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# EIGHT NONNATIVE PLANTS IN WESTERN OREGON FORESTS: ASSOCIATIONS WITH ENVIRONMENT AND MANAGEMENT

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**Abstract.** Nonnative plants have tremendous ecological and economic impacts on plant communities globally, but comprehensive data on the distribution and ecological relationships of individual species is often scarce or nonexistent. The objective of this study was to assess the influence of vegetation type, climate, topography, and management history on the distribution and abundance of eight selected nonnative plant taxa in forests in western Oregon. These eight taxa were selected as being reliably detected by a multi-resource inventory of 1127 systematically-placed plots on non-federal forest lands from 1995 to 1997 by the USFS Forest Inventory and Analysis (FIA) program. One or more of the eight nonnative taxa studied were found on 20% of the sampled subplots in the study area, but relatively few stands were dominated by them. Overall abundance of nonnative taxa was likely much greater, because few composites and graminoids were identified to species in this general-purpose inventory. Distribution of most taxa was more closely associated with low density of overstory trees than with climate. Nonnative taxa were significantly more abundant in stands that had been recently clearcut or thinned than in stands that had not. Frequencies of several taxa decreased with elevation, which may reflect proximity to source populations and intensive land use rather than any climatic constraints. Although the greatest potential for displacement of native forest species appears to be in early-successional communities, the potential for spread of some shade-tolerant evergreen shrubs also seems high.

**Keywords:** autecology, conifer forest, invasive plants, management, monitoring

## 1. Introduction

The spread of nonnative organisms into new regions around the world has had a profound impact on human and ecological communities. Nonnative species have reduced the economic viability of some land uses, required costly eradication efforts to maintain others, and are a major cause of extinction of native species (Vitousek *et al.*, 1996; Mooney and Hobbs, 2000). Nonnative plants can affect ecosystems and land use by competitively excluding desired species and altering disturbance cycles (D'Antonio and Vitousek, 1992). Human activity is usually responsible for introducing nonnative species to new regions, and can also contribute to their maintenance and spread through land use practices (Stapanian *et al.*, 1998; Hobbs, 2000).

Despite the impacts of nonnative plants, our understanding about attributes that contribute to species' invasiveness and ecosystems' vulnerability to invasion is limited (Rejmánek and Richardson, 1996). The spatial distributions and temporal trends of nonnative plant populations are usually not well known, because available information usually consists of qualitative descriptions, chronologies of herbarium specimens, single-species surveys, or narrowly-focused research. Systematic, regular sampling of plant communities, preferably with permanent plots, is probably the most effective way to assess invasions of nonnative species – as well as status of native species – but has so far been implemented in few places (Mack, 2000).

Broad-scale, systematic sampling not only provides inventories of species' distributions, but advances our understanding of plant autecology. An extensive system of vegetation plots across regional environmental and land-use gradients allows examination of the attributes that affect species abundance (Stapanian *et al.*, 1998; Ohmann and Spies, 1998). The objective of this paper was to examine the association between vegetation type, climate, site quality, and management history and the distribution and abundance of selected nonnative species on forest lands in western Oregon.

## 2. Methods

### 2.1. DATA COLLECTION

The study area consisted of the counties of western Oregon state, U.S.A., between 41.9 and 46.3° N latitude and 121.4° and 124.6° W longitude (Figure 1). Strong gradients in climate and forest vegetation occur, ranging from the *Picea sitchensis* Zone along the Pacific Ocean, to the *Tsuga heterophylla* Zone in the Coast Ranges and the lower Cascade Mountains, to *Quercus garryana* communities in the interior valleys (Franklin and Dyrness, 1973). Some of this variation can be expressed using four main ecoregions: Coast, Cascade, Willamette Valley, and Klamath (Bailey, 1980).

The data used in this study were collected by the USDA Forest Service's Forest Inventory and Analysis (FIA) program for the inventory of forest lands of western Oregon. The objectives of FIA inventories are to characterize multiple resource attributes for lands that meet the criteria for 'forest land (i.e. land areas $\geq$ 0.4 ha in size that supported, or had previously supported, 10% canopy cover of trees and were not primarily managed for a non-forest land use) with a probability-based sample design (Olsen *et al.*, 1999). This study did not include inventory data for lands managed by the US Bureau of Land Management and the US Forest Service because the inventories were not conducted by FIA and comparable data on understory vegetation was not collected. The forest lands in western Oregon examined by this study were primarily owned by forest industry (60.5%), followed by nonindustrial private (27.2%), and state and other public (12.3%) (Azuma *et al.*, 2002).
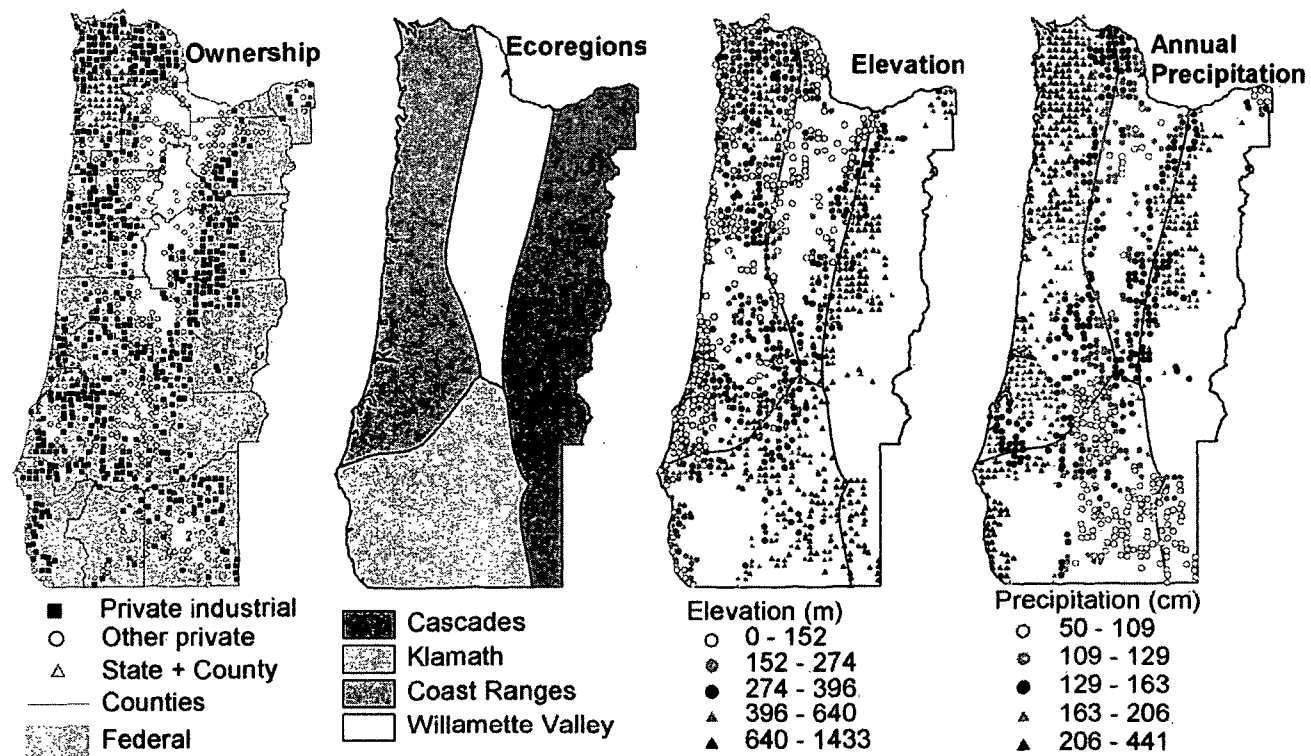
Ownership

**Private industrial**
○ Other private
△ State + County
— Counties
Federal

Ecoregions

Cascades
Klamath
Coast Ranges
Willamette Valley

Elevation

Elevation (m)
○ 0 - 152
◉ 152 - 274
● 274 - 396
▲ 396 - 640
▲ 640 - 1433

Annual Precipitation

Precipitation (cm)
○ 50 - 109
◉ 109 - 129
● 129 - 163
▲ 163 - 206
▲ 206 - 441

*Figure 1.* Maps of the western Oregon study area, showing approximate locations of forested FIA plots sampled and important plot attributes. Shaded areas in the ownership map are federally-managed lands, for which comparable data was not available; plot locations were unforested in unshaded areas without symbols. For the other attributes, symbol darkness increases with increasing values (threshold values are quantiles of the data), and lines are boundaries of primary ecoregions.

Approximately 81% of these forests were less than 60 yr old, with proportions for increasing stand size classes of seedling/sapling (mean tree diameter < 12.5 cm DBH [Diameter at Breast Height], 1.4 m), pole (12.5–22.9 cm DBH), small sawtimber (23.0–53.3 cm DBH) and large sawtimber (> 53.3 cm DBH) of 30.1, 15.4, 49.4, and 5.1%, respectively.

The field sample design consisted of a systematic grid on a 5.4 km spacing (1 point per 3,000 ha). At each forested sample grid point, five subplots were installed (or remeasured) over a 2 ha area in a fixed design (four subplots were located 66 m from a central one in the cardinal directions). Trees ≤ 12.5 cm DBH were selected with 2.35 m radius plots at each subplot, and larger-diameter trees were selected with a variable-radius, 7 m basal area factor prism. Diameter, height, species, and crown class were measured for all selected trees. Tree canopy cover was measured using three 17 m long line-intercept transects on each subplot, recording portions of the transect covered (using vertical projection from crown edges) by each species. Understory vegetation was sampled on 5 m radius plots around each subplot center. Cover of all species of shrubs, and of tree seedlings < 2.5 cm DBH were recorded. Cover of 'herb' species (forbs, graminoids, and ferns) were recorded if present at ≥ 3% cover. The forestry skills of inventory crews varied widely; crews were expected to identify all trees and most shrubs encountered, as well as the most abundant forbs and ferns. Therefore, many forbs and ferns, and most graminoids, were not identified to species by most crews. Plants that could not be identified to species were given a generic or life-form code.

The systematically-placed subplots often sampled different forest types, stand age classes, or land types, e.g., clearcut vs. pole-size stand, nonforest (e.g., pasture, lake, or road) vs. forest, hardwood stand vs. conifer stand. A comprehensive set of rules was applied in the field to delineate obvious differences among vegetation types, regardless of the number or portions of subplots on which they occurred, and all collected data was identified as to the type in which it was found. In this paper, all forested delineations are referred to as 'stands'.

## 2.2. DATA ANALYSIS

There were 489 plant species recorded on the 1127 western Oregon forest inventory plots. Nonnative species were identified in the inventory data based on a national list of nonnative species (USDA NRCS, 2000). Sixty of these species were non-native and were recorded on 512 of the sampled plots. However, only a few of these species would have been readily identified by most inventory crew members, since botanical expertise differed greatly among crews. In order to examine species' distributions across the study area, it was necessary to select species that had a high probability of being detected by most field crews. Based on personal experience and discussions with experienced crew members, eight of the nonnative species were judged to be reliably identified by most field crews across the study area; all further analyses were based on these species. Generic records in

## TABLE I

Independent variables used in the regression analyses: variable name, distribution (minimum, median, maximum), and definition. See text for details

| | | |
|---|---|---|
| *Site physiography* | | |
| aspect | 0,1,2 | Cosine conversion of aspect with SW shift $(\cos(45-\theta) + 1)$ |
| slope | 0,30,99 | Slope (percent) |
| light | 3.2,8.2,10.9 | Potential annual direct radiation (MJ m$^{-2}$ yr$^{-1}$) |
| topography | 3,5,6.8 | Topographic moisture index (equation in text) |
| | | |
| *Climate* | | |
| elevation | 0,313,1433 | Elevation (m) |
| annual precip | 6.3,7.4,8.4 | Annual precipitation (mm), ln-transformed |
| summer precip | 4.4,5.4,6.3 | Summer precipitation (mm), May-September, ln-transformed |
| annual temp | 6,10.9,12.7 | Mean annual temperature (°C) |
| summer temp | 11.8,15.9,18.8 | Mean summer temperature (°C), May-September |
| temp range | 13.7,25,32.5 | Annual temperature range: mean Aug maximum – mean Jan minimum (°C) |
| elev*precip | 0,4.8,38.2 | Elevation (m) multiplied by annual precipitation (mm), divided by 10,000 |
| moist stress | 2,2.9,4.2 | Moisture stress index: smrtmp/smrpre |
| | | |
| *Stand structure* | | |
| tree cover | 0,78,100 | Tree canopy cover (%) |
| hardwood cover | 0,0.3,1 | Percent of tree canopy cover contributed by hardwoods (%) |
| basal area | 0,25,85 | Tree basal area (m$^2$ ha$^{-1}$) |
| tolerant basal area | 0,0,59 | Basal area of shade-tolerant tree species (*Abies amabilis, Abies concolor, Abies grandis, Cornus nuttallii, Taxus brevifolia, Thuja plicata, Tsuga heterophylla*) (m$^2$ ha$^{-1}$) |
| stand diameter | 0,19,81 | Quadratic mean diameter of trees in dominant and codominant crown classes (cm) |
| stand age | 0,35,400 | Stand age (yr) |

the genus *Cirsium* were combined with records for the nonnative *C. arvense* or *C. vulgare*, because these species made up 86% of the *Cirsium* records identified to species, and because many plots were visited too early in the season to observe mature and flowering forbs, which also made some of the identifications to species questionable. Nevertheless, this lumping of species does obscure some differences between the primary species, since *C. vulgare* is monocarpic, often biennial, and non-rhizomatous, while *C. arvense* is perennial and strongly rhizomatous.

Analyses of taxa frequency and abundance in relation to environment and management were evaluated at the stand level. Independent variables were a variety of potentially important climatic, site, and stand attributes (Table I). Slope, aspect, and topographic position were estimated by field crews to characterize the majority of the portion of the stand sampled by the inventory plot. Potential annual direct radiation was estimated from equations in Oke (1987). Topographic moisture index was calculated with equations used by regional Forest Service ecologists based on topographic position and slope (Cindy McCain, pers. comm.: TM = 5.68-A + 3.32 + $4.42*e^{-0.0081*slope}$, where A = 1.73 for ridge tops, 1.49 for upper third of slopes, 0.7 for middle third of slopes and benches, 0.25 for draws, 0.07 for lower third of slopes, 0.03 for toe slopes, and 0 for valley bottoms). This index decreases with slope and drier topographic positions, and although similar to Parker's (1982) index, variables are combined differently, and the regional index was much more significant in the analyses. Climatic variables were extracted by geographic overlay of plot coordinates with maps created by the PRISM model, which uses elevation and coarse-scale aspect to interpolate data from climate stations (Daly *et al.*, 1994). Stand structure variables were calculated from tree measurements on the plot.

Some plots sampled multiple stands, but the regression analyses used in this study could not accommodate multiple stands, because many of the independent, plot-level variables would be identical for different stands. Therefore only the stand sampled by the largest number of subplots on each plot was included in the analyses. The proportions of plots where one stand type was sampled by different numbers of subplots was: 50% by 5 subplots, 74% by 4 or more, and 88% by 3 or more.

Frequency of nonnative species was assessed with logistic regression on the odds ratio, or the number of subplots in a stand occupied by a species over the total number sampled (GENMOD procedure, SAS Institute Inc., 1999). Although a coefficient of determination cannot be calculated in logistic regression, a somewhat comparable statistic, proportional reduction in deviance (PRD) was calculated using the deviance of the fitted model and the deviance of a null model with only an intercept fitted. Regression trees (e.g., De'ath and Fabricius, 2000) were also developed for each species, but results mainly confirmed those of logistic regression, and are not presented here. Species cover was assessed using multiple linear regression. Cover was averaged across the subplots in a stand (subplots without a species record were given a cover of zero first), transformed with the logit transformation [ln(cover/(1-cover))], and the analysis weighted by the number of sampled subplots in a stand. A modified stepwise procedure was used by running the regressions for each species on all independent variables individually, then building the model with the strongest variable and assessing the strength of additional (uncorrelated, r < 0.25) variables. Additional variables were only included if the sign and parameter of existing variables did not change dramatically and if visual examination of residuals indicated the relationship was not determined by a few outliers.

TABLE II

Selected nonnative species on 1127 FIA plots on nonfederal forest lands in western Oregon, their frequency, characteristic cover (mean cover on subplots where present), and number of plots where cover on at least one subplot was ≥ 25%

| Species | Frequency | (n, %) | Cover (%) | Plots ≥ 25% cover (n) |
|---|---|---|---|---|
| *Cirsium* spp. | 102 | 9.1% | 13.6 | 19 |
| *Cytisus scoparius* | 55 | 4.9% | 11.2 | 10 |
| *Digitalis purpurea* | 57 | 5.1% | 8.9 | 5 |
| *Hedera helix* | 9 | 0.8% | 15.6 | 3 |
| *Hypericum perforatum* | 32 | 2.8% | 6.5 | 0 |
| *Ilex aquifolium* | 41 | 3.6% | 3.0 | 1 |
| *Rubus discolor* | 264 | 23.4% | 17.7 | 88 |
| *Rubus laciniatus* | 148 | 13.1% | 5.4 | 11 |

The effect of logging on species' frequency and abundance was tested within the regression models. Both regeneration harvest (clearcutting, usually with no retention of trees from the prior stand), and partial harvest (primarily commercial thinning) were assessed. The best regression models for each species were developed using the approach described above, but without including stand density or stand size attributes (e.g., tree cover, basal area, stand diameter), and then the least-square means test was applied on either stand size-class or thinning (Ramsey and Schafer 1997). The former was evaluated by comparing seedling/sapling stands (those with a mean tree DBH ≤ 12.5 cm) with pole/mature stands (those with mean tree DBH > 12.5 cm). The effect of thinning in pole- and mature-size stands was assessed by comparing stands where crews recorded evidence of partial harvest in the 10 yr prior to measurement to stands without partial harvest.

## 3. Results

The eight nonnative taxa judged to be reliably identified by most field crews across the sample area included three forbs (*Digitalis purpurea* L., *Cirsium* P. Mill and *Hypericum perforatum* L.), three deciduous shrubs (*Cytisus scoparius* (L.) Link, *Rubus discolor* Weihe and Nees and *Rubus laciniatus* Willd.), and two evergreen shrubs (*Hedera helix* L. and *Ilex aquifolium* L.) (Table II). Overall, 450 of 1127 stands (40%) and 988 of 4908 forested subplots (20%) had one or more of the selected nonnative taxa recorded. The most frequent species was *Rubus discolor*, while the least frequent was *Hedera helix*. Characteristic cover (mean cover where present on subplots in a stand) for each taxa did not exceed 20%, although on 88 of the plots on which it was found, cover of *R. discolor* exceeded 25% on at
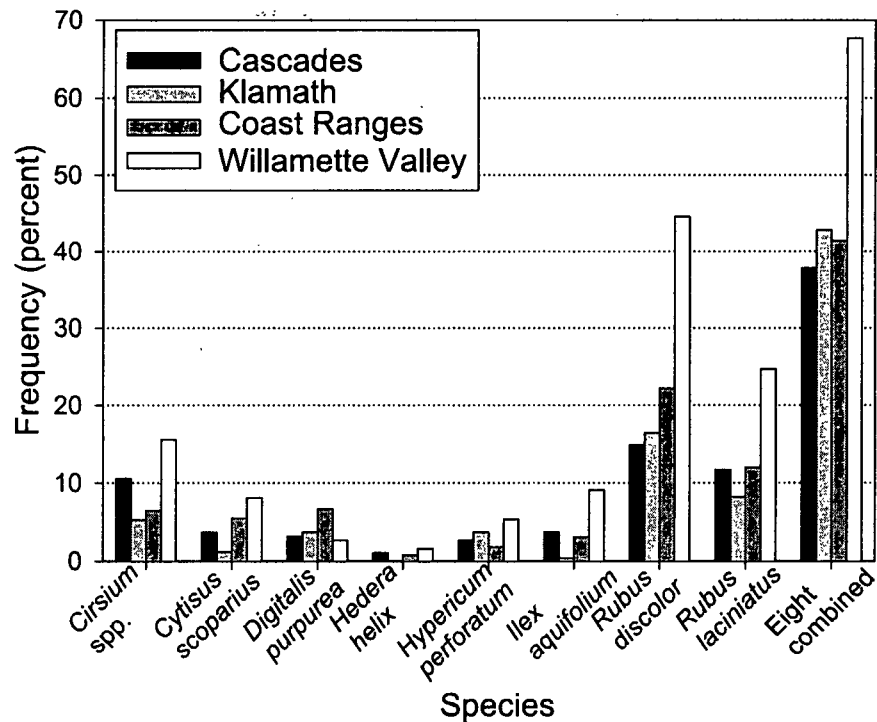
*Figure 2.* Percent of sample plots in an ecoregion with occurences of selected nonnative taxa, individually and as a group.

least one subplot (Table II). To assess relative abundance of nonnative and native species, cover of the selected nonnatives was summed by lifeform (shrub or herb) and divided by the estimated total plant cover by lifeform on each subplot. On average, selected nonnatives made up 5.5% of shrub cover and 1.5% of herb cover. Selected nonnatives made up more than 50% of life-form cover in 4.5% and 1.1% of the subplots for shrubs and herbs, respectively.

Most selected nonnative taxa were more frequent in forest lands in the Willamette Valley than in other ecoregions (Figure 2). The exception was *Digitalis purpurea*, which was most frequent in the Coast Range ecoregion (given the caveat that this species, as with the other two forb taxa, was only recorded if cover exceeded 2% on one or more subplots). The proportion of plots within an ecoregion with at least one recorded nonnative taxa was 68% for the Willamette Valley, and close to 40% for the other three.

*Cirsium* taxa were fairly well-distributed across the study area (Figure 3). There was a strong negative association between the species' frequency and tree canopy cover and a negative association with annual precipitation (Table III). For those

TABLE III

Variables selected for regression models of species' frequency or cover, their parameter estimates, and the significance of the parameter ($p$ values for all variables in the frequency models were < 0.0005 and are not shown). Proportional reduction in Deviance (PRD) is shown for the frequency models; coefficient of variation and sample size are shown for the cover models

| Frequency | | | Cover | | | |
|---|---|---|---|---|---|---|
| Variable | Estimate | $F_{(1,1124)}$ | Variable | Estimate | $F_{(1,n)}$ | $P > F$ |
| *Cirsium* spp. | (PRD = 0.36) | | ($R^2$ = 0.21, n = 96) | | | |
| tree cover | −0.052 | 613.1 | tree cover | −0.0414 | 9.95 | 0.0022 |
| annual precip | −1.008 | 31.3 | tree cover$^2$ | 0.0003 | 3.11 | 0.0811 |
| *Cytisus scoparius* | (PRD = 0.14) | | ($R^2$ = 0.05, n = 50) | | | |
| elevation | −0.003 | 76.9 | summer precip | −1.1075 | 2.58 | 0.1146 |
| tree cover | −0.020 | 70.4 | | | | |
| aspect | −0.665 | 30.9 | | | | |
| *Digitalis purpurea* | (PRD = 0.29) | | ($R^2$ = 0.11, n = 48) | | | |
| basal area | −0.081 | 293.2 | tree cover | −0.01056 | 5.87 | 0.0194 |
| annual precip | 2.698 | 172.6 | | | | |
| topography | −0.353 | 11.5 | | | | |
| *Hedera helix* | (PRD = 0.23) | | ($R^2$ = 0.64, n = 8) | | | |
| elevation | −0.011 | 257.1 | summer precip | −6.3641 | 10.57 | 0.0175 |
| tree cover | 0.053 | 102.8 | | | | |
| *Hypericum perforatum* | (PRD = 0.14) | | ($R^2$ = 0.33, n = 31) | | | |
| tree cover | −0.029 | 131.3 | stand diameter | −0.0681 | 9.52 | 0.0045 |
| temp range | 0.173 | 50.5 | stand diameter$^2$ | 0.0010 | 4.98 | 0.0339 |
| *Ilex aquifolium* | (PRD = 0.15) | | ($R^2$ = 0.10, n = 41) | | | |
| elevation | −0.005 | 124.5 | topography | 0.3848 | 4.25 | 0.0461 |
| stand diameter | 0.037 | 51.5 | | | | |
| *Rubus discolor* | (PRD = 0.26) | | ($R^2$ = 0.16, n = 252) | | | |
| elevation | −0.005 | 242.3 | elev*precip | −0.2578 | 37.1 | < 0.0001 |
| basal area | −0.043 | 139.3 | tree cover | 0.0366 | 5.88 | 0.016 |
| | | | tree cover$^2$ | −0.0004 | 7.2 | 0.0078 |
| *Rubus laciniatus* | (PRD = 0.16) | | ($R^2$ = 0.09, n = 137) | | | |
| elevation | −0.004 | 128.2 | basal area | −0.0207 | 7.9 | 0.0057 |
| tree cover | −0.018 | 77.3 | summer precip | 0.7477 | 4.44 | 0.0369 |
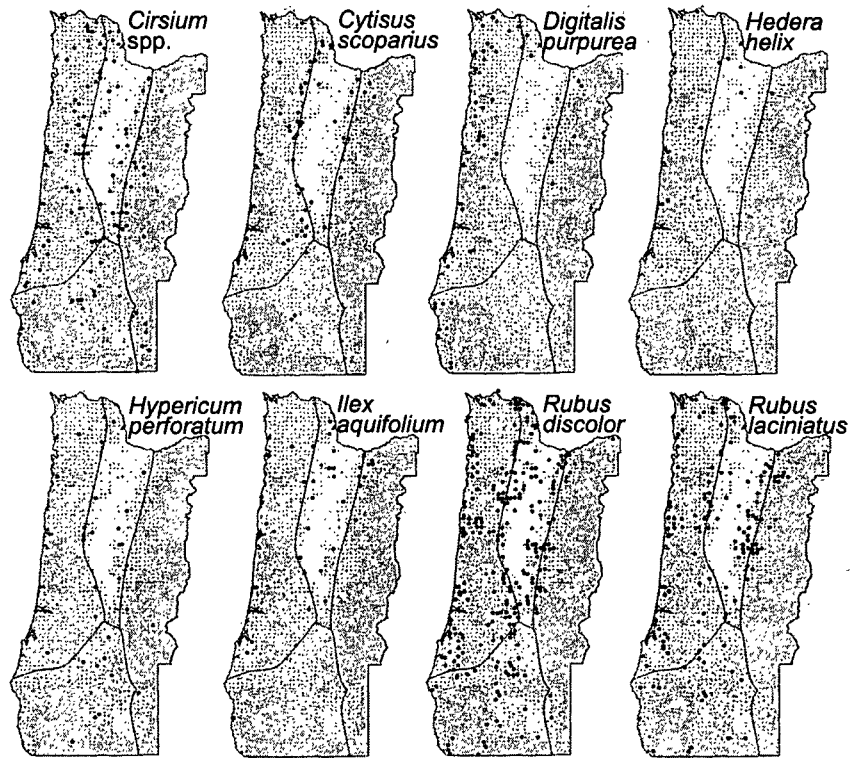
*Figure 3.* Maps of approximate locations of plots on which different nonnative taxa were sampled. Map layout is described in Figure 1; large dots represent plots where taxa were recorded, small dots represent plots where they were not recorded.

plots on which it was found, *Cirsium* cover declined sharply with increasing tree canopy cover.

*Cytisus scoparius* was primarily found in the Cascade and Coast Range foothills around the Willamette Valley, and scattered along the coast. Its frequency was negatively associated with increased elevation and tree cover, and positively associated with southern exposures. There were no significant variables associated with cover, but cover tended to be greater on plots with low summer precipitation.

*Digitalis purpurea* occurred frequently in the Coast Range and the lower slopes of the northern Cascades. Its frequency was negatively associated with tree basal area and topographic moisture index (i.e. toe slopes and valley bottoms), and positively associated with annual precipitation. For those plots on which it was found, cover declined with increasing tree canopy cover.

*Hedera helix* was found on relatively few plots, so regression results are merely suggestive. Most of the plots were within about 50 km of the Portland metropolitan

area. Frequency was negatively associated with elevation, and positively associated with tree canopy cover. Cover was negatively correlated with summer precipitation.

*Hypericum perforatum* was scattered across the study area, particularly along the foothills of the interior valleys. Frequency was negatively associated with canopy cover, and positively associated with range in annual temperature. Cover was negatively correlated with mean tree diameter.

*Ilex aquifolium* was primarily found in the foothills around the Willamette Valley and at a few locations along the coast. Frequency was negatively associated with elevation, and positively associated with mean tree diameter. Cover was positively correlated with topographic moisture index.

*Rubus discolor* was common throughout the study area. Frequency was negatively associated with elevation and stand basal area. Cover was negatively correlated with elevation and precipitation; the shape of the relationship with the canopy cover quadratic term indicated a positive effect at low to moderate canopy levels and a negative one at high levels.

*Rubus laciniatus* was also common throughout the study area. Frequency was negatively associated with elevation and tree canopy cover. Cover was negatively correlated with stand basal area, and positively correlated with summer precipitation.

The frequency of all selected nonnative taxa, except for *Hedera helix*, was significantly ($p < 0.05$) related to both clearcutting and thinning (Figure 4). After accounting for climatic and site variables, least-square means indicated that for most taxa, frequency was at least double in seedling/sapling-size stands than in pole/mature-size stands (up to 10 times greater for *Cirsium*). The reverse was true for *Ilex aquifolium*, and *Hedera helix* was only found in the larger-diameter stands. Recent thinning (within 10 yrs of sampling) in pole and mature-size stands also had a significant positive effect on species frequency (except *Hedera helix*), with the greatest effect on *Cirsium* spp. and both *Rubus* species.

Cover on plots where nonnative taxa were found was less strongly affected by clearcutting and thinning than was frequency (Figure 5). Only cover of *Rubus laciniatus* was significantly greater ($p = 0.045$) in seedling/sapling stands than in pole/mature stands. Thinning did not appear to have a significant effect on cover.

## 4. Discussion

This analysis of a multi-purpose inventory indicates that the eight selected nonnative plants have become an important part of the flora in the nonfederal forests of western Oregon, being found on at least 35% of the plots and 20% of the subplots that were sampled in the mid-1990's. These species can be significant competitors to native forest plants, and examples exist of *Cytisus scoparius* and *Rubus discolor* contributing to tree plantation failures (Wheeler *et al.*, 1987; McClennan *et al.*, 1991; Randall and Rejmánek, 1993; Peterson and Prasad, 1998). Although the
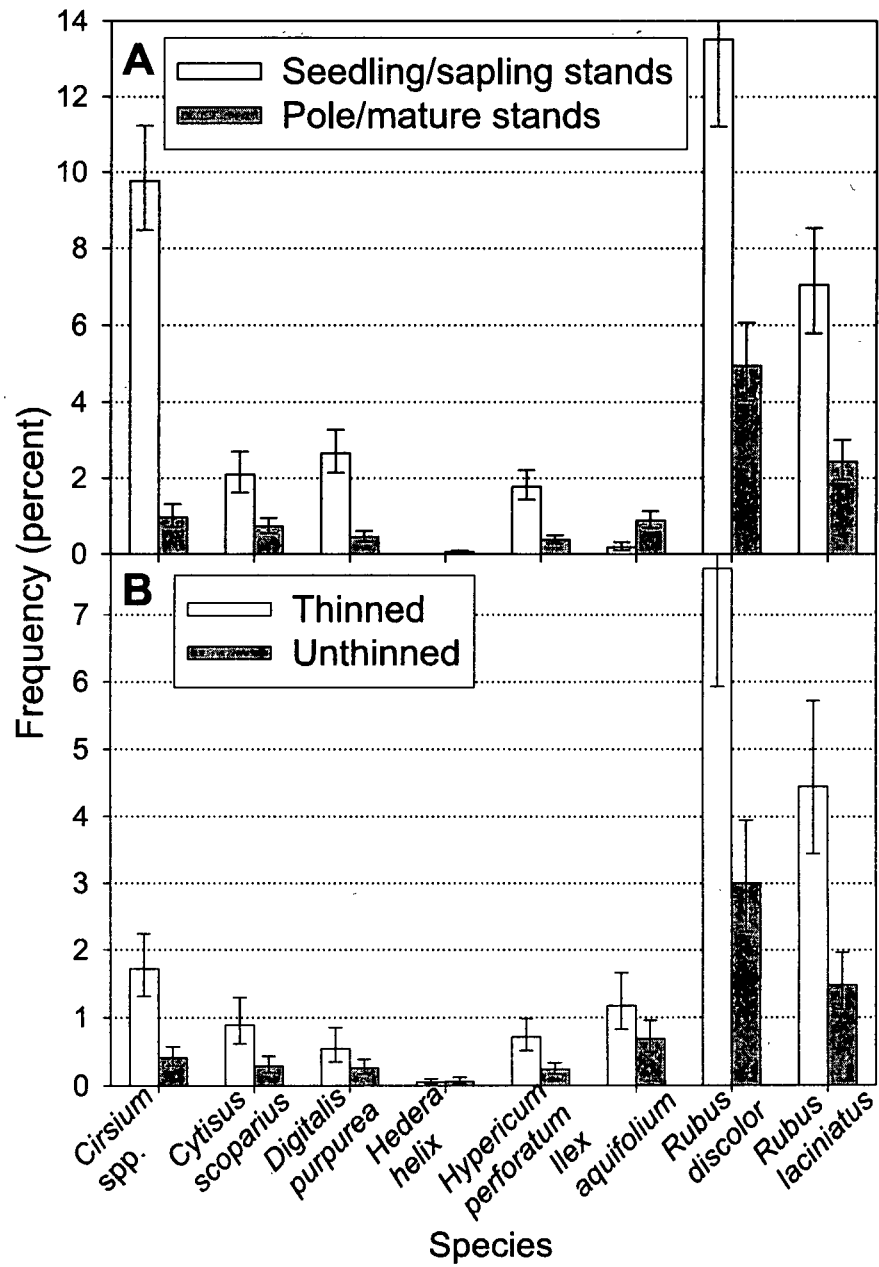
*Figure 4.* Effect of clearcutting (A) and thinning in pole and mature stands (B) on the frequency of nonnative species, showing means and 95% confidence intervals estimated by least-square means in species regression models.
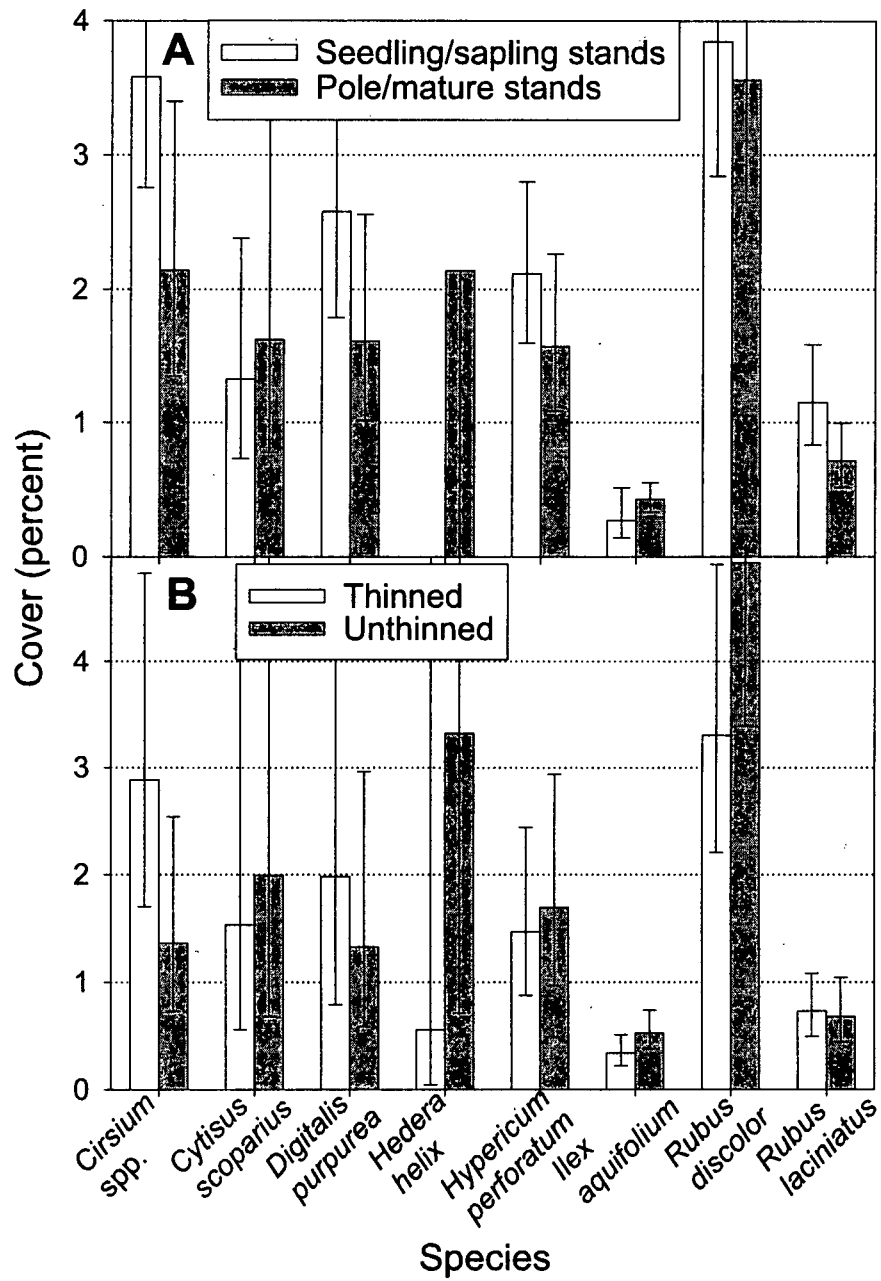
*Figure 5.* Effect of clearcutting (A) and thinning in pole and mature stands (below) on the cover of nonnative species, showing means and 95% confidence intervals estimated by least-square means in species regression models.

selected nonnative species dominated vegetation in some stands, in most cases they were a minor part of the overall cover. In addition, most of the selected nonnative species in this study had a high affinity for disturbed, open conditions, which are relatively ephemeral in most forest types in western Oregon. At the landscape scale, however, disturbed conditions are fairly ubiquitous on nonfederal lands, so that the seed of these species may be well-distributed and able to readily colonize new disturbances. If plant or animal species are being displaced by these nonnative species, it will probably be those adapted to early-successional and open-forest habitat types.

Because the inventory used in this study was not intended to census all vascular plant species, it is likely this overall assessment does not apply to all nonnative species in the forests of western Oregon. The greatest expense in most inventories is getting crews to the plot locations, and crews in this inventory had many resource attributes to measure in a limited amount of time. Thus inventory personnel were trained and expected to identify all shrubs and only the most common forbs. The occurrence of many nonnative species on the plots, particularly graminoids and composites, and the presence of any forb at less than the 3% cover threshold, is not known. For example, herbarium vouchers indicate *Centaurea pratensis* and *Elymus repens* occur in western Oregon, and they are on the state's noxious weed list (Oregon Department of Agriculture, 2001), but were not detected on the FIA plots. The presence of additional nonnative species may be high: combined measurements for 'grasses' were common on FIA plots, being recorded on 58% of the plots, and measured at $\geq$ 25% cover on 13% of the subplots. Results of tests of a full-species inventory on a subset of FIA plots found several nonnative grasses; for example, *Hocus lanatus* was found on one-fifth of the test plots in western Oregon. Another limitation, common to any systematic survey, is that vegetation types that cover relatively small areas (e.g. forested wetlands in western Oregon) are sampled by relatively few plots, so threats from nonnative species to specific communities may not be readily apparent. While stratified sampling would be most efficient for inventorying specific communities or species, and might complement a systematic inventory, no single sample design would be efficient for all of the communities or species of interest. In contrast, one of the advantages of systematic sampling is that results are automatically representative of the entire population, with no extrapolation or assumptions necessary.

This study of a systematic inventory provided new information on the distribution of several nonnative species that are important in the region, and allowed examination of potential environmental controls on their distribution. Climatic variables were not as important in most of the models of species' frequency or cover as the other variables in this study. Annual precipitation was associated negatively with frequency of *Cirsium* and positively with frequency of *Digitalis purpurea*. *Hypericum perforatum* tended to be found in areas with a high range in annual temperature, which also tended to be relatively dry. Once estimated as covering over 1 million ha in western North America, the introduction of two beetles in

the Pacific Northwest greatly reduced the abundance of *Hypericum* to ephemeral populations or relatively shady areas where the beetles do not thrive (Crompton *et al.*, 1988). In this study it was associated with low canopy cover, suggesting many of these populations may have been relatively ephemeral. The species is apparently quite persistent along roads in more moist, shady conditions (Parendes and Jones, 2000), but roads were not well-represented in the FIA vegetation sample (new sample protocols require sampling understory vegetation on entire subplots, without excluding portions occupied by nonforest areas like roads).

Elevation was the most important of the site variables associated with the distribution of the selected nonnative species. Analyses of woody plant community composition across Oregon also found elevation to be the most important variable (Ohmann and Spies, 1998). Elevation represents a complex gradient of several factors in western Oregon, where the terrain ranges from wet coastal lowlands and mountains to dry rain-shadow valleys and interior ranges. Across the plots in this dataset, elevation was correlated with annual temperature (r = −0.50), but not with annual precipitation (r = −0.11). It is possible that elevation reflects climatic gradients that the plants respond to better than the individual climatic variables do. Alternatively, the importance of elevation may be related to agricultural and urban land uses, where some of these species seem abundant. To evaluate this, distance from each plot to major highways was calculated and evaluated with the logistic regression models, but the F-values were always lower than for elevation.

Stand density variables were associated with frequency and cover of all the nonnative species in this study. Six of the eight species declined in frequency with increasing stand density, expressed as either tree canopy cover or basal area. Canopy cover was important for four taxa, and for *Cirsium* spp. in particular. Although their life-histories differ dramatically, and they were not differentiated in the analyses in this study, both *Cirsium arvense* and *C. vulgare* seedlings require relatively high light levels to establish and are quite sensitive to shading or competition (Hodgson, 1968; Doucet and Cavers, 1996). Studies in forests of western Oregon have found that *Cirsium* species were present in the first growing season, peaked in abundance within 5 yr, and were not present a few years later (Halpern, 1989; Pabst and Spies, 2001), presumably due to competition from other plants.

For *Digitalis purpurea* and *Rubus discolor*, basal area had a stronger negative association with frequency than did canopy cover. Because basal area increases more slowly with stand development than does canopy cover, this might indicate greater persistence in shaded conditions for these species. Although germination of *Digitalis purpurea* seems to require high light levels and soil disturbance, the species is able to maintain populations into later successional stages (van Baalen, 1982; van Baalen and Prins, 1983; Pabst and Spies, 2001). The ability of *Rubus discolor* to grow canes several meters high may allow it to maintain foliage above tree canopies as they close in developing stands, and to persist until tree canopies grow too tall.

Unlike the other nonnative species in this study, frequency of the evergreen shrubs *Hedera helix* and *Ilex aquifolium* was positively related to stand density. Whether this relationship reflects simply a temporal lag of plants increasing in abundance with time since disturbance, or a habitat effect for these bird-dispersed, highly shade-tolerant species, is unknown. *Ilex aquifolium* exhibits photoinhibition under high light and low temperatures, which might explain its occurrence as an understory tree in most areas, and it does not seem to occur in Europe in areas where the mean temperature of the coldest month falls below –0.5 C (Groom *et al.*, 1991). Similarly, all of the FIA plots where *Ilex aquifolium* was found were predicted to have a mean minimum December temperature > 0 C, and most of them had > 50% canopy cover. The high shade tolerance of these shrubs makes it likely they will continue to spread in the lower elevation forests of western Oregon.

Clearcut logging and thinning had significant positive effects on the frequency of most of the nonnative species. The results of the test of clearcutting effects were analogous to the importance of stand density discussed above, since the great majority of low-density stands were regenerating following clearcutting. Apparently, thinning in established stands also caused sufficient disturbance and made enough resources available to support the relatively shade-intolerant nonnative species. Many of the species in this study develop abundant and persistent seed banks in the soil, which may allow them to respond quickly to changes in conditions (Hodgson, 1968; van Baalen, 1982; Crompton *et al.*, 1988; Doucet and Cavers, 1996). A study of thinning in stands in western Oregon also found greater richness of nonnative species in thinned stands than in unthinned stands, even 10–24 yr after thinning (Bailey *et al.*, 1998).

This study suggested some of the more important environmental constraints on the distribution of the selected nonnative species. Logging and stand density were important for most species, climatic limitations were important for some species, but site topography variables appeared least related to frequency and cover. Similar types of analyses have been developed from systematic inventory plots to evaluate the role of climate on plant distributions (Iverson and Prassad, 1998; McKenzie and Halpern, 1999; Ohmann and Gregory, 2002). The lack of comparable data on non-forest lands and on federal forest lands made it difficult in this study to distinguish the importance of elevation from climate or land use. Future evaluations may be able to evaluate this better; since 2001, all forest lands in Oregon are being inventoried with the same vegetation protocols. Although personal observation suggests that most of the nonnative plant species in western Oregon are concentrated near agricultural, urban, and range lands, there is no systematic data to support analysis, conduct basic monitoring, or evaluate the spread of nonnative species into forest lands.

Threats from nonnative species are often identified in a somewhat haphazard fashion, as a result of expert botanists helping protect native species in specific areas. In many cases these represent a 'last stand' for the native species and communities. A comprehensive, systematic vegetation inventory can provide defensible

data on plant invasion and abundance, making it easier to communicate threats and impacts to the public and policymakers before such 'last stands' are required (Mack, 2000). As part of the Forest Health Monitoring effort, the FIA program has been developing a complete vascular plant inventory for several years. This inventory would sample one-sixteenth of the standard FIA plots every five years, across all forest lands, and regardless of ownership. Despite considerable logistical challenges, including acquiring botanical expertise in the field and for plant sample identification, accounting for phenology, and coordinating access with inventory crews, pilot studies and early implementation suggest it holds great promise for monitoring invasions of nonnative species (Stapanian *et al.*, 1997; Gray, *in review*).

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