centrocercus urophasianus* Bonaparte) habitat, and providing winter forage for ungulates. Additionally, the USDA published a *Strategic Plan for FY2010–2015*, in which the second goal is to "Ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources." Protecting natural areas from adverse responses after treatments, such as downy brome invasion, has always been difficult and will likely prove more difficult in the future.

Treatment of areas that have been naturally disturbed is often necessary, and these areas can suffer from weed invasions if management activities are not well planned. For example, consider the probability of the downy brome occurrence after a large disturbance, such as the "B and B Complex" fire that burned in 2003. About 36,855 ha (91,000 ac) of mostly mixed conifer and ponderosa pine forests west of Camp Sherman, OR, burned in that fire. The equation in this article predicted a 21% chance of finding downy brome in one of the CVS plots that occurred in the mixed conifer wet PAG before the fire. The field crew that visited this plot before the B and B Complex fire noted that, at 690.5 trees ac^{-1}, this was a "relatively dense unit." They did not find downy brome. After the B and B Complex fire, though, the field crew noted that "nearly every tree in the hectare was killed." Leaving all other variables the same and reducing the total number of trees per acre, our equation would predict a 73% chance of finding downy brome in that plot. The field crew that visited after the fire found downy brome in three of the five subplots.

Thinning, burning, and mowing can cause the introduction of, or an increase in, downy brome cover. Measures to mitigate the spread of downy brome and other invasive weeds can be taken, such as cleaning gear, working from the least weedy areas toward the most weedy areas, avoiding travel through weedy infestations, minimizing soil disturbance, timing treatments to avoid seed set, and restricting the movement of materials that could contain seed (Clark 2003). Using the model equation to calculate the probability of downy brome occurrence or the maps generated in ArcGIS will help Central Oregon land managers select areas where these measures can be taken. Using the methods in this article will help land managers in other areas develop a similar model. The results of this study suggest that, for land managers who want to retain healthy xeric shrubland, juniper steppe, juniper woodland, and grasslands, as well as dry mid-elevation forests, choices can be difficult and planning must be done carefully.

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