13 Monitoring and Assessment of Regional Impacts from Nonnative Invasive Plants in Forests of the Pacific Coast, United States

Andrew Gray

CONTENTS

13.1 INTRODUCTION

13.1.1 PROBLEM STATEMENT

Invasions of nonnative plants into new regions have a tremendous impact on many natural and managed ecosystems, affecting their composition and function. Nonnative invasive species have a large economic impact through lost or degraded land use and eradication costs, and are a primary cause of extinction of native species (Vitousek et al. 1996; Mooney and Hobbs 2000; Pimentel et al. 2005). Nonnative invasive plants can affect ecosystems and land use by competitively excluding desired species and altering disturbance regimes (D'Antonio and Vitousek 1992). As a result, characterizing the prevalence of invasive species is a key element of several efforts to assess ecosystem health and sustainable management (Anonymous 1995; National Research Council Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments 2000; Heinz Center 2002).

Despite their importance, few data on the abundance, distribution, and impact of nonnative invasive plants are available (Blossey 1999). Information is often incomplete (e.g., quantifying distribution, but not abundance) and available for only a few species in a few areas for selected time periods. As a result, it is currently not possible to provide a comprehensive assessment of the abundance and impacts of nonnative invasive plants in the United States (National Research Council Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments 2000; Heinz Center 2002). The objective of this chapter is to describe recent efforts to monitor nonnative invasive plants for strategic forest inventories in the Pacific coastal states of California, Oregon, and Washington, and evaluate the utility of the information developed. A general introduction to various monitoring approaches and common challenges is presented, along with brief discussion of the pros and cons of each. Analyses of two types of vegetation data from the extensive forest inventory of the Forest Inventory and Analysis (FIA) Program are presented as case studies to illustrate some of the difficulties, strengths, and tradeoffs faced in the design and implementation of an effective monitoring program.

13.1.2 MONITORING OBJECTIVES

Natural resource monitoring undertaken without clearly defined questions and objectives can lead to unusable data or ambiguous results (Morrison and Marcot 1995). There are many different objectives for collecting data on invasive plant populations, including:

1. Detecting species early enough in their invasion to facilitate control and eradication
2. Assessing the effectiveness of control efforts on detected populations
3. Evaluating species' impacts on selected habitats
4. Quantifying species' distribution and abundance
5. Quantifying changes in species' distribution and abundance over time
6. Predicting species' future spread

Addressing any single monitoring objective adequately and efficiently places unique demands on the type, quality, and quantity of data that must be collected. As a corollary, no single monitoring strategy can adequately address all objectives.

13.2 MONITORING APPROACHES

A wide range of approaches and types of data have been used to inventory and monitor invasive plants. Some of the common approaches are presented later and their suitability for addressing different objectives discussed.

Published floras are critical for documenting the presence of an invasive species in a region and facilitating the reliable identification of suspected plants. Detecting recently-arrived invasive species can be hampered if they are not included in the accepted floristic references for the area, so keeping these references up to date would help the monitoring of invasive species. A global information service that compiled information on invasive species' detections, traits, and habitat preferences would be very useful, particularly for early detection, perhaps even before species escape from their original vector into an area (Ricciardi et al. 2000). The descriptions of species' ranges and habitat preferences in flora are generally too brief and ambiguous to characterize species abundance and distribution, however.

Records and specimens maintained by herbaria are very useful for documenting changes in a region's flora. Because plant specimens are usually well preserved, identifications can be updated to match current taxonomic references, and confidence in species' identifications is high. However, herbarium records result from many different types of sampling, which vary in geographic, temporal, and taxonomic intensity. To account for some of the variations, it is possible to adjust the number of records of the species of interest by the total number of herbarium records or by records of species found in similar habitats (Delisle et al. 2003). Herbarium data have been primarily useful in the retrospective analysis of changes in invasive plant distributions over large geographic areas (Pyšek and Hulme 2005).

Intensive research projects are another important source of information that usually focuses on single species and specific attributes of a species' distribution, reproduction, dispersal, community interactions, or other life-history traits. This information provides valuable insights that inform the design of management and monitoring efforts. But results can rarely be extrapolated to assess a species' overall distribution, abundance, and impact on plant communities because intensive efforts are usually limited in space and time. However, some landscape-scale studies (e.g., Parendes and Jones 2000), if documented sufficiently, could be repeated after several years and used to assess change.

Field surveys focused on invasive plants are conducted by many local, state, and federal government agencies in the United States, although scope and strategy vary widely among efforts. For instance, surveys may be focused on specific species or specific areas (or both) of the landscape. Some can be quite focused on examining suitable habitat for specific invaders to detect new infestations as soon as possible and facilitate control. To promote greater standardization, many agencies in the United States have adopted a set of rules developed by the North American Weed Management Association in 2002 for collecting and storing data on invasive plants. These standards specify the data fields to be used to describe the location, size of area, and cover within the assessed area, for the surveyed species. This information should be most useful for land managers interested in early detection and monitoring of eradication efforts. However, with little information provided concerning the sampling strategy (i.e., area searched, species searched for) or on the spatial and temporal sampling intensity, it is not possible to determine how representative the data are for a species, a habitat type, or a management unit. The standards also lack quality control and quality assurance provisions for plant identification, cover estimation, and area mapping. It might be possible to assess change over time by reassessing previously mapped patches, but it would be difficult to develop reliable change estimates for larger areas of interest (e.g., management units). Land managers do have options for collecting more reliable data on management units, for example, with the Forest Service stand exam sampling approach.

Other types of surveys proposed for national action would focus monitoring on the primary vectors of invasive plant introductions. Most of these vectors are associated with the horticultural trade (e.g., arboreta, nurseries, seed companies); intensive monitoring of these locations could prevent potentially invasive species from being released into the environment in the first place (Reichard and Hamilton 1997; Reichard and White 2001). The proposed global information service mentioned above would help monitoring programs to identify potential species of concern (Ricciardi et al. 2000).

Strategic inventories collect resource information across large regions using relatively stable and well-defined procedures and probability-based sampling. The USDA Forest Service's FIA program is the most comprehensive and consistent inventory and monitoring program in the United States (National Research Council Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments 2000). Field sample points are installed on forestlands across all ownerships and measurements taken periodically. Data are usually appropriate for the state or multicounty level; the spatial density of sample points is generally insufficient for providing accurate information for any but the largest landowners. Recent efforts across the country have included a variety of approaches to monitoring invasive plants as part of the FIA inventory (Rudis et al. 2005). Results and the strengths and weaknesses of this kind of monitoring are the primary focus of this chapter.

13.3 CHALLENGES TO MONITORING

There are several challenges to monitoring nonnative invasive plant species in a way that provides high-quality data in a repeatable fashion. The challenges can be grouped into difficulties with species selection and logistical difficulties with collecting data.

Determining which species are "nonnative" to an ecosystem or region is not always straightforward. Plant species' distributions change continuously in response to changes in climate, land management, urbanization, and natural disturbance frequency and intensity. Assuming a species' origins can be determined, large geographic areas (continent or subcontinent) are usually used as criteria for determining nonnativity; for example, Eurasian plant species found in North America, or the barred owl (*Strix varia*) invasion of western North America from the east. In some cases, new genotypes of a species are introduced, which are not morphologically distinguishable from local populations, and which may hybridize with them.

For example, *Achillea millefolium* is one of the most abundant species in disturbed western forestlands, but it is unknown if this is a trait common to the native genotypes or a result of the spread of the introduced genotypes (Hitchcock et al. 1955; Hurteau and Briggs 2003).

Determining which nonnative species to consider "invasive" is not always clear. In its broadest application, the term invasive applies to "alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (U.S. Executive Office, 1999). Quantifying economic and environmental harm is not always easy, and different interest groups tend to give greater weight to different kinds of impacts. For agriculture and production forestry, substantial research has been dedicated to quantifying the impact of noncrop plants on crop yields and the economic costs of control. Most states in the United States maintain noxious weed lists of the species of greatest concern. Because these lists often include legal requirements for control or eradication by landowners, however, adding species to these lists can be a contentious political process. Most state lists tend to be dominated by species that impact agriculture and grazing (and often include some undesirable native species in addition to nonnatives).

There have been some efforts to formalize the criteria for ranking the invasiveness of nonnative species that are focused on nonagricultural plant communities (e.g., Morse et al. 2004). These expert-opinion approaches give high rankings to species that tend to dominate the cover of invaded ecosystems, particularly if those ecosystems are rare or otherwise threatened. Rankings are also higher for plants that have lasting presence or impact (e.g., allelopathy) or are difficult to control and eradicate. This approach to ranking is sensible from a biodiversity conservation standpoint, but has some interesting implications when applied to forest ecosystems. For instance, even though early seral stages for most forest types are transitory, they can be dominated by nonnative species. However, early seral stages are generally not a concern of most biodiversity conservation efforts, so nonnatives that primarily occur in them are generally not ranked highly in terms of invasiveness. Similarly, plants that may be ubiquitous in common forest types may be ranked lower than plants covering much less total land area that impact a rare forest type. Because specific impacts of nonnative species on native ecosystems (e.g., competition for resources, competition/suppression of pollinators, redirection of grazing impacts, and allelopathic effects) are usually unknown, species' rate of spread and cover levels are used by default as the primary criteria in ranking invasiveness.

The sheer number of plant species presents many challenges to monitoring. There are 4139 nonnative vascular plant species thought to be introduced to the United States (USDA NRCS 2000). Although not all of these species would be found in any particular region or land type, an effort to identify invasive species on forestlands in California, Oregon, and Washington (which is discussed further in the next section) initially resulted in a list of 245 species. Reliable identification of even a portion of that number of species in the field requires considerable expertise, especially considering the need to distinguish them from the numerous and varied native species (e.g., 3400 vascular plant species are listed for the state of Oregon alone).

The taxonomic skills needed to reliably identify invasive species can be difficult to acquire. Some species can be very distinctive, but many invasive species belong to families that require special skills to reliably key out and identify (e.g., *Compositae* or *Gramineae*). Focused inventories of a single or a few selected species, however, can effectively use nonspecialist personnel by providing some training and thorough guides for plant identification. These guides can usually incorporate more tips on identification and distinction from similar species than those available in the formal keys of published flora.

Monitoring approaches may need to be tailored to the expected habitats and abundance of the species of interest. Early in the invasion process, a species may occur on a small part of the landscape, requiring extensive travel and searching to locate populations. Later in the invasion process, plants may be more abundant, making sampling and quantification easier (but making control more difficult). Where species occur and how rapidly they disperse are functions of climatic tolerances, seed production, seed dispersal, competitive ability, and microsite requirements. Therefore, any species' spatial and temporal pattern of invasion is bound to be individualistic. However, many nonnative invasives are ruderal in many environments, and tend to occur in areas that are disturbed or have high levels of resources (e.g., roads, clear-cuts, and riparian areas). Therefore, monitoring that targets specific habitats or is stratified by different types could be more efficient than systematic sampling. Stratified sampling does have risks, however. A species may be shade intolerant and limited to cut areas or roads in wetter forest types, but may also invade high-light understories in dry forest types, or dry areas of otherwise moist regions (e.g., ridgetops). Some ruderal species with high dispersal abilities are also able to establish in small disturbed patches of otherwise intact forests (e.g., tree-fall gaps) and establish a seed bank for future spread. There are also many examples of shade-tolerant nonnative species that are invading intact forests. For these reasons, any stratified sampling strategy would ideally include some measurements in areas that are not preferred habitats for selected species.

Species are not equally identifiable at all times of the year. Phenology can have a big effect on the reliability of monitoring. Some species may be unambiguously identified for only a few weeks during the year when the diagnostic plant parts are present (e.g., flowers or fruits). The timing of those periods may not be very predictable in years when weather patterns differ substantially (e.g., a cool wet spring vs. a warm dry one). For monitoring programs in mountainous regions (e.g., western North America), it can be logistically impossible to sample locations in each elevation zone during the peak phenological time. For multiple-species monitoring, the peak phenological period may not coincide on a given site; for example, herbs may flower and senesce before grasses are fully developed. Specific sites can also be affected by other things, like intense grazing, which make plant sampling difficult. Phenology also affects the amount of cover a species has on a site at the time it is sampled, although plant cover in some forest types can be quite stable for extended periods. Although it is possible to sample most locations when most plant species are identifiable, phenology can be an important source of measurement error.

13.4 FOREST INVENTORY OF INVASIVE PLANTS

13.4.1 Forest Inventory Design

The FIA employs three "phases" of data collection to inventory and monitor the forestlands of the United States. The first phase uses remotely sensed images (historically aerial photo points, currently satellite images) to poststratify field plot data and improve the accuracy of inventory estimates (Bechtold and Patterson 2005). The second phase consists of a systematic grid of field locations on a 4.9 km spacing (1 point per 2,400 ha), hereafter referred to as the *standard* plots. The third phase consists of 1 out of every 16 standard locations (or 1 point per 38,800 ha), hereafter referred to as the *forest health* plots. The plot grids extend across all lands and all ownerships. The number of forested plots per Pacific state ranges from 4,068 to 8,170 for standard plots and from 256 to 428 for forest health plots (Table 13.1). With the implementation of the *annualized* approach in the Pacific states starting in 2001, 1 out of every 10 plots is sampled each year and evenly distributed across each state (Gillespie 1999). Earlier inventory designs did not sample all ownerships and/or used different plot designs in different areas. Although not discussed here, the data have been useful for assessing some invasive species (Gray 2005).

Vegetation data are collected at all standard plot locations on lands defined as "forestland" (i.e., land areas ≥0.4 ha in size that support, or recently supported, 10% stocking or 5% canopy cover of tree species and are not primarily managed for a nonforestland use) that are accessible (i.e., permission granted by owners and not hazardous to sample). (On land managed by the National Forest System in the Pacific states, vegetation is also sampled on accessible nonforest areas.) Each plot consists of a cluster of four 0.017 ha (7.32 m radius) subplots distributed over a 1 ha area. Because the plot design is fixed around the systematic plot location, plots can sample multiple land-use conditions, vegetation types, and stand age classes, termed "condition classes," which are distinguished in the field using an elaborate set of criteria. All collected data are identified to the condition class on which they were sampled. Travel is a large portion of the cost of inventory plot measurement, so crews strive to complete measurements of each plot in a single day.

TABLE 13.1
Land Area and Numbers of Standard and Forest Health Inventory Plots in the Pacific States, by State and Land Class

	California	Oregon	Washington
Total land area (ha)	40,393,282	24,863,054	17,234,832
Standard plot locations	16,860	10,356	7,276
Forested standard plots	7,170	5,514	4,068
Forest health plot locations	1,049	634	453
Forest health plots	428	334	256

Source: From U.S. Census Bureau, Census 2000 gazetteer of counties of the United States, http://www.census.gov/tiger/tms/gazetteer/county2k.txt, 2000.

Tree size and status information are collected at standard plots across the nation on trees ≤12.5 cm diameter at breast height (DBH, at 1.37 m height) with 2.07 m radius *microplots* at each subplot, and larger-diameter trees on the 7.32 m radius subplot. Sampling of other vegetation on standard plots is optional for each FIA unit, but most units across the country collect some information on invasive species (Rudis et al. 2005). In the Pacific coastal states of California, Oregon, and Washington, understory vegetation is sampled on subplots by recording the cover of individual species with ≥3% cover or species that are among the three most abundant of their growth form (i.e., tree, shrub, forb, or graminoid) on the subplot. Standard plots are measured during a long sample window (April to October) by crews with general forest resource measurement skills. Crew members are expected to be able to identify all trees and most shrubs encountered, as well as the most common forbs and ferns. Therefore, many forbs, ferns, and most graminoids may be identified to genus or growth form instead. To allow sufficient time for other inventory measurements, crews are limited to 15 min per subplot to record understory vegetation measurements.

On the subsample of forest health plots, all vascular plant species found in forestland conditions are recorded. A nested sampling design is used (Mueller-Dombois and Ellenberg 1974; Stohlgren et al. 1995), with measurements taken at three 1 m^2 quadrats within each subplot, and on the subplot as a whole (Stapanian et al. 1997; Gray and Azuma 2005). The measurements taken at both scales have changed slightly over the last decade; the currently stable protocols are described here and by Schulz (2003). Each species with canopy cover within 0–1.8 m above each quadrat is recorded. Plant cover estimates made on standard and forest health FIA plots use the standard cover definitions of Daubenmire (1959).

Cover of each species found on the subplot is also recorded. Vegetation on forest health plots is only measured during the summer season of peak phenology by experienced botanists. Plants that botanists cannot confidently identify to species and are deemed to be potentially identifiable (e.g., are sufficiently developed, or have flowers or fruits) are collected for later identification by herbarium experts. To allow completion of the protocol in a day, the subplot search for species and cover estimation is limited to 45 min per subplot. The forest health vegetation protocol has not been fully implemented nationally; data have only been collected for a few years in selected states.

13.4.2 INVASIVE PLANT LISTS

The PNW-FIA program began a collaborative project with the University of Washington in autumn 2005 to develop a prioritized list of invasive species to monitor on forestlands in California, Oregon, and Washington. The project will also develop the guides and training aids needed to ensure reliable sampling. Although the work is still in progress, the challenges faced to date are instructive.

The first step was to compile existing lists of invasive species from state and federal agencies and nongovernmental organizations in each state. This resulted in 421 species that were present on at least one list. Of those, 11 species were either native to the region or were thought to have both native and nonnative populations; these were excluded from further consideration. Forty-three species were added to the list that were nonnative and had already been recorded on an FIA forest health plot or more than five standard FIA plots. The next step was to determine whether the species had been found in forestland habitats. This was difficult to ascertain with much certainty because habitat descriptions in most flora and herbarium sources were very general. Only species whose habitat descriptions included "forest," "woodland," or "riparian" were selected, resulting in 245 species.

Since 245 species was too many for a targeted monitoring list, it was necessary to rank the species' invasiveness. Some organizations in the Pacific states have adopted the expert-opinion approach described in Section 13.3 (Morse et al. 2004); these rankings were used where available. To avoid undue emphasis on highly localized or potential threats, species were also ranked according to available information about how widespread they were.

The ranking process resulted in a list of 95 species with a combined invasiveness and distribution ranking of medium to high. This list was sent to botanists and invasive plant experts in state and federal agencies in the three states for feedback on which species were important in their areas and how they would prioritize the lists. The steps yet to be completed are to develop regionalized lists (as opposed to a single list for all three states) of 30–40 species to monitor, assemble identification guides for reliable field sampling, and elicit support from cooperators for final implementation (or not).

13.4.3 INVASIVE PLANT INVENTORY RESULTS

The data used for the analyses in this chapter were collected on forestlands in California, Oregon, and Washington, USA, between 32.8° and 49.0° N latitude and 116.5° and 124.8° W longitude (Figure 13.1). Strong gradients in climate and forest vegetation occur across this region, ranging from moist Sitka spruce (*Picea sitchensis*) and redwood (*Sequoia sempervirens*) forests along the Pacific Ocean, oak (*Quercus*) woodlands in the interior valleys, and mountain hemlock (*Tsuga mertensiana*) and red fir (*Abies magnifica*) forests in the Cascade and Sierra Nevada ranges, to the Ponderosa pine (*Pinus ponderosa*) and pinyon–juniper (*P. monophylla–Juniperus occidentalis*) forests of the dry interior basins (Franklin and Dyrness 1973; Munz and Keck 1959). Some of these variations can be captured using geographic zones defined as *ecoregions* (Omernik 1987), shown in Figure 13.1.

13.4.3.1 Forest Health Monitoring Results

The forest health vegetation measurements were taken on 110 plots in Oregon in 2000 and 2001 and 91 plots in Washington in 2004 and 2005. Repeatability of sampling and some invasive species results from the Oregon plots have been presented elsewhere (Gray and Azuma 2005). Species were identified as nonnative to the United States based on the PLANTS database list (USDA NRCS 2000); species for which some populations were thought to be native (e.g., *Achillea millefolium*) were not included. Frequency points were summed for each species by assigning a score of 3 for each quadrat record, and a score of 1 for each additional subplot-search record, for a maximum possible 40 points per species per plot.

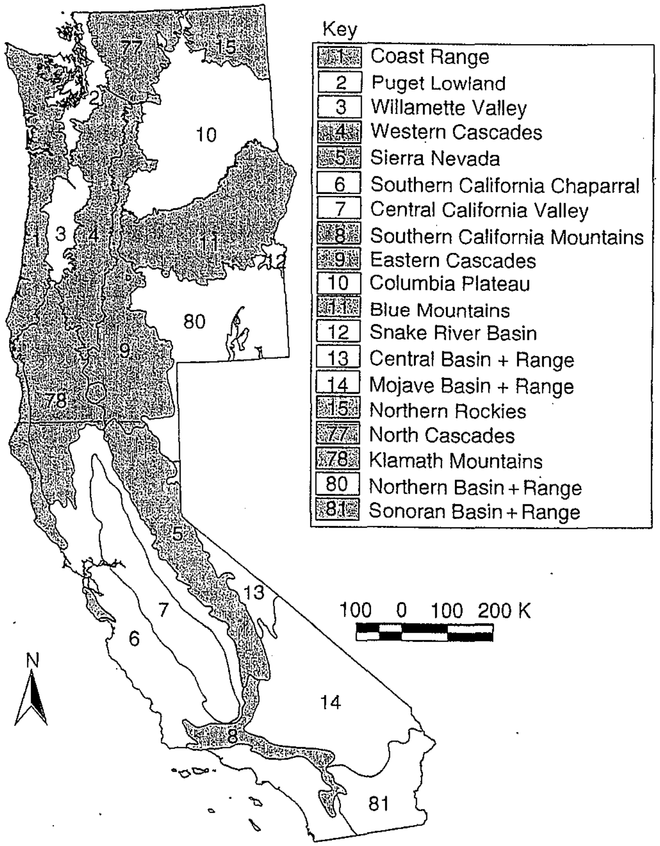

FIGURE 13.1 Map of California, Oregon, and Washington showing the ecoregions; ecoregions that are predominantly forestland sampled by the FIA program are shaded. (From Omernik, J.M., *Ann. Assoc. Am. Geogr.*, 77, 118, 1987.)

Plot-level measures of nonnative plant importance used proportions of nonnative to total species, and were calculated for species richness, summed frequency points, and summed cover. Data were grouped by ecoregion, forest type, and stand size class for analysis. Species summaries were compiled with plot counts, sums of frequency points, and means of plot-level cover from plots where species were recorded. One-way ANOVAs were performed to test for differences in nonnative proportion of species richness, frequency points, and total cover within different plot-level categories. The proportions were transformed with the arcsine square-root transformation to meet the normality requirements for ANOVA.

One or more nonnative species were recorded on 63% of all sampled plots in Oregon and Washington (Table 13.2). This percentage varied among ecoregions, from 100% for the Northern Basin and Range to 33% for the North Cascades; the latter was the only ecoregion where more than half the plots had no nonnative species recorded. The mean percentage of species on a plot that were nonnative differed by ecoregion ($p = .0006$), but was less than 10% except for the Willamette and Blue Mountains ecoregions. The nonnative proportions by ecoregion of summed frequency points ($p = .0001$) and plot-level cover ($p = .0061$) generally followed the same patterns found with species richness, but suggest some intriguing differences in the plot-level scale of dominance of nonnatives among ecoregions.

TABLE 13.2
Summary of Nonnative Plant Abundance by Ecoregion

Ecoregion	Number of Plots	Plots with Nonnatives Number	Plots with Nonnatives %	Number of Species	Nonnative Species Number	Nonnative Species %	Nonnative Percentages Frequency	Nonnative Percentages Cover
Coast Range	35	18	51.4	31.5	3.2	7.5	4.9	4.2
Puget Lowland	5	3	60.0	23.2	1.8	6.4	5.4	6.5
Willamette Valley	5	4	80.0	37.8	11.4	25.3	35.7	25.4
Western Cascades	41	25	61.0	36.5	2.4	6.1	3.3	3.8
Eastern Cascades	24	15	62.5	23.0	1.8	7.2	7.8	6.6
Blue Mountains	34	29	85.3	36.1	4.0	10.7	12.8	7.3
Northern Rockies	15	11	73.3	51.7	4.3	7.6	5.7	6.8
North Cascades	27	9	33.3	31.1	1.0	2.7	2.3	2.8
Klamath Mountains	9	5	55.6	28.8	1.3	5.2	1.0	0.7
Northern Basin and Range	6	6	100.0	22.2	1.3	6.7	5.8	3.5
Total	201	127	63.2					

Note: Table shows proportions of forest health plots with one or more nonnative species, and means of proportions of species, plot-level frequency points, and plot cover by nonnatives.

As expected, proportional richness, frequency, and cover of nonnative species differed by forest stand size class, a surrogate for time since stand-replacing disturbance ($p = .0001$, .0026, and .0019, respectively) (Figure 13.2). The highest nonnative proportions for species richness, frequency points, and cover were found in the smallest size classes, and the lowest proportions were found in the largest size classes. Both size class and ecoregion were significant factors when included in the same ANOVA model for proportional nonnative species richness ($p = .0001$), but the interaction was not significant, suggesting that the stand-size trend was similar across ecoregions.

The most important nonnative species on forestland in Oregon and Washington was *Bromus tectorum* (Table 13.3), a species well known in the region for its marked impacts on rangelands, and the most common nonnative species in the eastern Cascades, Blue Mountains, and Northern Basin and Range ecoregions. The next two most commonly encountered species (*Mycelis muralis* and *Tragopogon dubius*), however, have not received much attention on the region's invasive lists. *M. muralis* was the most common nonnative in the western and north Cascades ecoregions, while *T. dubius* was important in the Blue Mountains and northern Rockies

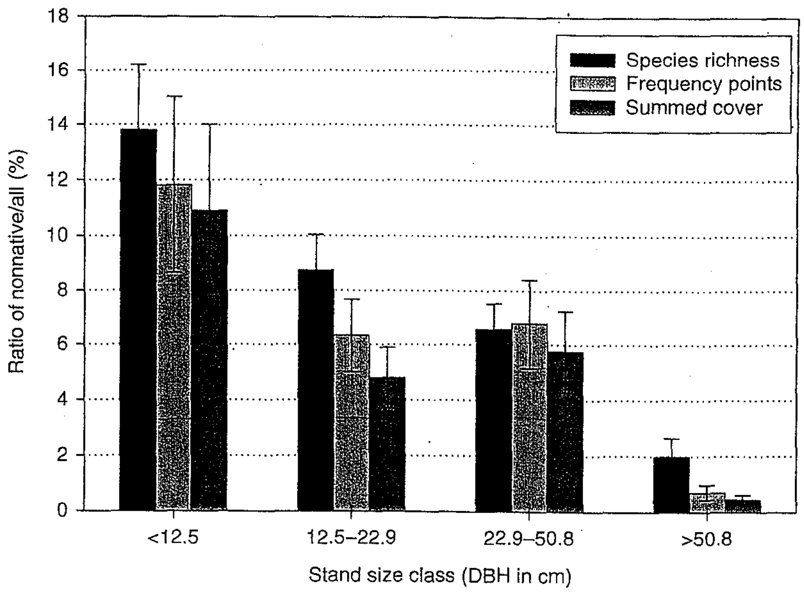

FIGURE 13.2 Importance of nonnative species by forest stand size class, as measured by the proportion of plot-level species richness, frequency points, and cover by nonnatives.

TABLE 13.3
Nonnative Species Found on Five or More Forest Health Plots

Scientific Name	Common Name	Number of Plots	Frequency Points	Cover	Number of Invasive Lists
B. tectorum	Cheatgrass	40	688	7.11	4
Mycelis muralis	Wall-lettuce	27	220	1.17	0
Tragopogon dubius	Yellow salsify	24	100	0.43	1
Hypericum perforatum	Common St. John's wort	21	156	1.73	6
Digitalis purpurea	Purple foxglove	20	124	1.89	3
Cirsium vulgare	Bull thistle	19	120	2.31	6
Dactylis glomerata	Orchard grass	18	102	1.55	2
Rumex acetosella	Common sheep sorrel	18	95	0.43	1
Hypochaeris radicata	Hairy catsear	17	139	3.18	3
Rubus laciniatus	Cutleaf blackberry	17	135	2.90	0
Senecio jacobaea	Stinking willie	16	86	1.09	7
Holcus lanatus	Common velvet grass	15	199	17.02	2
R. discolor	Himalayan blackberry	15	165	7.21	6
Leucanthemum vulgare	Oxeye daisy	14	96	0.88	4
Lactuca serriola	Prickly lettuce	14	88	0.25	2
Verbascum thapsus	Common mullein	12	52	0.43	4
Cynosurus echinatus	Bristly dogstail grass	10	56	0.98	2
Cirsium arvense	Canada thistle	10	53	4.18	7
Poa bulbosa	Bulbous bluegrass	9	85	3.27	0
Phleum pretense	Timothy	9	46	2.13	0
Cerastium fontanum	Common mouse-ear chickweed	8	18	0.31	0
Ranunculus repens	Creeping buttercup	8	13	0.83	2
Trifolium repens	White clover	7	28	0.60	0
Ilex aquifolium	English holly	7	13	1.43	4
B. japonicus	Japanese brome	6	69	0.38	0
Agrostis capillaries	Colonial bent-grass	6	33	6.67	0
Plantago lanceolata	Narrowleaf plantain	6	26	0.53	2
B. secalinus	Rye brome	5	56	1.01	0
Cytisus scoparius	Scotch broom	5	29	6.42	7
Lolium arundinaceum	Tall fescue	5	27	2.89	0
Torilis arvensis	Spreading hedge parsley	5	22	0.50	1
Agropyron cristatum	Crested wheatgrass	5	17	0.50	0

Note: Table shows the number of plots the species was recorded on (out of 201), sum of frequency points, mean characteristic cover at the plot level, and the number of invasive lists the species was found on (out of 8).

ecoregions. Some of the common nonnative species were found on several invasive species lists (e.g., *Hypericum perforatum* and *Cirsium vulgare*), but other prevalent species were on few or no lists (e.g., *Rubus laciniatus* and *Holcus lanatus*).

13.4.3.2 Standard Inventory Results

The Pacific states FIA program is investigating regional invasive species lists for inclusion in their standard plot inventory. However, the existing procedures of recording abundant, readily identifiable species provide valuable information for selected species and an indication of the kind of information that could be developed in the future for species selected to be part of an invasive list. Vegetation measurements were taken on 7558 forestland plots in California, Oregon, and Washington in 2001–2005. The same criteria were used to identify nonnative species in the database as with the forest health plot data. Plot-level frequencies were calculated as the proportion of measured subplots where each species occurred, and mean cover per species was calculated at the plot level. Nonnative occurrence was summarized by ecoregion, and mean frequency, mean cover, and plot counts were summarized for each species.

Logistic regression was used to assess relationships between the occurrence of selected nonnative species and climatic, topographic, and stand variables. The dependent variable was the odds ratio of species frequency, or the number of subplots occupied by a species over the total number of subplots sampled in the stand (GENMOD procedure, SAS Institute Inc. 1999). The analysis employed the same techniques that were used on older data from a portion of western Oregon (Gray 2005). The climate variables for this analysis were selected by intersecting plot locations with grids of the same climatic variables used by Ohmann and Gregory (2002), except that the base climate data were derived from the DAYMET model (Thornton et al. 1997). Regression models were built manually by including the strongest variable and assessing the strength of additional (uncorrelated, $r < .5$) variables. Additional variables were only included if the sign and parameter of existing variables did not change markedly and if visual examination of residuals indicated that the relationship was not determined by a few outliers.

The percentage of standard plots with nonnative species recorded was 26%, much lower than the 63% detected with the forest health plots (Table 13.2). This is not surprising given that only the most abundant species on a plot were recorded, ability of crews to identify composites and graminoids was limited, and some plots were sampled during suboptimal times of the year. Percentages of standard plots with nonnatives by ecoregion were more similar to those found on forest health plots in those ecoregions where the nonnatives were readily identifiable and tended to be dominant where found (e.g., 74% in the Willamette Valley and 58% in the Puget Lowland, where *R. discolor* is important). The most frequently recorded nonnative species—found on more than 100 standard plots—in descending order were *B. tectorum, R. discolor, C. vulgare, Hypericum perforatum, Digitalis purpurea*, and *Cynosurus echinatus*. Comparison of this list with the top of Table 13.3 indicates that some of the nonnative species were not sampled well with the standard plot protocols. Logistic regression models were developed for the most frequently recorded species.

The importance of climate and stand variables for describing nonnative frequency differed among species. *B. tectorum* was most frequently recorded in the Eastern Cascades and Blue Mountains ecoregions, but was well distributed in the eastern areas of the three Pacific states (Figure 13.3). In this region, the frequency of *B. tectorum* was primarily associated with low annual precipitation and low tree basal area (Table 13.4). In contrast, *Cirsium vulgare* was well distributed throughout the region, and its frequency was primarily associated with low basal area and secondarily associated with climate variables. *Cynosurus echinatus* was primarily found in the Klamath and southern California Chaparral ecoregions; its frequency was primarily associated with high annual temperatures and annual variation in precipitation. Most of the *D. purpurea* was recorded in the Coast Ranges; high annual vapor pressure and low tree basal area were the most important variables associated with its frequency. Although *H. perforatum* was well distributed in the region, its frequency was primarily associated with annual variation in precipitation and low elevations. *R. discolor* was well distributed in the

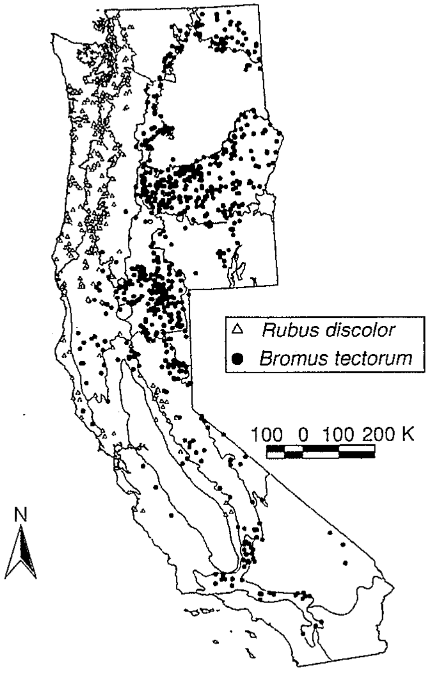

FIGURE 13.3 Distribution of the two most abundant nonnative species found on standard FIA plots, showing ecoregion outlines.

TABLE 13.4
Variables Selected for Regression Models of Species' Frequency, Their Parameter Estimates, and Significance of Parameter

Variables	Estimate	$F_{(1,7505)}$
B. tectorum ($N = 676$)		
Annual precipitation	−1.6969	960.7
Live tree basal area	−0.0143	707.1
Mean minimum temperature, December	−0.0533	55.5
C. vulgare ($N = 214$)		
Live tree basal area	−0.0141	764.7
CV of summer and winter precipitation	0.0808	181.9
Mean temperature, May to September	−0.1504	148.0
Cynosurus echinatus ($N = 111$)		
Annual temperature	0.3689	926.1
CV of summer and winter precipitation	0.0513	204.5
Aspect, cosine-transformed (SW = 0)	−0.3248	47.0

TABLE 13.4 (continued)
Variables Selected for Regression Models of Species' Frequency, Their Parameter Estimates, and Significance of Parameter

Variables	Estimate	$F_{(1,7505)}$
D. purpurea ($N = 146$)		
Annual vapor pressure	0.0102	2803.2
Live tree basal area	−0.0149	1667.0
Mean maximum temperature, August	−0.2490	798.7
H. perforatum ($N = 159$)		
CV of summer and winter precipitation	0.1570	801.0
Elevation above sea level	−0.0016	653.4
Live tree basal area	−0.0086	385.4
R. discolor ($N = 257$)		
Elevation above sea level	−0.0043	3355.3
Live tree basal area	−0.0081	531.4
Mean temperature, May to September	−0.0446	19.8

Note: P values for all variables were less than 0.0001.
N is the number of plots with each species (out of 7558).

western parts of the region (Figure 13.3), but was primarily associated with low elevations. Although some of these relationships were similar to those found in a portion of western Oregon (Gray 2005), this analysis described a broader range of conditions, and climate tended to be more important. Despite the variety of climate variables available for the models in both analyses, elevation was an important factor for several species, which may reflect proximity to large plant populations on nonforest areas of human habitation and agriculture.

13.5 CONCLUSIONS

The results from the strategic forest inventory data on nonnative invasive species in the Pacific coast states illustrate the power of having a comprehensive assessment with consistent protocols and sampling effort. The high percentages of plots with nonnative species could be quite surprising to policy makers and the general public, many of whom regard most of the regions' forestlands as rather pristine and consider invasive species to still be an emerging threat. The lack of bias in sample location and sampling effort provides high confidence in the representativeness of the data. Indeed, having a consistent plot size and spatial plot design is critical to plant sampling because the probability of species' detections and species richness is very sensitive to plot size and shape and is not easily comparable across different sampling schemes. Inventory results are applicable to the entire sample population of forestland in a region, and regional or subregional estimates (e.g., by county or owner group) and associated statistical errors can be readily calculated.

By systematically sampling all vascular plants, the forest health monitoring design not only provides a comprehensive evaluation of nonnative invasive species, but also makes it possible to assess the importance and potential impact of invasives on the rest of the species in a stand. Results also document the considerable importance of many nonnative species that for whatever reason have not made it onto many agencies' invasive lists. Although the protocol is not part of the base FIA program, the data could be quite valuable if fully implemented. Analyses based on the full forest health plot grid would have more information than the partial set presented here and could take greater advantage of the other stand data collected on the same plots (e.g., disturbance history, stand structure, and topography).

The standard FIA plot grid provides a much higher density of points with which to assess the distribution and abundance of nonnative invasive species. This sample can be used to identify and map large invasions and regional hotspots and explore plausible relationships among associated attributes, including disturbance and management history (Gray 2005). It is not logistically feasible, without substantial increases in funding, to sample a large number of (or all) plant species on the standard plot grid, however. Several FIA regions have developed lists of invasive species that crews are trained to detect on standard plots (Rudis et al. 2005). If adopted in the Pacific states, an invasive list would need to be limited to fewer than 40 species to be feasible without a large increase in resources. Unfortunately, selecting these lists given the current absence of reliable data on invasive plant abundance and impacts introduces the risk of missing important species or searching for species that are not a threat in forestland. Although the list could be adapted to new information, this temptation should be weighed against the value of collecting long-term trend data.

The FIA inventory sample will rarely be useful for monitoring programs whose primary goal is early detection of new invasions. With a standard grid density of one plot per 2430 ha and a sample area of 0.067 ha, inventory plots sample one-36,000th of the landscape. The number of plots falling in rare forest types or those that occupy small portions of the landscape (e.g., riparian stands) can be quite small, particularly for small regions (e.g., a county). Therefore, a species would have to be fairly widespread before many detections would occur on inventory plots. The inventory data do supplement existing knowledge of species distributions (indeed, new county records in Oregon have been established for some vouchered species from forest health plots). The primary value from strategic monitoring of nonnative invasive species is probably the unique ability to quantify the abundance and impact of multiple species of concern on our forestlands. This information could aid managers' efforts to allocate scarce resources, inform policy makers about the magnitude of the issue, and provide a baseline of forest condition with which to judge the success of future prevention and control efforts.

ACKNOWLEDGMENTS

Thanks to B. Shulz for protocol design and quality assurance; K. Barndt for invasive ranking; J. Morefield, J. Pijoan, J. Belsher-Howe, and C. Grenz for data collection; and S. Jovan for manuscript edits.

REFERENCES

Anonymous, Statement on criteria and indicators for the conservation and sustainable management of temperate and boreal forests, *J. For.*, 93, 18, 1995.

Bechtold, W.A. and Patterson, P.L., Eds. The enhanced Forest Inventory and Analysis program-national sampling design and estimation procedures. USDA For. Serv. Gen. Tech. Rep. SRS-80, USDA Forest Service, Asheville, NC, 2004.

Blossey, B., Before, during and after: The need for long-term monitoring in invasive plant species management, *Biol. Invasions*, 1, 301, 1999.

D'Antonio, C.M. and Vitousek, P.M., Biological invasions by exotic grasses, the grass/fire cycle, and global change, *Ann. Rev. Ecol. Syst.*, 23, 63, 1992.

Daubenmire, R., A canopy-coverage method of vegetational analysis, *Northwest Sci.*, 33, 43, 1959.

Delisle, F., Lavoie, C., Jean, M., and Lachance, D., Reconstructing the spread of invasive plants: Taking into account biases associated with herbarium specimens, *J. Biogeogr.*, 30, 1033, 2003.

Franklin, J.F. and Dyrness, C.T., Natural Vegetarian of Oregon and Washington, USDA For. Serv. Gen. Tech. Rep. PNW-8, USDA Forest Service, Portland, OR, 1973.

Gillespie, A.J.R., Rationale for a national annual forest inventory program, *J. For.*, 97, 16, 1999.

Gray, A., Eight nonnative plants in western Oregon forests: Associations with environment and management, *Environ. Monit. Assess.*, 100, 109, 2005.

Gray, A.N. and Azuma, D.L., Repeatability and implementation of a forest vegetation indicator, *Ecol. Indicat.*, 5, 57, 2005.

Heinz Center (H. John Heinz III Center for Science, Economics, and the Environment), *The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States*, Cambridge University Press, Cambridge, UK, 2002.

Hitchcock, C.L., Cronquist, A., Owenby, M., and Thompson, J.W., *Vascular Plants of the Pacific Northwest*, University of Washington Press, Seattle, Part 5, 1955.

Hurteau, M.D. and Briggs, R., Common yarrow *Achillea millefolium* L. plant fact sheet, United States Department of Agriculture, http://plants.usda.gov, 2003.

Mooney, H.A. and Hobbs, R.J.H., *Invasive Species in a Changing World*, Island Press, Washington, DC, 2000.

Morrison, M.L. and Marcot, B.G., An evaluation of resource inventory and monitoring program used in national forest planning, *Environ. Manage.*, 19, 147, 1995.

Morse, L.E., Randall, J.M., Benton, N., and Hiebert, R., An invasive species assessment protocol: Evaluating non-native plants for their impact on biodiversity, Version 1, NatureServe, Arlington, VA, http://www.natureserve.org/library/invasiveSpeciesAssessmentProtocol.pdf, 2004.

Mueller-Dombois, D. and Ellenberg, H., Aims and methods of vegetation ecology, Wiley, New York, 1974.

Munz, P.A. and Keck, D.D., *A California Flora*, University of California Press, Berkeley, CA, 1959.

National Research Council Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments, *Ecological Indicators for the Nation*, National Academy Press, Washington, DC, 2000.

Ohmann, J.L. and Gregory, M.J., Predictive mapping of forest composition and structure with direct gradient analysis and nearest neighbor imputation in coastal Oregon, U.S.A., *Can. J. For. Res.*, 32, 725, 2002.

Omernik, J.M., Ecoregions of the conterminous United States, Map (scale 1:7,500,000), *Ann. Assoc. Am. Geogr.*, 77, 118, 1987.

Parendes, L.A. and Jones, J.A., Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon, *Conserv. Biol.*, 14, 64, 2000.

Pimentel, D., Zuniga, R., and Morrison, D., Update on the environmental and economic costs associated with alien-invasive species in the United States, *Ecol. Econ.*, 52, 273, 2005.

Pyšek, P. and Hulme, P.E., Spatio-temporal dynamics of plant invasions: Linking pattern to process, *Ecoscience*, 12, 302, 2005.

Reichard, S. and Hamilton, C.W., Predicting invasions of woody plants introduced into North America, *Conserv. Biol.*, 11, 193, 1997.

Reichard, S. and White, P., Horticulture as a pathway of invasive plant introductions in the United States, *Bioscience*, 51, 103, 2001.

Ricciardi, A., Mack, R.N., Steiner, W.M., and Simberloff, D., Toward a global information system for invasive species, *Bioscience*, 50, 239, 2000.

Rudis, V.A., Gray, A., McWilliams, W., O'Brien, R., Olson, C., Oswalt, S., and Schulz, B., Regional monitoring of non-native plant invasions with the Forest Inventory and Analysis program, in *Proceedings of the Sixth Annual Forest Inventory and Analysis Symposium*, McRoberts, R.E., et al., Eds., USDA For. Serv. Gen. Tech. Rep. WO-70, USDA Forest Service, Washington, DC, 49, 2005, SAS Institute Inc., SAS/STAT User's Guide, Version 8, Carny, NC, 1999.

Schulz, B., Forest inventory and analysis: Vegetation indicator, FIA fact sheet series, USDA Forest Service, Washington, DC, http://fia.fs.fed.us/library/fact-sheets/p3-facsheets/vegetation.pdf, 2003.

Stapanian, M.A., Cline, S.P., and Cassell, D.A., Evaluation of a measurement method for forest vegetation in a large-scale ecological survey, *Env. Mon. Assess.*, 45, 237, 1997.

Stohlgren, T.J., Falkner, M.B., and Schell, L.D., A modified-Whittaker nested vegetation sampling method, Vegetation, 117, 113, 1995.

Thornton, P.E., Running, S.W., and White, M.A., Generating surfaces of daily meteorology variables over large regions of complex terrain, *J. Hydrol.*, 190, 214, 1997.

U.S. Census Bureau, Census 2000 gazetteer of counties of the United States, http://www.census.gov/tiger/tms/gazetteer/county2k.txt, 2000.

U.S. Executive Office, Executive Order 13112 regarding invasive species, Federal Register 64, 6183, Washington, DC.

USDA NRCS, *The PLANTS Database*, National Plant Data Center, Baton Rouge, LA, http://plants.usda.gov, 2000.

Vitousek, P.M., D'Antonio, C.M., Loope, L.L., and Westbrooks, R., Biological invasions as global environmental change, *Am. Sci.*, 84, 468, 1996.

Invasive Plants and Forest Ecosystems

Edited by

Ravinder Kumar Kohli
Shibu Jose
Harminder Pal Singh
Daizy Rani Batish

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2009 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works
Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-13: 978-1-4200-4337-2 (Hardcover)

This book contains information obtained from authentic and highly regarded sources Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The Authors and Publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (http://www.copyright.com/) or contact the Copyright Clearance Center, Inc. (CCC) 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Invasive plants and forest ecosystems / edited by Ravinder K. Kohli ... [et al.].
p. cm.
Includes bibliographical references and index.
ISBN-13: 978-1-4200-4337-2
ISBN-10: 1-4200-4337-4
1. Invasive plants. 2. Invasive plants--Ecology. 3. Forest ecology. I. Kohli, R. K. II. Title.

SB613.5.157 2009
634.9'65--dc22 2008008314

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Contents

SECTION I Invasion Ecology

SECTION II Ecological Impacts

SECTION III Management of Invasive Plants

SECTION IV Socioeconomic and Policy Aspects