Nonnative Plants in the Inventory of Western Oregon Forests

Andrew N. Gray[1]

Abstract.—Vegetation data from the 1997 inventory of non-Federal forests in western Oregon were examined to assess the abundance of invasive nonnative plants detected by the inventory. Inventoried plants were the more common, identifiable species; composites and graminoids were underrepresented. Nonnative species were found on 1,040,000 ha (35 percent) of the non-Federal forest land in western Oregon. Abundance of most nonnatives was greater on lands that had been recently clearcut or thinned and was more closely related to stand density than climate. Most species were shade-intolerant, but shade-tolerant ivy and holly have the potential to greatly increase in abundance.

Invasion of plants and animals into new regions around the world dramatically impacts the economics of human communities, and seriously threaten native species and ecosystems (Mooney and Hobbs 2000, Vitousek *et al.* 1996). Biological invasions may be second only to land use change as causing species extinction (D'Antonio and Vitousek 1992). Competition from nonnative plants is a ubiquitous problem in most agricultural areas, and can also jeopardize the success of forest plantations and the availability of forage on rangeland (e.g., Crompton *et al.* 1988, Randall and Rejmánek 1993).

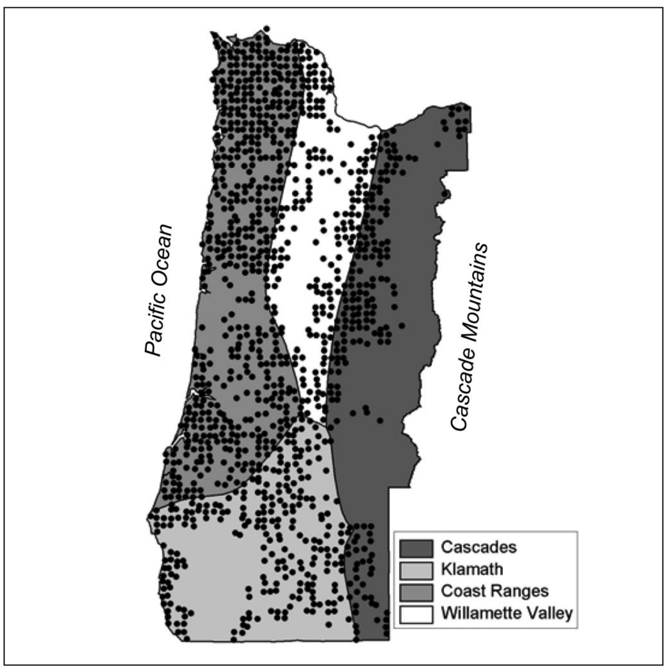
Public agencies in the Pacific Northwest are struggling to evaluate and control the spread of invasive, nonnative plant species. The Oregon Department of Agriculture maintains lists of the most threatening exotic plants and has guidelines for controlling them (Oregon Department of Agriculture 2001). However, there have been few assessments of the distribution and rate of spread of many of these species. Most published information about the distribution of individual species is derived from collected locations of specimens in herbaria, or from general descriptions of their association with plant community types published in floras. The objective of the study reported here was to assess the abundance of nonnative plant species recorded during an inventory of non-Federal forests in western Oregon and to examine the effects of environment and management on their abundance.

Methods

Inventory Design

Forest land in western Oregon was inventoried from 1995 to 1997 by the USDA Forest Service's Forest Inventory and Analysis (FIA) unit in the Pacific Northwest Research Station. The study area consisted of the counties of western Oregon, generally extending west from the crest of the Cascade Mountains to the Pacific Ocean, and south from the Columbia

Figure 1.–*Map of western Oregon study area, showing boundaries of ecoregions (Bailey 1980) and approximate locations of forestland FIA plots.*



[1] Research Ecologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR 97331. Phone: 541–750–7252; e-mail: agray01@fs.fed.us.

River to the California border. The area has a broad range of climate and vegetation, ranging from the *Picea sitchensis* Zone along the moist, warm coastline, to the *Tsuga heterophylla* Zone in the cooler Coast Ranges and the lower Cascades, to *Quercus garryana* communities in the dry, warm interior valleys (Franklin and Dyrness 1973). This range of conditions can be stratified into four main ecoregions: Coast Range, Cascades, Willamette Valley, and Klamath (Bailey 1980) (fig. 1).

The field plot sample design consisted of a systematic grid on a 5.4-km spacing (1 point per 3,000 ha). Inventory data from land managed by the Bureau of Land Management and the USDA Forest Service were excluded from this study because they were not collected by FIA and did not have comparable information on vegetation composition. Field plots were installed by FIA at all grid locations on remaining lands that met the criteria for "forest land" (i.e., land area ≥0.4 ha in size that had, or had previously had, 10 percent canopy cover by trees and was not primarily managed for nonforest land use). A total of 1,127 plots were sampled.

At each forest sample grid location, five subplots were installed (or remeasured) over a 2-ha area at 66-m intervals. Understory vegetation was sampled on 5-m radius plots around each subplot center. All species of shrubs, and of trees <2.5-cm diameter at breast height (d.b.h.) ("seedlings") were recorded; "herb" species (forbs, graminoids, and ferns) were recorded if present at ≥3 percent cover. Species' cover was estimated in 5-percent increments. Trees were identified by species and sampled more intensively than other plants. Trees ≤12.5-cm d.b.h. were measured on 2.35-m fixed radius plots at each subplot point, and larger diameter trees were sampled with a variable-radius, 7-m basal area factor prism, up to a maximum distance of 17 m. Diameter, height, species, crown class, and other attributes were recorded for all sample trees. Additional measurements of tree canopy cover were made along three 17-m transects on each subplot. Trees were assigned to as many as three canopy layers, and the portions of the transect covered (using vertical projection from crown edges) by each species were recorded. Other data collected on FIA plots (e.g., root disease, snags, and down wood) were not used in this study.

The systematically placed subplots often sampled different forest types, stand age classes, or land types, termed "condition classes" (e.g., clearcut vs. pole stand, pasture vs. forest). Obvious differences in vegetation types were distinguished and mapped in the field, and all collected data were identified to the condition class in which they were found.

Analysis

There were 545 plant species recorded at the 1,127 sample grid locations that were forested. To reliably examine the distribution of a given species, it was first necessary to select only those species that had a high probability of being detected by most field crews. For each species, an estimate was made of the ability of most of the crew members to identify it if encountered (low, medium, or high) based on personal experience with plant identification in the region, and corroboration with an experienced field crew member (Erica Hanson, personal communication). Some species were combined at the genus level based on similar ecological attributes and/or difficulty of identification. Of the

Table 1.—*Plant species not native to western Oregon selected for analysis, and their frequency in the FIA inventory*

Species	Code	Common name	Number of plots	Percent frequency
Cirsium spp.	CIRSI	thistle	102	9.1
Cytisus scoparius	CYSC4	Scotch broom	55	4.9
Digitalis purpurea	DIPU	foxglove	57	5.1
Hedera helix	HEHE	English ivy	9	0.8
Hypericum perforatum	HYPE	St. John's wort	32	2.8
Ilex aquifolium	ILAQ80	English holly	41	3.6
Rubus discolor	RUDI2	Himalayan blackberry	264	23.4
Rubus laciniatus	RULA	cutleaf blackberry	148	13.1

species recorded, all 37 tree species were judged to have a high to medium probability of being identified by most crews; 84 shrubs, 50 forbs, and 0 graminoids were judged to meet the same criteria (there was no specific training for identification of graminoids for this inventory). These species were then matched with a national list of nonnative species (USDA 2002), resulting in a final list of eight species examined in this study (table 1).

Summaries of species frequency and abundance were calculated for the study area and by ecoregion. Additional analyses of species frequency in relation to environment and management history were done at the stand level. Independent variables were various potentially important site, stand, and climatic attributes. Site attributes consisted of elevation, aspect (linearized to reflect solar heating with the coversion cosine(aspect-45)), percent slope, potential annual direct radiation (from equations in Oke (1987)), and topographic moisture index (Parker 1982). Stand attributes included percent tree canopy cover, proportion of cover in hardwoods, basal area per hectare of all trees and of shade-tolerants only, quadratic mean diameter, stand size class, and stand age. Climatic variables included mean annual and mean summer precipitation, mean annual and mean summer temperature, mean annual range in temperature, and a moisture stress index of summer temperature divided by summer precipitation, all derived from the PRISM climatic interpolation model (Daly *et al.* 1994).

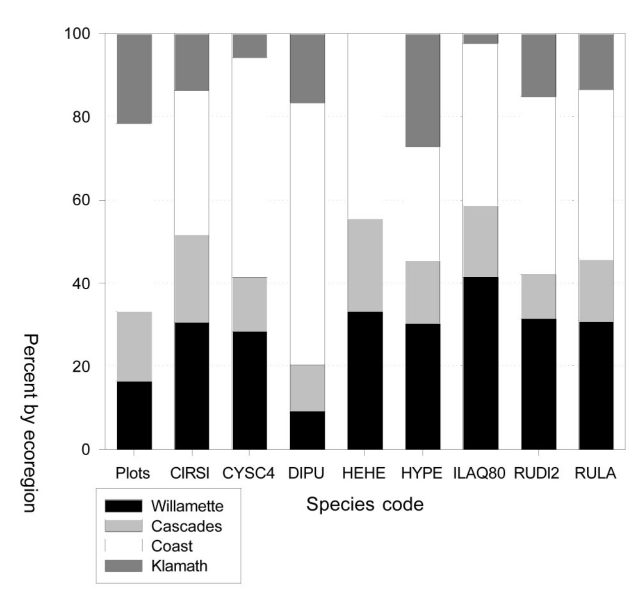
Logistic regression was used to examine species-distribution patterns where the dependent variable was the odds ratio, expressed as the number of subplots with a species over the number of subplots sampled within a stand on a plot (GENMOD procedure, SAS Institute (1999)). The regression analyses could not accommodate multiple conditions ("stands") on the same plot because many of the independent, plot variables would be identical for different stands. Therefore, only the largest condition on each plot was included in the analyses. A modified stepwise procedure was used by running the logistic regressions for each species on all independent variables individually, and then building the model with the strongest variable and assessing the strength of additional (uncorrelated) variables. Pearson correlation coefficients among the independent variables were used to help guide model development. Residuals were examined and plotted against the next variable in the model to avoid inclusion of spurious relationships.

Additional analyses were used to evaluate the effect of logging on the presence of the selected species. Two types of logging were evaluated: stand-replacing harvest (clearcutting, usually with no retention of trees from previous stand), and partial harvest (primarily commercial thinning). The former was assessed by comparing seedling/ sapling stands with a mean tree d.b.h. ≤12.5 cm with stands with larger trees. Thinning was assessed for pole- and sawtimber-sized stands (d.b.h. >12.5 cm) by comparing stands that had been partially harvested in the 10 years before measurement to stands that had not. To test the effect of logging, the best logistic regression model for a species was developed using the approach described above but without including stand density or stand size attributes, and then applying a least-square means test on either stand size or thinning (Ramsey and Schafer 1997).

Results

Overall, 450 of the 1,127 stands (40 percent), and 1,726 of the 4,924 vegetation subplots (35 percent) had one or more of the selected weed species. Applying the latter percentage to the

Figure 2.–*Proportion of sample plots by ecoregion, compared to the proportion of sample plots where each nonnative species was found, by ecoregion. Species codes are defined in table 1.*



area of non-Federal forestland in western Oregon (Azuma *et al.* 2002) suggests these species were present on 1,040,000 ha of non-Federal forestland in western Oregon. Himalayan blackberry (*Rubus discolor* Weihe & Nees) was the most abundant of the nonnative species, having been found on almost one-quarter of the plots and across most of the study area (table 1). On the other hand, English ivy (*Hedera helix* L.) was the least abundant of the nonnative species and was primarily found close to Portland and other urban areas.

The proportion of sample plots by ecoregion was usually different from the proportion of sample plots where nonnative species were found (fig. 2). All of the nonnative species, except for foxglove (*Digitalis purpurea* L.), were more common in the Willamette Valley ecoregion than in the other ecoregions. Foxglove was particularly common in the Coast Range ecoregion. The Klamath ecoregion had fewer plots with Scotch broom (*Cytisus scoparius* (L.) Link), English ivy, or English holly (*Ilex aquifolium* L.).

Stand density was strongly associated with the frequencies of all of the nonnative species, but the most significant variables, and their signs, differed among species (table 2). Increasing tree canopy diminished the frequency of thistles (*Cirsium* P. Mill.), Scotch broom, St. John's wort (*Hypericum perforatum* L.), and cutleaf blackberry (*Rubus laciniatus* Willd.). In addition, the greater the basal area the less the frequency of foxglove and Himalayan blackberry. Increasing stand density increased the frequency of English ivy and English holly, with the most important variables being canopy cover and quadratic mean diameter, respectively.

Climatic and site variables were also strongly associated with the frequency of most species. Increasing annual precipitation reduced the frequency of thistle, but increased the frequency of foxglove. There was a positive relation between annual range in temperature and frequency of St. John's wort. For the rest of the species, frequency diminished with increasing elevation. Although elevation is a complex climatic gradient, across this population of plots (where elevation ranged from 0 to 1433 m) the correlations between elevation and climatic variables were not high: r=-0.50 for annual temperature, and r=-0.11 for annual precipitation.

All the species were significantly affected by harvest activity, except for English ivy (possibly due to low sample size for this species). Most species were at least twice as frequent (close to 10 times more for thistle) in seedling-sapling stands (d.b.h. ≤12.5 cm) than in pole and sawtimber stands (d.b.h. >12.5 cm) (fig. 3). The reverse was true for English holly, and English ivy was only found in the larger size classes. Thinning the larger size classes within the 10 years before inventory also significantly affected frequency of most of the species. Except for English ivy, species were two to four times more likely to be found in thinned stands than in unthinned stands of the same size class.

Discussion

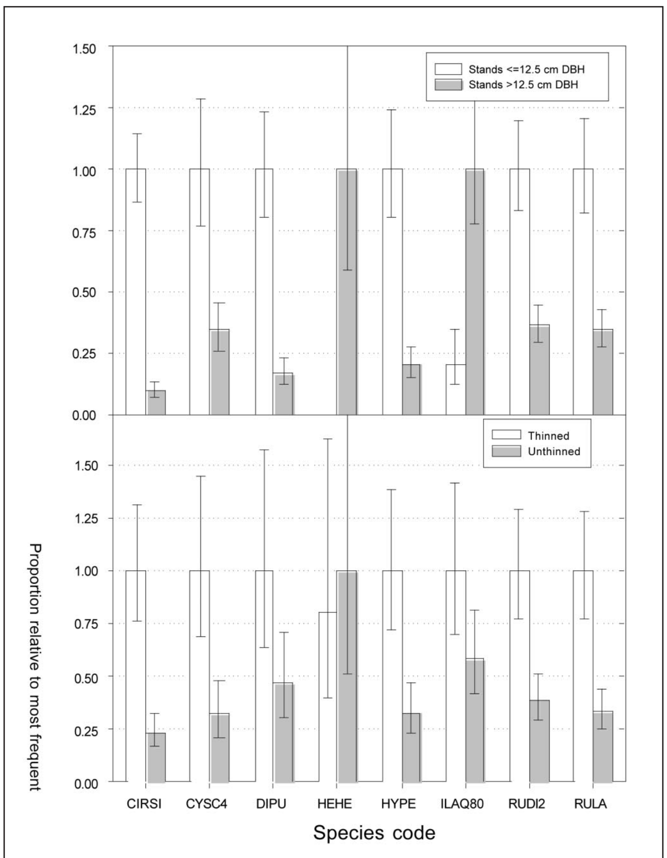
This analysis of recent forest inventory data in western Oregon indicates that nonnative species have become an important part of the flora in these forests, having been detected on 40 percent

Table 2.—*Variables selected for final logistic regression models of frequency for each nonnative species on FIA plots, the direction of the effect (as sign, positive or negative), and the strength of the variable (only F-statistics are shown; P values for all variables were <0.0005)*

Species code	Variable	Sign	$F_{(1,1124)}$
CIRSI	Tree cover	–	613.13
	Annual precipitation		31.28
CYSC4	Elevation	–	76.85
	Tree cover	–	70.4
	Aspect (cosine)	–	30.89
DIPU	Basal area	–	293.19
	Annual precipitation	+	172.57
	Topographic moisture	–	11.53
HEHE	Elevation	–	257.13
	Tree cover	+	102.82
HYPE	Tree cover	–	131.34
	Annual temperature range	+	50.49
ILAQ80	Elevation	–	124.45
	Quadratic mean diameter	+	51.52
RUDI	Elevation	–	242.33
	Basal area	–	139.34
RULA	Elevation	–	128.22
	Tree cover	–	77.29

of the plots on non-Federal forest lands. It is unknown, however, if a complete botanical inventory on these plots (i.e., geared to sample species that were difficult to identify or that were regionally uncommon) would have revealed a greater prevalence of nonnative species. Many composites and grasses are hard to identify, even if encountered during peak phenology. For example, spotted knapweed (*Centaurea maculosa* auct. non Lam.) and quakgrass (*Elymus repens* (L.) Gould) are nonnative species on the Oregon Department of Agriculture (ODA) noxious weed list (Oregon Department of Agriculture 2001) but

Figure 3.–*Magnitude of logging effect on the frequency of nonnative species. Estimated frequencies for each species were determined by least-square means from logistic regression models, and means and 95-percent confidence intervals were expressed as proportions of the largest value to display all species on the same scale. For each species, the upper panel compares estimated frequency between stands with mean d.b.h. ≤12.5 cm with those greater, and the lower panel compares thinned and unthinned stands for stands >12.5-cm d.b.h.. Differences were significant at the p=0.05 level for all species except HEHE. Species codes are in table 1.*



have not been detected yet on the FIA plots. It is hoped that the planned implementation of full species sampling on a subset (one of every 16) of the standard FIA plots (known as "forest health monitoring plots") in Oregon beginning in 2004 will provide information on the abundance of many more species than is currently available.

Most of the nonnative plants in this study were more likely to be found in the Willamette Valley ecoregion than in the other ecoregions of western Oregon. Many of the species were more affected by elevation than by any climatic variable. These results suggest that the presence of these plants on forest land is strongly affected by proximity to urban and agricultural settings, where anecdotal evidence indicates they are often locally abundant; unfortunately there is no comparable inventory of vegetation on nonforest land to assess this quantitatively.

Shade tolerance was an important trait determining species distributions. Six of the eight species in this study declined with increasing stand density, were significantly more common in seedling/sapling stands than in larger stands, and were more common in thinned stands than in unthinned stands. While thistle, Scotch broom, St. John's wort, and cutleaf blackberry appeared to be more sensitive to canopy cover than other measures of stand density, foxglove and Himalayan blackberry appeared to be more sensitive to basal area. Because basal area increases slower than canopy cover, foxglove and Himalayan blackberry may be more shade-tolerant than the other four species. Because they are most common during early stages of succession, these six species may be ephemeral on forest land. Nevertheless, their prevalence in recently thinned stands indicates the presence of persistent seed banks in the soil or abundant seed sources.

Unlike the relatively shade-intolerant species, the frequency of English ivy and English holly was associated with increasing stand density, and both were more common in larger stand size classes than in seedling/sapling stands. These evergreen shrubs are common in urban areas where they are planted as ornamentals, they are shade-tolerant, and their seed is readily consumed and dispersed by native birds. The ivy is currently on the ODA weed list while the holly is not. Their ability to persist in closed-canopy stands and their lack of association with any climatic variables in this study suggest a high potential for future spread in the forests of western Oregon.

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