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Repeatability and implementation of a forest vegetation indicator

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Abstract

The composition, diversity, and structure of vascular plants are important indicators of forest health. Changes in species diversity, structural diversity, and the abundance of non-native species are common national concerns, and are part of the international criteria for assessing sustainability of forestry practices. The vegetation indicator for the national Forest Inventory and Analysis (FIA) Program, USA, was designed to assess these issues. The objectives of this study were to: (1) assess the repeatability and practicality of the vegetation field techniques using independent measurements of 48 plots by two botanists and (2) examine the interpretation of forest health indicators from 2 years of data collected on 110 plots in the state of Oregon. Plant identification was similar for both botanists, with 80% of all plant species on the plot being identified to species, and another 14% identified to the genus level; the greatest problems were in dry forest types where plants had senesced by July. Agreement among botanists for species identification was 71% at the subplot level and 67% at the quadrat level, with many differences caused by plants being identified as closely related species, usually in the same genus. As a result, agreement between botanists on species richness and the abundance of non-native species was high, with correlation coefficients of 0.94 and 0.98, respectively. Quadrats detected only 20% of the species found from the subplot search, on average. Although botanists differed in their speed, 22% of subplot searches were completed within 15 min and 71% were completed within 30 min. Dramatic differences in patterns of plant diversity were found across the ecological regions of Oregon, with high plot richness and the highest species turnover among plots found in the Blue Mountains. Abundance of non-native species varied from 15% of the species in juniper (*Juniperus occidentalis* Hook.) stands to 1% in high-elevation conifer stands. The proportion of cover made up of non-native species was highest in juniper and Ponderosa pine (*Pinus ponderosa* P. & C. Lawson) forest types. Numbers of non-native species on a plot increased with the number of native species, but the relationship was weak ($R^2 = 0.09$). Results suggest that the vegetation indicator provides a robust and valuable tool for assessing forest health.

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1. Introduction

The composition, diversity, and structure of vascular plants are important indicators of ecosystem health (National Research Council Committee to

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Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments, 2000). Because vegetation is the source of primary production and a primary determinant of habitat for other organisms, changes in vegetation can affect many elements of an ecosystem. The composition and structure of plants can, therefore, serve as indicators of undesirable impacts to ecosystems and as indicators of the status of other organisms and ecosystem processes that are more difficult to measure. Reductions in the species diversity and structural diversity of forests, from management practices, pollution, or changes in the disturbance regime, have raised concerns for biodiversity, ecosystem function and risk of catastrophic wildfire (Halpern and Spies, 1995; Weatherspoon, 1996; Stapanian et al., 1998). The ongoing spread of invasive non-native plants into forests and rangelands can have significant economic impacts on land use and ecological impacts on ecosystem function (D'Antonio and Vitousek, 1992; Vitousek et al., 1996).

Before an indicator can be useful, the ability of a monitoring program to detect significant ecosystem change given measurement errors and natural fluctuation must be determined. Measurement errors in vegetation studies arise from observer variation in the identification of individual species and in estimates of species abundance (e.g., Sykes et al., 1983; Scott and Hallam, 2002). Natural variation in vegetation occurs from seasonal differences in plant size and developmental stage at the time of measurement and inter-annual differences in abundance related to climate (Kennedy and Addison, 1987; Ristau et al., 2001).

The vegetation indicator was developed by the Forest Health Monitoring (FHM) project (Cline et al., 1991; Alexander et al., 1993; Stapanian et al., 1997) and is implemented by the USDA Forest Service Forest Inventory and Analysis (FIA) Program. This indicator was designed to monitor changes in vertical vegetation structure as well as document hot spots of native diversity, areas of invasion by non-native plants, and effects of land use in the forests of the United States of America. There was initial recognition that the vegetation indicator was relevant to federal mandates regarding plant species diversity (e.g., the Endangered Species Act of 1973) and habitat diversity (e.g., the National Forest Management Act of 1972). More recently, the vegetation indicator has become directly relevant to the Santiago Criteria and

Indicators concerning conservation of biological diversity (e.g., number of forest-dependent species) and maintenance of forest ecosystem health and vitality (e.g., area of forest affected by competition from exotic species, area of forest with diminished biological components) (Anonymous, 1995).

The vegetation indicator is designed as a multi-scale, systematic sample of forest vegetation across the country. FHM field plots are located every 38,900 ha by subsampling one out of every 16 standard, systematically placed FIA plot locations, and are sampled on a 5 year cycle by measuring one-fifth of all plots across each state each year (Gillespie, 1999). The practicalities of the inventory, where the greatest expense is usually travel to field plots, lead to operational requirements that all measurements be completed in a day, and plots are visited only once per season (Stapanian et al., 1997). At each field location, the cover of different plant species is estimated with nested plots of different sizes (Mueller-Dombois and Ellenberg, 1974; Stohlgren et al., 1995). Some aspects of the repeatability of this indicator have been reported previously (Alexander et al., 1993; Stapanian et al., 1997), but we felt a new study was justified in order to evaluate: the repeatability of species identifications and non-native species in particular, in addition to species richness; repeatability across the range of forest communities found in a state, rather than from selected plots; and the utility and cost of a protocol addition which sampled larger areas with a nested subplot design.

The objectives of this study were to (1) evaluate the repeatability and practicality of frequency and abundance estimates using the vegetation indicator sampling protocol and (2) examine the interpretation of various indicators of forest health considering measurement repeatability and two years of data collected in the state of Oregon.

2. Methods

For the first objective, 48 plots were randomly selected from the plots systematically scheduled for measurement in 2000, pre-stratified based on previous measurements to represent a range of plant communities and understory abundance across the state of Oregon (Fig. 1). The forest zones ranged from moist

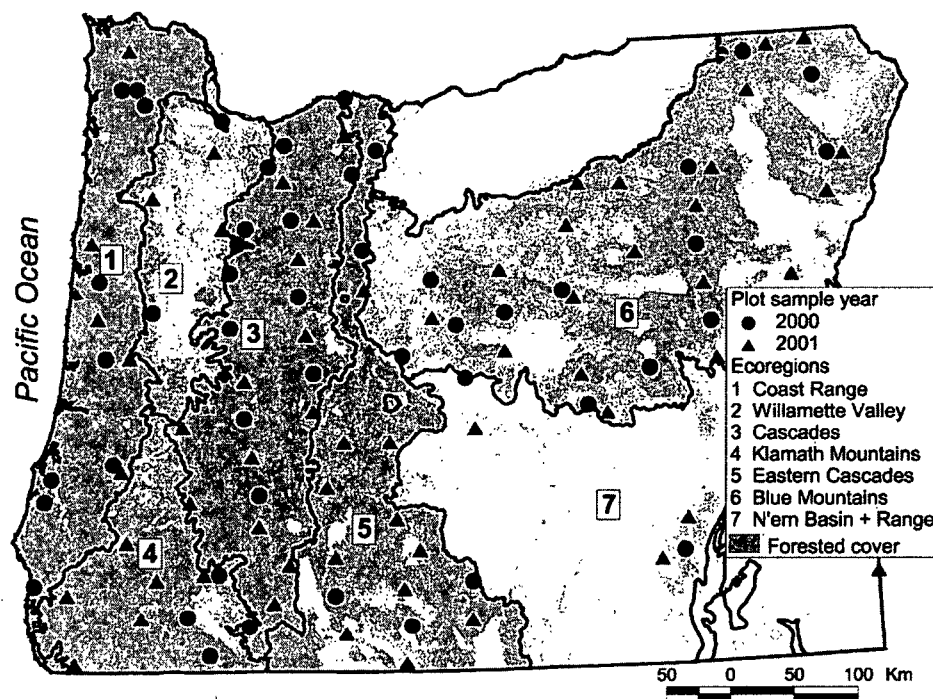


Fig. 1. Map of the state of Oregon, showing approximate plot locations for both sample years, ecoregions (Thorson et al., 2003), and forested areas classified by the NLCD project from satellite data (U.S. Geological Survey, 1999).

coastal, interior valley, and subalpine to pine and juniper woodland (Franklin and Dyrness, 1973). Seral stage ranged from young plantations to unmanaged mature forests.

The plot design and the majority of the field methods have been described previously (Stapanian et al., 1997). Each plot consisted 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 systematically located points, plots can sample multiple land use conditions and vegetation types, termed “condition classes”, which are distinguished in the field using an elaborate set of criteria. Within each subplot, three 1 m² quadrats were placed 4.57 m from subplot center along transects oriented at 30°, 150°, and 270° from true north. At each quadrat, cover was estimated for each species present in two layers, from 0 to 61 cm (0–2 ft), and from 61 to 183 cm (2–6 ft). Upon completion of the quadrat sampling, subplots were searched for up to 45 min, and any additional vascular plant species (regardless of height) encountered were recorded. Plants that botanists could

not confidently identify to species and were deemed to be potentially identifiable (e.g., were sufficiently developed, or had flowers or fruit) were collected off the subplot.

Two botanists sampled the same two randomly selected subplots and their component quadrats independently. Botanists are consistently distinguished throughout this paper as “botanist 1” and “botanist 2”. Botanists did not discuss species identification or cover estimates until all data had been collected. The botanist who sampled a quadrat first usually left pins marking the location of two of the corners in place (the national protocol calls for permanent marking where possible), and subplot boundaries were often delineated with temporary flagging. During the subplot search, botanists noted the number of species that had been recorded in each 15-min interval. Unknown samples were consolidated, labeled consistently and sent to the herbarium at Oregon State University for identification. Both botanists had University degrees in botany and at least two seasons’ botanical field experience in

Oregon. They spent 2 days with an expert in the flora of Oregon identifying plants (1 day each in different plant communities in eastern and western Oregon).

Analyses of repeatability consisted of constructing summary tables and statistics, graphs, and calculations of correlations between botanists. Species records were classified as to whether they were identified in the field to species, identified to genus, collected and sent in for identification, or identified as an unknown and not collected. Species were identified as non-native to the United States based on the PLANTS database list (USDA NRCS, 2000), except that one species for which only some populations are thought to be non-native was deemed “native” (*Achillea millefolium* L.). The metric for agreement between botanists was Sørensen’s index (SI) of similarity, calculated as $2 \times c / (a + b)$, where c is the number of species that were recorded by both botanists for a particular sample unit (e.g., a subplot, or a quadrat) and a and b are the total number recorded by each botanist, respectively (Mueller-Dombois and Ellenberg, 1974).

For the second objective, data from the repeatability study were combined with data collected the following year (2001) on the forested FHM plots scheduled for measurement that year across Oregon (62 plots). Field protocols were very similar to those described above, with the following differences: (1) all four subplots were sampled, unless the majority of a subplot qualified as non-forest or botanists did not have sufficient time to complete sampling; (2) quadrat species records were not divided into two layers; and (3) cover was estimated for species found during the subplot search using a standard cover protocol (Daubenmire, 1959). In addition, total foliar cover was estimated on each subplot for four different layers: 0–0.6, 0.6–1.8, 1.8–4.9, and >4.9 m. The mean subplot cover by layer for each plot sampled in 2001 was used to calculate foliage height diversity, an indicator of bird habitat structure (MacArthur and MacArthur, 1961). Plots were sampled by either of two experienced botanists. Several approaches were used to group data from similar vegetation types, including ecoregions (Thorson et al., 2003), forest type groups, stand size classes, and presence of multiple conditions on the plots. Forest type groups were combinations of forest types (Eyre, 1990) determined in the field with similar environmental

and vegetative characteristics. The “moist west-side conifer” group consisted of Douglas-fir (*Pseudotsuga menziesii* Mirbel (Franco)), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) forest types west of the Cascade crest. The “Klamath region” group consisted of Douglas-fir and Oregon white oak (*Quercus garryana* Dougl. ex Hook.) forest types in the Klamath ecoregion. The “high-elevation conifer” group consisted of noble fir (*Abies procera* Rehd.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) forest types. The “mesic east-side conifer” group consisted of Douglas-fir and white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) forest types east of the Cascade crest. Finally, the “Ponderosa pine” (*Pinus ponderosa* P. & C. Lawson) and “juniper” (*Juniperus occidentalis* Hook.) groups are named after their respective forest types.

Calculations of the proportional cover of non-native species used the quadrat cover data from plots sampled in both years. α , β , and γ diversity indices were calculated to describe stand-level species richness, species turnover along environmental gradients within landscapes, and landscape-level species richness, respectively (Mueller-Dombois and Ellenberg, 1974). Frequency “points” were summed for each species by assigning a score of three for each quadrat record, and a score of one for each additional subplot-search record, for a maximum possible 40 points per plot. One-way ANOVAs were calculated to test for differences in plot richness, non-native proportion of species richness, non-native proportion of total cover, and foliage height diversity (FHD) within each group. The proportions were transformed with the arcsine-square-root transformation prior to analysis to meet normality requirements. Fisher’s protected LSD was used to test for differences among means.

3. Results

3.1. Sampling repeatability

Species identification rates were similar for the two botanists, with about 67% of all of the plants recorded

Table 1

Numbers and proportions of subplot plant records by record type for each botanist

Type	Botanist 1		Botanist 2	
	N	%	N	%
Species identified in field	1822	66.2	1737	67.5
Collected identified to species	385	14.0	341	13.3
Genus identified in field	312	11.3	246	9.6
Collected identified to genus	105	3.8	89	3.5
Unknown not collected	101	3.7	136	5.3
Collected unidentified	24	0.9	22	0.9
Total	2746		2571	

on the 98 sampled subplots having been identified to species in the field (Table 1). Additionally, three-quarters of the records for species sent to the herbarium were identified to the species level, bringing the final proportions for both botanists to 80%. An additional 15 and 13% of the plant records were identified to the genus level for botanists 1 and 2, respectively. On most plots (83 and 88% for botanists 1 and 2, respectively), more than 70% of the plant records were identified at the species level (Table 2). Low identification rates tended to occur on the same plots for both botanists. Of the five plots with the lowest identification rates for each botanist, three plots were the same for both botanists, all of which occurred in eastern Oregon. Despite being sampled in mid-July, the botanists' comments suggest that two of these plots were fairly dry and many of the plants had senesced. The third plot was sampled in mid-August at high elevation in a Wilderness area, but sufficient time was not available to collect all of the unknown plants and return to camp before dark.

Table 2

Number of repeatability-study plots with plant records identified to species (in field or by herbarium) in different proportions

Percent identified	Botanist 1	Botanist 2
0–39.9	0	0
40–49.9	1	0
50–59.9	0	2
60–69.9	7	4
70–79.9	14	13
80–89.9	14	20
90–100	12	9
Total number of plots	48	48

Table 3

Agreement between botanists on the species identity by same sample unit

Sample unit	Botanist 1	Botanist 2	Match	SI (%)
Subplot	2746	2571	1877	70.6
Quadrat × layer	2093	1957	1339	66.1
Quadrat	1815	1699	1171	66.6

Numbers are the total number of records for each botanist, the number of records that matched for each sample unit, and Sørensen's index (SI).

Comparison of plant identification between botanists used all plant records, regardless of level of taxonomic identification. The overall percent agreement between botanists for species found on the subplots was 71% (Table 3). Agreement was somewhat lower for the layer within quadrat records. A slightly higher rate of agreement was found for quadrat records with layers combined, suggesting that the assignment of species into different layers was a small source of error. If analysis were restricted to records identified to the species level (field plus herbarium) only, the agreement rates for the three categories improve to 80, 72, and 72%, respectively. Inspection of the data suggested that the lack of agreement was caused by disagreement on species identification as well as detection of a species by one botanist and not another. Many disagreements in identification appeared to be between similar species (e.g., *Symphoricarpos albus* (L.) Blake versus *S. hesperius* G.N. Jones and *Equisetum arvense* L. versus *E. telmateia* Ehrh.) or between genus-level versus species-level identification (e.g., *Ranunculus* L. versus *R. repens* L. and *Collomia* Nutt. versus *C. grandiflora* Dougl. ex Lindl.).

Comparison of species richness found by each botanist, counting all plant records regardless of level of identification, found a high degree of agreement, with a correlation coefficient of 0.87 for estimates on quadrats, and a coefficient of 0.94 on subplot records (Fig. 2). Correlations between botanists were also high for non-native species, either as a proportion of valid species records per subplot ($r = 0.94$), or simply as numbers of non-native species ($r = 0.98$).

The correlation coefficient between botanists for cover estimates for the same species on each quadrat was only 0.76. Unfortunately, the comparison is not an accurate test of this aspect of the indicator, because it was discovered after the fact that the botanists were

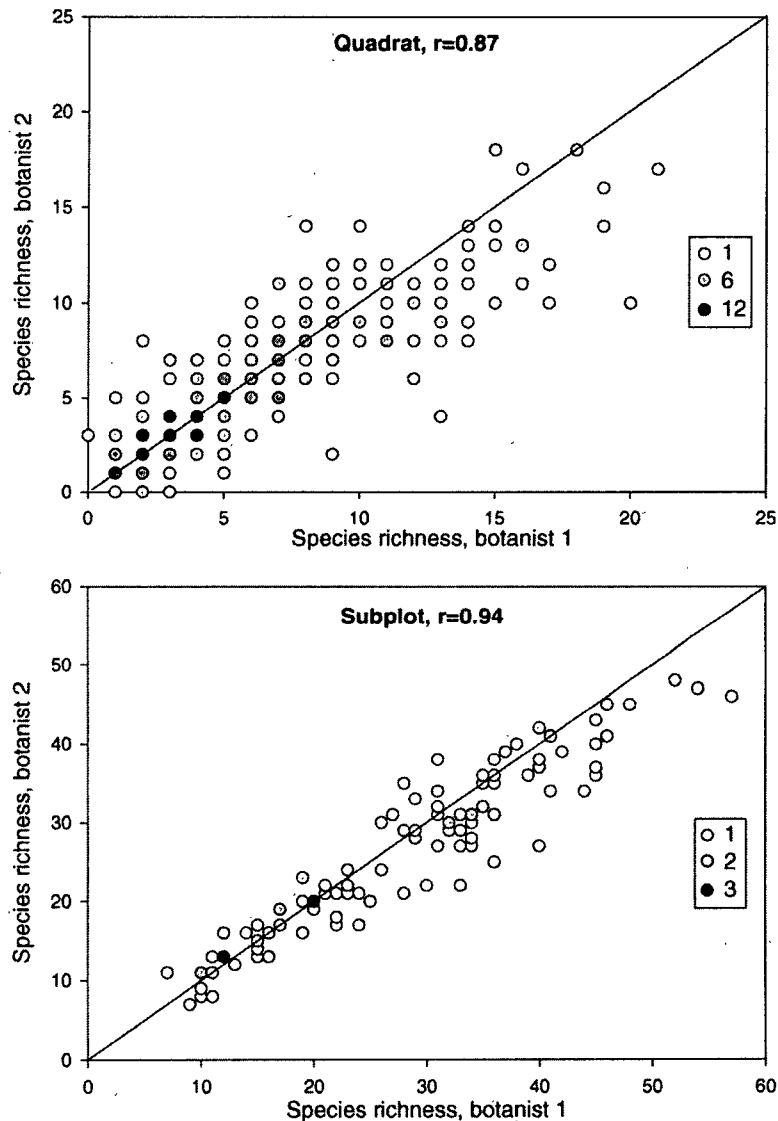


Fig. 2. Correlations of species richness between botanists, by subplot and by quadrat. Multiple instances of the same values are indicated by symbol shading (e.g., there were three subplots on which both botanists recorded 20 species), and the $y = x$ line is shown for reference.

inadvertently applying different protocols. One botanist was trained to discount any spaces in the canopy when vertically projecting cover of each species, while the other used the Daubenmire (1959) method, which includes all area within the outline of a plant's canopy when vertically projecting cover. Thus, botanists' records were in the same Braun-Blanquet (1965) cover classes 59% of the time, and within one cover class 94% of the time. Agreement among cover estimates

tended to be greatest for forbs and small shrubs and lowest for graminoids, large shrubs, and small trees.

3.2. Sampling effort

Examination of the time spent on the subplot search for species during the repeatability study indicated that both botanists found similar numbers species on a subplot in similar amounts of time, and rarely needed

the full 45 min to complete the subplot search. On average, 62% of the total number of species on a subplot were identified within 15 min and 94% within 30 min of beginning the search (Fig. 3). However, botanist 1 apparently stopped searching for additional species sooner than botanist 2, completing 36% of the subplot searches within 15 min, and 82% within 30 min, compared to 8 and 61% for botanist 2, respectively.

Of the 62 plots sampled during the inventory implementation in 2001, 52, 9, and 1 had data collected on four, three, and two subplots, respectively.

Five of the three-subplot plots were not completed because the botanist was not able to spend a substantial amount of additional time on the plot once the rest of the inventory crew had completed their tasks. The missing subplots on the other five plots were excluded by the sample protocol because they were primarily (or entirely) on non-forest land.

The number of species detected increased with sample area but did not entirely level off over the range of areas sampled (Fig. 4). The proportion of species sampled by 12 quadrats across a plot was slightly higher than the proportion of species sampled by an

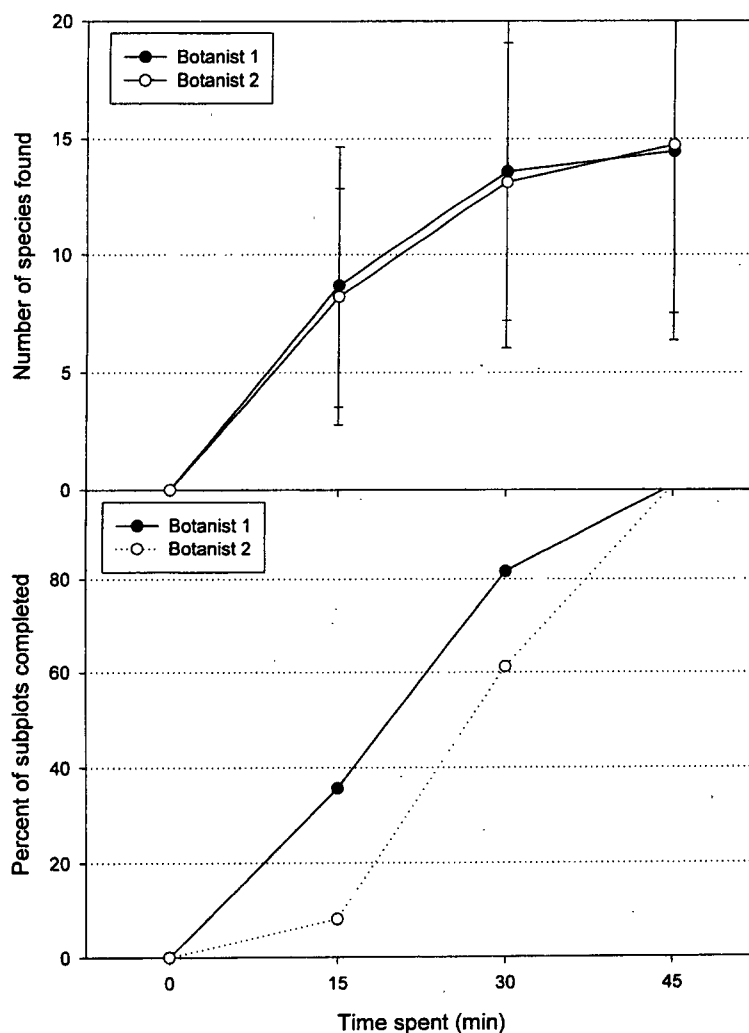


Fig. 3. Amount of time spent by each botanist on the subplot search, showing at top the cumulative number of species found within a particular window of time (mean and standard deviation), and at bottom the proportion of subplots that were completed within a given amount of time.

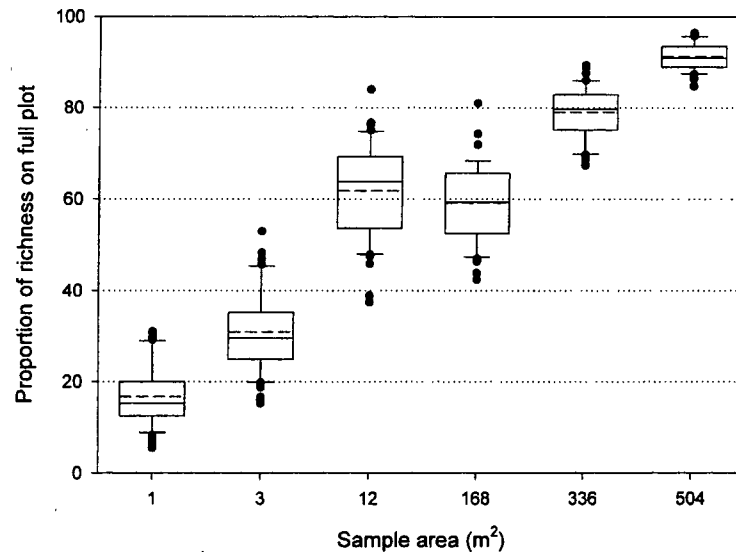


Fig. 4. Distribution of the proportion of total species richness recorded on sample units of different sizes for fully sampled plots (i.e., with four subplots). The ends of the boxes are the 25th and 75th percentiles; the solid lines and dashed lines within each box are the median and mean, respectively; the whiskers are the 10th and 90th percentiles; and individual records beyond 10th and 90th percentiles are shown as dots.

individual subplot, with a mean value of 62%. As would be expected, the species sampled with quadrats tended to be those present in greater abundance than those only found on the subplots outside quadrats, with mean subplot covers of 3.6 and 1.6%, respectively. The range of values decreased and the mean proportions increased to 79 and 91% for 2 and 3 subplots (336 and 504 m²), respectively.

3.3. Forest health indicators

Species–area curves were developed from the inventory implementation in 2001 for full-sampled (four-subplot) plots that did not contain multiple condition-classes. The curves tended to differ among forest type groups in their slopes, yet tended to have similar shapes for the larger subplot areas (Fig. 5). There were differences in the relative ranking of forest types at the 1 and 3 m² quadrat level compared to the larger plot sizes, indicating differences in species dominance at different spatial scales. For example, richness was relatively low at the quadrat scale for moist west-side conifer and Klamath forests but relatively high at the larger subplot scales.

The combined plot data from the two sample years revealed significant differences in diversity and

abundance of non-native species among ecoregions, forest types, stand size classes, and the number of conditions sampled on a plot (Table 4). Selected results of significant one-way ANOVAs within each category are presented in the text below; significantly different means are identified in Table 4. Examining the different categories, the highest plot-level richness (α diversity) was found in the Willamette Valley and Blue Mountains ecoregions ($F_{6,103} = 3.68$, $p = 0.0024$), the moist west-side, mesic east-side, and Ponderosa pine forest type groups ($F_{6,103} = 5.7$, $p < 0.0001$), and the plots that straddled multiple conditions ($F_{3,106} = 4.2$, $p = 0.0075$). However, species turnover among plots (β diversity) was highest in the Blue Mountains ecoregion and the Ponderosa pine forest type. The greatest differences in foliage height diversity were among stand size classes ($F_{3,58} = 4.78$, $p = 0.0048$), indicating a greater evenness of cover among layers (higher FHD) in larger stand size classes than in smaller ones. Differences in FHD were also found among ecoregions ($F_{6,55} = 3.83$, $p = 0.0029$) and forest types ($F_{5,56} = 4.06$, $p = 0.0033$), with the lowest values found in the Ponderosa pine forest type, where cover in most mature stands was concentrated in the overstory and understories were sparse. At least one non-native species was found on 71% of all the

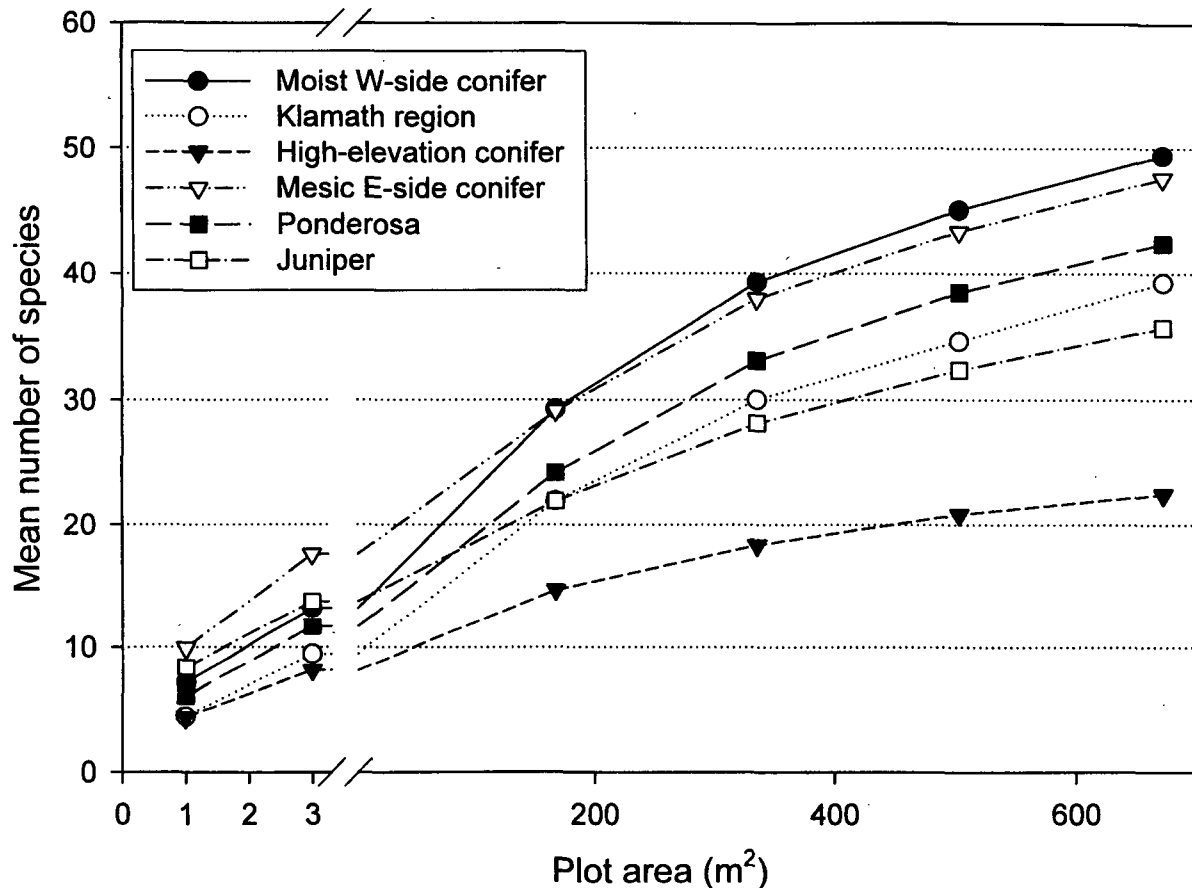


Fig. 5. Mean species–area curves by forest type group for plots without split conditions that were fully sampled (i.e., with four subplots). Note break in scale on x-axis, representing the difference in area from three quadrats to one subplot.

plots, and on more than half of the plots in each ecoregion, but differences were more pronounced by forest type group, with low proportions in high-elevation conifer types, and high in juniper types. Non-native species made up the greatest proportion of total species on the plots in the Willamette Valley and Blue Mountain ecoregions ($F_{6,103} = 2.89$, $p = 0.0120$), juniper forest type group ($F_{6,103} = 4.37$, $p = 0.0006$), <5" DBH stand size class ($F_{3,106} = 5.45$, $p = 0.0016$), and on plots with non-forest split conditions ($F_{3,106} = 3.32$, $p = 0.0226$). Trends among categories were similar for the proportion of total cover consisting of non-native species, although the maxima indicate that plots were sampled in several ecoregions where non-native species dominated the vegetation cover.

The most abundant non-native species in eastern Oregon by far was *Bromus tectorum*, with the most of the 10 most common species from the grass, mustard, or aster families (Table 5). Abundance of individual non-native species was lower in western Oregon and species were from a greater variety of families than in eastern Oregon, with *Rubus discolor* being the most abundant. Plot-level richness of non-native species was positively correlated with native species richness, although the variation in the relationship was high (Fig. 6).

4. Discussion

Eighty percent of the plant records in the repeatability study were identified to the species

Table 4

Summary of plant diversity and non-native abundance by ecoregion, forest type group, stand size class, and condition split on plots

	Plots		Diversity ($\alpha/\gamma/\beta$)	Plots w/Nnat (%)	ID'd species		Nnat (%) of cover		
	N	FHD			Rich	Nnat (%)	Med	Third q	Max
Ecoregion									
Coast Range	15	1.22 ^a	42.1/231/5.5	53.3	35.4	8.6	0.0	0.4	21.2 ^a
Willamette Valley	5	1.28 ^a	55.8 ^a /188/3.4	80.0	37.8	25.8 ^a	11.6	40.9	60.5 ^b
Western Cascades	25	1.28 ^a	45.8/381/8.3	68.0	37.4	7.4	0.0	0.1	52.4 ^a
Klamath Mountains	9	1.15	37.8/173/4.6	55.6	28.8	5.2 ^b	0.0	0.0	0.2 ^a
Eastern Cascades	18	1.19 ^a	27.2 ^b /250/9.2	55.6	19.0	5.5 ^b	0.0	1.6	45.0 ^a
Blue Mountains	32	0.99 ^b	46.9 ^a /562/12.0	87.5	34.5	12.1 ^a	1.4	11.4	70.8 ^c
N'ern Basin + Range	6	0.93 ^b	30.7 ^b /109/3.6	100.0	22.2	6.7	0.6	4.1	12.9 ^a
Forest type group									
Moist W-side conifer	38	1.25 ^a	50.7 ^a /501/9.9	76.3	40.4	11.7 ^b	0.0	3.1	60.5 ^b
Klamath region	9	1.15 ^a	37.8/173/4.6	55.6	28.8	5.2	0.0	0.0	0.2
High-elevation conifer	13	1.22 ^a	24.4 ^b /193/7.9	23.1	19.7	1.2 ^a	0.0	0.0	1.2 ^a
Mesic E-side conifer	10	1.13	51.2 ^a /284/5.5	80.0	39.6	8.0 ^b	0.1	1.9	6.8
Ponderosa pine	24	0.93 ^b	40.7 ^a /418/10.3	79.2	29.9	9.9 ^b	0.9	14.2	42.4 ^b
Juniper	13	1.09	32.3/202/6.3	100.0	20.2	14.5 ^b	9.6	16.8	70.8 ^c
Other	3	–	26.7/74/2.8	33.3	21.7	1.1	0.0	0.0	0.0
Stand size class									
<5" DBH	15	0.86 ^a	47.7/–/–	93.3	34.7	17.5 ^a	3.1	16.5	41.5
5–9" DBH	29	1.15 ^b	35.0/–/–	75.9	26.4	9.8 ^b	0.5	9.6	21.2
9–20" DBH	52	1.14 ^b	42.5/–/–	67.3	32.1	8.1 ^b	0.0	1.4	70.8
>20" DBH	14	1.27 ^b	45.1/–/–	50.0	38.5	3.4 ^b	0.0	0.1	1.6
Split conditions									
No split	93	1.13	39.2 ^a /–/–	68.8	29.8	8.0 ^a	0.0	1.6	70.8
Forested split	8	1.10	54.9 ^b /–/–	87.5	40.8	11.6	0.3	9.2	33.5
Large non-forest split	5	0.95	62.8 ^b /–/–	100	51.0	22.6 ^b	1.9	16.5	42.4
Small non-forest split	4	1.26	42.8/–/–	50	34.3	17.1	20.5	41.2	41.5

"Nnat" refers to non-native species, "Rich" refers to richness, and the median, third quartile, and maximum proportions of total cover on quadrats contributed by non-native species is shown. FHD refers to Foliage Height Diversity, and are only from plots sampled in 2001. Values within a category with different superscripts are significantly different ($p < 0.05$), except that tests on non-native proportional cover evaluated means among categories.

level. This seemingly low rate may partly be a result of the protocol, which instructed botanists to enter a record for any potential new species, regardless of its condition or likely identifiability. Plants may be unidentifiable for a variety of reasons, including either small size, early stage of development, lack of flowers or fruits, senescence, or damage (e.g., browsing). There is little comparable information in the literature, although in one study 2.3% of the plant records were not identified to species, and most of those were non-vascular plants (Scott and Hallam, 2002). It is not clear if most other studies only record plants that meet some criteria for identifiability or not. Conversely, since few botanical studies cover a region as diverse as this one, observers can often sample sites at the time of year when most plants are identifiable, and may be familiar

enough with the local flora to hazard species-level guesses for most plants. In this study, most of the records not identified to species were identified to genus, potentially allowing some resolution of identity at future measurement cycles.

Agreement among botanists differed by sample unit, but the rates of 66–71% (as calculated with Sørensen's index) were comparable to other studies, although different metrics are often used to calculate agreement. A study of relevés of vascular plants in meadows, bogs, and clear-cuts in central Europe estimated "pseudo-turnover" between two observers of 13% (Lepš and Hardincová, 1992), which is mathematically equivalent to a SI of $100 - 13 = 87\%$. A study comparing censuses of vascular plants on forested islands 0.03–2.19 ha in size in northern

Table 5
Ten most abundant species from plots on each side (east vs. west) of the Cascade range in Oregon

Species	Family	Points	Plots (N)
East-side			
<i>Bromus tectorum</i>	Poaceae	364	28
<i>Holosteum umbellatum</i>	Caryophyllaceae	109	4
<i>Draba verna</i>	Brassicaceae	56	3
<i>Tragopogon dubius</i>	Asteraceae	51	12
<i>Alyssum desertorum</i>	Brassicaceae	50	1
<i>Alyssum alyssoides</i>	Brassicaceae	46	2
<i>Rumex acetosella</i>	Polygonaceae	41	7
<i>Vulpia bromoides</i>	Poaceae	34	3
<i>Bromus secalinus</i>	Poaceae	33	3
<i>Taraxacum officinale</i>	Asteraceae	32	9
<i>Poa pratensis</i>	Poaceae	32	5
West-side			
<i>Rubus discolor</i>	Rosaceae	82	11
<i>Holcus lanatus</i>	Poaceae	74	11
<i>Hypericum perforatum</i>	Clusiaceae	62	12
<i>Rubus laciniatus</i>	Rosaceae	50	8
<i>Digitalis purpurea</i>	Scrophulariaceae	42	9
<i>Geranium lucidum</i>	Geraniaceae	40	1
<i>Mycelis muralis</i>	Asteraceae	39	9
<i>Leucanthemum vulgare</i>	Asteraceae	39	9
<i>Cynosurus echinatus</i>	Poaceae	37	9
<i>Hypochaeris radicata</i>	Asteraceae	35	10

Points are frequency points. Nomenclature follows USDA NRCS (2000).

Europe found an average pseudo-turnover rate of 11.4% (Nilsson and Nilsson, 1985), for an SI of 88.6%. However, each estimate was made by a group consisting of two people, with considerable effort per sample unit. Other studies evaluate agreement as the number of species recorded on both observer's lists divided by the total number of species on both lists combined. Quality assurance evaluation of monitoring plots for vascular and non-vascular plant species on a range of vegetation types in the United Kingdom estimated a mean agreement rate of 56.8% (Scott and Hallam, 2002), while a study of sets of quadrats in two woodlands in the United Kingdom found mean rates (and ranges) of 49.2% (38–60%) and 60.2% (56–66%) (Kirby et al., 1986). Applying the same calculation to this study provides comparable rates of 66.5, 55.9, and 56.6% for the different sample units listed from top to bottom in Table 3.

The causes of differences in species agreement vary among studies. In this study, placement of quadrat frames was probably not a large source of error, but

inclusion of species within the boundary of the larger subplot likely was. In addition, a species may have been detected by one botanist but not by the other, or may have been detected by both, but given a different identity. Given the much greater agreement between botanists on species richness, the latter is likely the greatest source of error in species agreement. Quantification of this "misidentification rate" is difficult, but at least one study estimated it to be much lower than observers over-looking species (although the placement of a large number of small quadrats was a factor in that study) (Scott and Hallam, 2002). Examination of the quadrat data in this study suggested many instances where plants were being placed in the same genus, but with different species calls, and others where one botanist felt confident enough to identify to the species level, while the other identified only to genus. The issues concerning phenology and the wide range of plant communities sampled that were discussed above may be largely responsible for those differences. In addition, several investigators have noted that most of the misidentifications are relatively predictable, happening among species that are difficult to distinguish, especially when all plant parts are not available (e.g., fruits or flowers).

Calculations of species richness were highly correlated between the data collected by the different botanists, a result found in other studies (Lepš and Hardincová, 1992; Stapanian et al., 1997; Scott and Hallam, 2002). In addition, this study found that calculations of frequency of non-native species were also highly correlated between botanists, probably because the species misidentifications were among closely related species. Therefore, despite the problems in identification presented by a portion of the species, many of the metrics used for the vegetation indicator are quite robust.

We were not able to evaluate differences in cover estimates between botanists because of ambiguity in the protocol about the cover-estimation technique to be used. This problem was rectified for the 2001 and subsequent field seasons by adopting the well-documented cover method developed by Daubenmire (1959). It is curious that most vegetation studies neglect to specify the methods used to estimate cover, especially given the well-documented variability in cover estimates (e.g., Sykes et al., 1983; Kennedy and

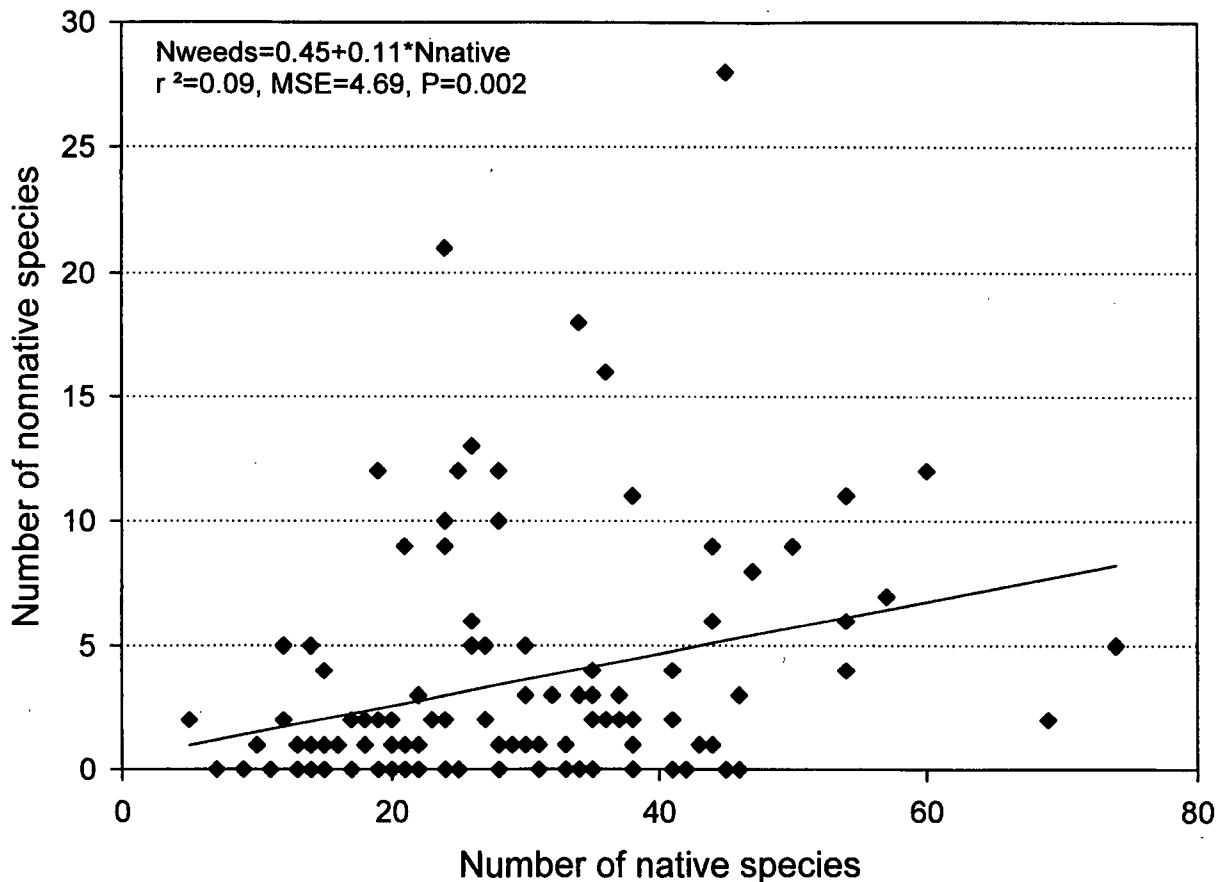


Fig. 6. Association between numbers of non-native species and numbers of native species on a plot, with linear regression equation and statistics.

Addison, 1987; van Hees and Mead, 2000). Nevertheless, careful documentation of cover protocols, rules for plants with different physiognomies, training, and calibration among estimators can greatly reduce the variability in such estimates (Huenneke et al., 2001).

It is well known that larger plot sizes and greater effort will increase the number of species recorded for an area (e.g., Nilsson and Nilsson, 1985; Stohlgren et al., 1995). While greater information is always desirable, the greatest expense in a regional inventory is travel to plot locations, so operational requirements are that all measurements (usually) be completed in a day, and plots are only visited once in a season (Stapanian et al., 1997). For a given sample area, spatially dispersing sample units and nesting different sample sizes captures more of the within-site variation

and allows the construction of a species–area curve, an important vegetation attribute which captures spatial patterns of species richness that differ among communities (Mueller-Dombois and Ellenberg, 1974; Stohlgren et al., 1995). Multiple sample units also allow the calculation of species frequency, which is a more seasonally stable and less error-prone estimate of abundance than cover alone. There are no universally accepted criteria for the selection of minimum sample area, although Mueller-Dombois and Ellenberg (1974) noted that the size corresponding to a 90% sample of community species richness has been commonly used. The number of species sampled with 12 quadrats dispersed across the plot in this study was variable, relatively low, and tended to capture the more abundant species present. Thus, the larger subplot sample maybe a better approach for detecting

early changes in community composition and invasions of non-native species. The richness sampled with three subplots averaged 91% and never fell below 84% of the richness sampled with all four. The times recorded in the repeatability study and the implementation sample the subsequent year suggest that botanists are generally able to complete the current design in a day. However, the effort required increases with the number of species found, and preliminary results with the indicator in South Carolina suggest that quadrat and subplot-level richness is higher on average than that recorded across Oregon (B. Schulz, USDA Forest Service FIA program vegetation indicator lead, personal communication).

The analysis of basic attributes of two-fifths of the full vegetation indicator data (2 years out of a 5-year plot measurement cycle) for Oregon reveals many important aspects of forest ecosystems in the state. Comparisons across this range of plant communities are usually not possible because consistent sample protocols across large regions are rare. Species richness and landscape diversity metrics differed substantially among ecoregions and forest type groups. β diversity tended to be higher in the drier mountains of the eastern part of the state than in the west, but except for the Blue Mountains, α diversity tended to be lower. Canopy structural diversity, as measured by FHD, differed among stand diameter classes, which would be expected because foliage would be skewed towards the lowest layers in the small stand size classes. The forest types with the lowest FHD's tended to either have sparse understory layers (Ponderosa pine) or be relatively short, with little cover in the upper layers (juniper). The frequency of plots with non-native species, and the proportion of species richness which was non-native, varied dramatically among stand size classes, forest types, and ecoregions. Results indicate that non-native species made up more than 10% of the total vegetation cover on more than 25% of the plots in several categories. Community dominance by non-native species appears to be greatest in the drier eastern forest types (Ponderosa pine and juniper), but instances of high dominance also occur in the moist western forest types. As has been found in other studies, the number of non-native species on a plot is positively correlated with the number of native species present (Stohlgren et al., 1999). This information on

the forests of Oregon is unique and valuable, but a larger sample size will be needed to examine interactions of forest attributes (e.g., stand size class by forest type) on indicator response (e.g., Stapanian et al., 1998; Gray, in press).

The forest health vegetation indicator data in their basic form address some of the Santiago Declaration's criteria and indicators for sustainable forestry (Anonymous, 1995). Once a cycle of plot measurements is available to serve as a baseline, remeasurement of plots on a 5-year cycle will allow determination of trends and investigation of their causes. Richness and diversity are important ecosystem attributes (Dale and Beyeler, 2001), but there are several options to further develop the vegetation indicator. Data from relatively pristine forests in reserves (either from indicator plots, focused studies, or historic surveys) could be used to determine the range of natural variation of vegetation conditions, which could be compared to similar forest types outside reserves (Riitters et al., 1992). Existing information or new analyses could identify individual species of particular importance, that function as keystone species in particular ecosystems or that can serve as indicators of disturbance or degradation (Dale et al., 2002; Slik et al., 2003). Examination of community composition as a whole could be used to develop indices of plant community integrity (DeKeyser et al., 2003).

The forest health vegetation indicator has been under development for several years, with ongoing concerns about the expense and logistical difficulties of carrying out a rigorous survey of vascular plant species. If implemented, it would be the first statistically sound, quality-assured, multi-scale assessment of native and exotic plant diversity in the forests of the United States. There is no comparable information available. Because of the probability-based inventory design, the results apply unequivocally to the entire population of forested ecosystems (Olsen et al., 1999). A quality-assurance system consisting of remeasurement of randomly selected plots by expert botanists has been developed that will provide current information on the quality of the information provided by the indicator.

Focused research is valuable for investigating causation, but application of results is always limited to some nebulous population of stands similar to those used in the study. Monitoring for specific attributes

(e.g., a set of non-native species) could no doubt be done more efficiently with stratified sampling, but no single design would be optimal for a variety of objectives (e.g., native and non-native species, vegetation structure, community structure), and extrapolation of results to the population of all forested ecosystems would always depend on some assumptions and additional, often questionable data (e.g., maps of ecosystem distribution). Instead, the availability of data on vascular plant composition from well-distributed, permanently established plots on a regular remeasurement cycle will be valuable to researchers and managers across the nation. Several government agencies in the western U.S. are currently implementing the indicator on an increased density of inventory plots for special assessments. Implementing the indicator across all lands would provide a more comprehensive evaluation than sampling only the forested lands that are FIA's mandate; multi-agency, multi-resource inventories have been discussed and tested (e.g., Goebel et al., 1998; Olsen et al., 1999) but additional work would be necessary before implementation could occur.

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