Chapter 8: Invasive Plants

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Introduction

Nonnative invasive plants are a potential threat to the sustainability of Western U.S. forests. In the implementation of the Montréal Process Criteria and Indicators, invasive plants are recognized as affecting native species diversity (indicator 1.6), the status of endangered species (indicator 1.7), and the area of forest outside the range of natural variation (indicator 3.15) (Robertson et al. 2011).[2] Invasive plants can affect forest ecosystems by reducing the abundance and functions of native species, and they can affect nutrient cycling and the fitness of native plants and animals (Pyšek et al. 2012). Invasive plants can also change the probability of other disturbances, most notably increasing the probability of wildfire (D'Antonio and Vitousek 1992). Because many invasive species are well suited to disturbed and early-seral vegetation conditions, this can set up a positive feedback loop that further degrades native ecosystems. It is estimated that invasive plants cost the U.S. economy $34 billion per year in lost productivity and control and eradication costs, primarily on agricultural lands (Pimentel et al. 2005); a study of selected plants in Oregon forests suggested a cost of $80 million per year (The Research Group 2014).

This chapter assesses the abundance of nonnative plants in Western U.S. forests, draws from the literature to discuss control and eradication efforts and species' potential impact on forest sustainability, and evaluates options for continued monitoring and understanding of their role in our forests.

U.S. Federal Executive Order 11312 on Invasive Species (Feb. 8, 1999; Executive Order 1999) defines as "invasive" a species alien to a particular ecosystem whose introduction causes or is likely to cause economic or environmental harm, or harm to human health (Moser et al. 2009). Although many nonnative species were introduced accidentally (e.g., as contaminants in imported seed), others were purposely introduced to provide benefits in particular conditions (e.g., agricultural crops or erosion control) but are deemed invasive when they have unanticipated negative impacts or become established in other environments. Identifying which

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[2] Indicator numbers follow the system established in Robertson et al. (2011), in which the first numeral refers to the criterion and the second numeral refers to the indicator. This is a different numbering system than that used by the Montréal Process, although indicator titles are **identical.**

Identifying which plants are nonnative is straightforward, but prioritizing which are invasive depends on the values of interest.

species are "alien" or nonnative is relatively straightforward. Defining and prioritizing plants that are causing or are likely to cause harm depends to a large degree on the ecosystem and values of interest. For example, state noxious weed lists, which require control efforts for listed species, tend to focus on protecting agricultural production, with less emphasis on native forest and nonforest vegetation types. In contrast, organizations like The Nature Conservancy have developed specific criteria for prioritizing invasives based on ecological impact, current distribution, current trend, and management difficulty (Morse et al. 2004).

Usually, an introduction occurs with a few organisms in a limited geographical area, particularly if the introduction is unintentional. Although there are some areas where introductions are more likely than others (e.g., commercial ports, transportation corridors), detecting early introductions is difficult simply because few organisms are present, and the taxonomic expertise to recognize them may be rare (Hulme et al. 2006). Once established, plant invasions tend to follow a logistic population growth curve (Radosevich et al. 2005). However, many species may remain at low levels for years or decades and seem innocuous before they accumulate enough in population or something triggers an eruptive phase (e.g., Rosenthal et al. 2008). Or they may remain at a low frequency indefinitely. Although finding invasive plants becomes easier as they expand, eradicating them becomes more costly. Because of the low density of samples, broad-scale strategic forest monitoring will not be useful for detecting and characterizing invasive populations when they are rare. However, these monitoring efforts may help to identify the location and extent of existing infestations of invasive species and facilitate management responses.

Distribution and Abundance of Invasive Plants in Western U.S. Forests

Datasets

The only comprehensive and consistent source of information on the location and severity of plant invasions in Western U.S. forests are the inventories conducted by the Forest Inventory and Analysis program (FIA) (Gray et al. 2012). FIA samples the nation's lands with a base grid of points at a density of one per 2400 ha. Each year's samples are evenly distributed; under the base cycle in the West, they are remeasured every 10 years (Bechtold and Patterson 2005). Vegetation on grid points falling on forest land (≥10 percent current or recent cover of tree species and ≥0.4 ha) are measured with four 7.3-m-radius (168 m^2) subplots. Because the grid points are systematically located, some plots straddle stand boundaries, roads, and other nonforest conditions (nonforest has either never had 10 percent cover of tree species or is being currently mowed or otherwise managed for nonforest uses). Inventory crews note the occurrence and type of silvicultural activity or natural disturbance that affected vegetation on the plot since the previous measurement. In the Western United States, FIA crews use the "phase 2" (P2) vegetation protocol to record the identity and cover of the four most abundant species per life form (tree, shrub, forb, graminoid) present on each forested subplot with at least 3 percent areal cover[3] (USDA FS 2018). In addition, the presence in any amount of species on targeted invasive lists is also recorded in most states. In interior Western States, the invasive lists consist of each state government's noxious weed list; in Pacific states, the lists were compiled from literature and consultation with clients and experts to produce a short list of species of greatest concern (the protocol has not been implemented in California, Oregon, or Washington to date). In addition, FIA has a "phase 3" (P3) vegetation indicator protocol in which experienced botanists conduct a full sample of all vascular plants, during the peak phenological period, on a subset of plots (Schulz et al. 2009); the protocol has been implemented only in a few states for a few years in the West. The National Forest System's Northern Region (which includes Montana and northern Idaho), Pacific Southwest Region (which includes California), Pacific Northwest Region (Oregon and Washington), and Alaska Region also fund data collection on nonforest plots using the same FIA protocols and plot grid. Some national forests also fund data collection on a greater density of plots. FIA data and tools to query them are publicly available (https://www.fia.fs.fed.us/tools-data/).

The regional-scale sample and plot-level cover estimates enable calculation of the land area covered by a particular species as well as the mean cover for any domain of interest (e.g., forest type). This estimate of area covered is different than commonly presented statistics of area "infested" by invasive plants, which is based on delineated patches where invasive plant cover may range between a few to 100 percent. Given the number of different criteria that classify nonnative plants as invasive, we decided to analyze the abundance and distribution of any nonnative plant recorded in FIA inventories. We used the nonnative criteria in the PLANTS database (USDA NRCS 2019), which are defined for broad geographic areas (e.g., the conterminous United States), and treated species known to have mixed non-native/native genotypes (e.g., common yarrow) as native. Because invasive lists differ within and across regions, the analyses presented here rely primarily on the

[3] The 3 percent cover and four most abundant criteria result in underestimating species occurrence, particularly of species that typically occur at low densities; an analysis of older data with no maximum number limit indicated that 6.9 percent of species records would be missed, or 2.1 percent of the plant cover, by recording only the four most abundant per life form (unpublished analysis).

P2 dominant species sample and identify only the species found on one or more invasive lists to provide a sense of those identified as problematic. Most of the results present cover measurements taken in the most recent 10-year measurement cycle, 2007–2016. The change estimates are based on when a state began annual inventory and the 10-year intervals the plots have been remeasured since then, referred to generally as “change from the 2000s to 2010s”; for example, 2001–2006 to 2011–2016 for Arizona. For the states with available P3 data (collected irregularly 2001–2010), we compare estimates of nonnative abundance with those from the P2 sample. We report on nonnative plants as a whole and note those species that are found on one or more FIA invasive plant lists. From the cover estimates of nonnative plants on each plot, we calculate the land area covered, the mean cover for the population (referred to as “ground cover”), and the “relative cover,” calculated as the sum of nonnative species’ cover divided by the sum of all understory (non-tree) plant cover. Standard errors for the estimates reflect inventory sample error. Independent estimates can be compared by multiplying the standard error (SE) by 1.96, with values outside that range considered significantly different. We also provide some estimates of the proportion of plots occupied in the P2-P3 comparison.

Results

Cover of nonnative plants in forests differed dramatically by region and state within region. Nonnative plant cover was highest in Hawaii at 46 ± 2.5 percent (percentage ground cover ± SE) and lowest in coastal Alaska at 0.01 ± 0.01 percent (table 8.1). Nonnative cover was significantly lower in Rocky Mountain (RM) states than in Pacific Coast (PC) states. New Mexico had the lowest cover within RM states at 0.15 ± 0.02 percent, while Nevada had the highest at 1.4 ± 0.14 percent. Within PC states, nonnative cover was highest in California at 5.2 ± 0.19 percent, with cover in both Oregon and Washington at 2.2 ± 0.12 percent. Relative cover of nonnatives was substantially higher than ground cover, particularly in sparsely vegetated more arid states where the sum of all plant cover is substantially less than 100 percent. For example, relative cover of nonnatives was 20 ± 1.7 percent in Nevada and 17 ± 0.55 percent in California (table 8.1).

Cheatgrass covers 480 thousand hectares of forestland in the Western United States.

Cheatgrass was by far the most abundant species in western forests, covering 1.2 million ac [480 thousand ha], or 0.49 ± 0.017 percent cover of all forested land in the conterminous Western United States (fig. 8.1). The area of RM forest land occupied by the other 195 nonnative species found there was less than one-fifth the area of cheatgrass (table 8.2). Several of the most abundant nonnatives in RM states were grasses that were not on any of the individual states’ noxious weed lists, including timothy, crested wheatgrass, red brome, and orchardgrass. Of the 15 plants with the

Table 8.1—Forest land area and proportion covered by nonnative plants as total area and percentage (ground), and percentage of total vegetation cover (relative), from Forest Inventory and Analysis sample 2007–2016

		Nonnative cover					
Region/state	**Forest land**	**Total**	**SE**	**Ground**	**SE**	**Relative**	**SE**
	Thousand hectares			*Percent*			
Rocky Mountain:							
Arizona	7449	46.8	4.9	0.63	0.06	4.82	0.48
Colorado	9229	65.2	5.8	0.71	0.06	3.15	0.27
Idaho	8737	51.9	4.5	0.59	0.05	2.10	0.18
Montana	10 487	124.7	7.0	1.19	0.07	4.04	0.22
Nevada	4257	58.8	5.9	1.38	0.14	20.31	1.69
New Mexico	9956	15.2	2.4	0.15	0.02	1.36	0.22
Utah	7335	59.6	5.5	0.81	0.07	8.21	0.71
Wyoming	4226	39.8	5.8	0.94	0.13	3.31	0.46
Rocky Mountain total	61 675	461.9	15.2	0.75	0.02	3.87	0.12
Pacific Coast							
California	12 894	1647.8	64.1	5.17	0.19	16.95	0.55
Oregon	12 002	639.4	29.9	2.16	0.10	5.52	0.25
Washington	8966	501.0	28.3	2.26	0.13	3.91	0.21
Pacific Coast total	33 862	1128.4	30.8	3.33	0.09	8.17	0.21
Coastal Alaska	6226	0.6	0.3	0.01	0.00	0.01	0.01
Hawaii	595	272.1	18.6	45.70	2.52	50.46	2.41
Total	102 358	1862.6	39.1	1.82	0.04	6.54	0.13

SE = standard error.

most cover, spotted knapweed, Canada thistle, saltcedar, quackgrass, gypsyflower, and redstem stork's bill were on one or more states' noxious weed list. Grasses were also important in the PC states, although the species in the 15 most abundant list were different from those in the RM states (table 8.3). In the PC states, 259 nonnative plant species were recorded. Of the top 15 species, Himalayan blackberry and medusahead (fig. 8.1), as well as bulbous bluegrass and Scotch broom, were on the proposed FIA invasives list (Gray et al. 2011). In coastal Alaska, eight nonnative plant species were recorded (fig. 8.1). Common dandelion was the most abundant nonnative plant, followed by reed canarygrass and clover (table 8.4). In Hawaii, 136 nonnative species were recorded. The most abundant species in Hawaii was strawberry guava, covering 9 percent of the forested area in the state (table 8.5, fig. 8.1). There were more shrubs in the list of most abundant nonnative species in Hawaii than in the other states.

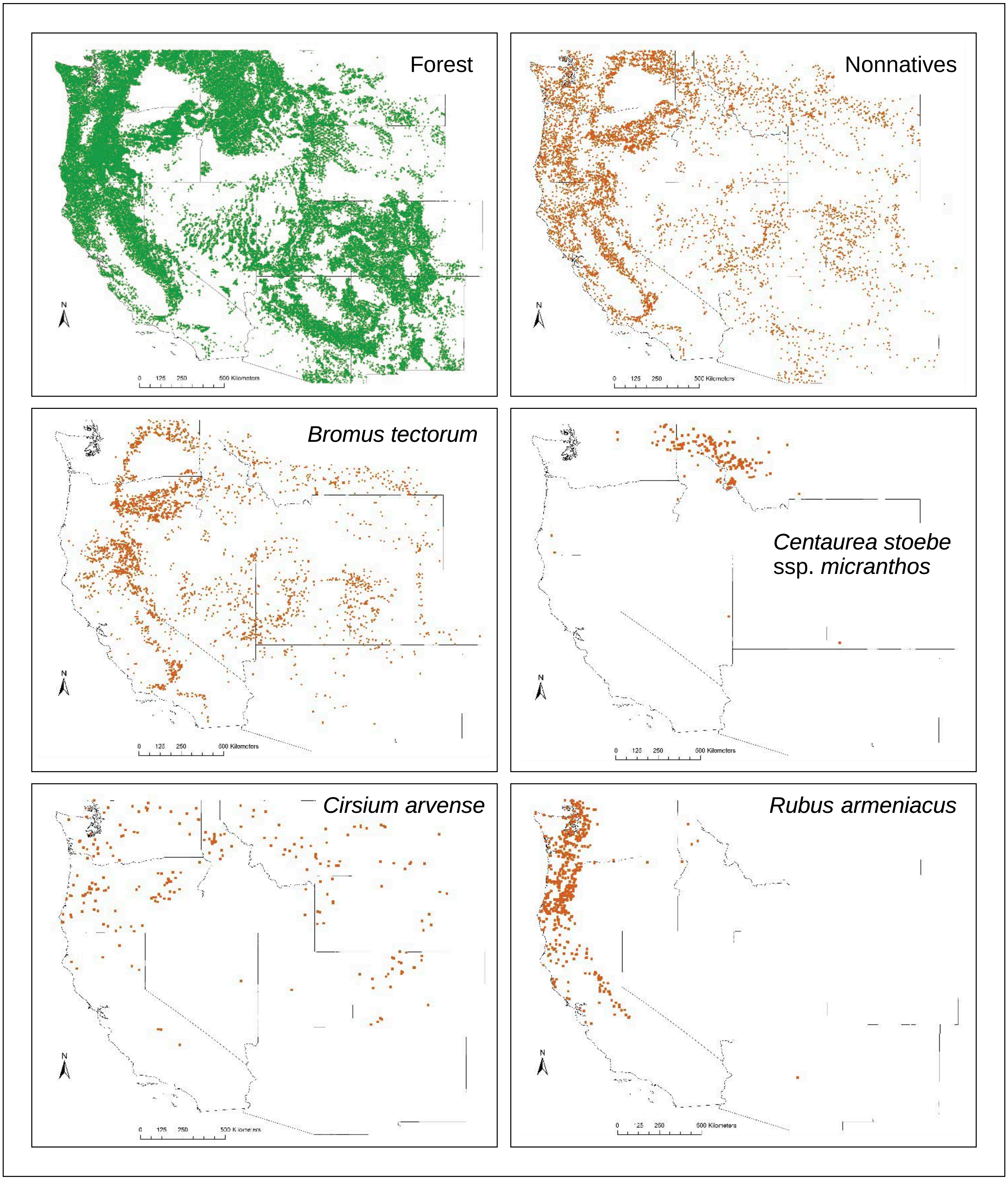

Figure 8.1—Maps of distribution of forested Forest Inventory and Analysis plots and those with cover of any nonnative plants, and of selected species, 2007–2016. Note that plot density is about three times higher on national forests in Oregon and Washington.

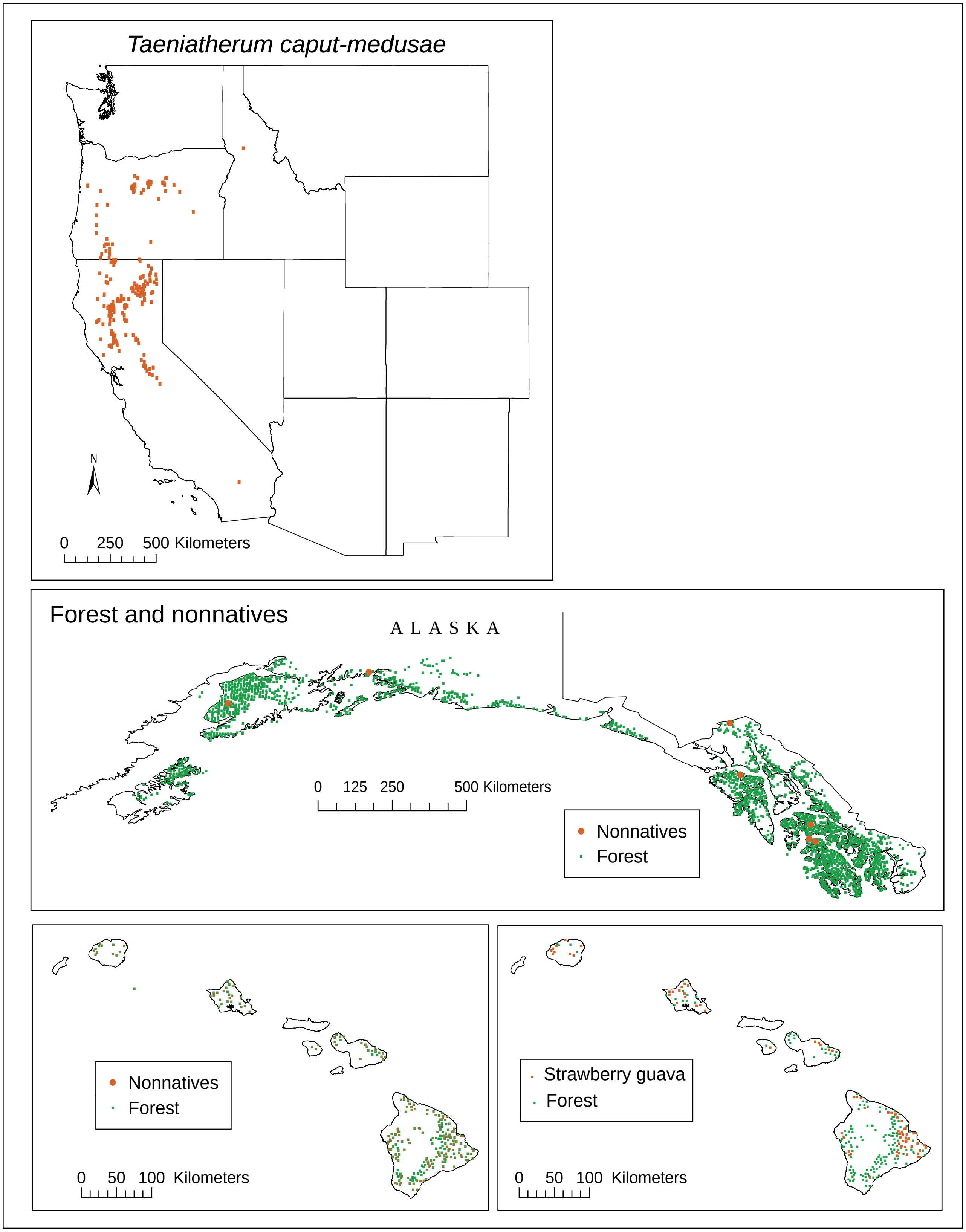

Figure 8.1—Continued.

Table 8.2—The 15 nonnative plants that cover the most forest land in the Rocky Mountain states out of 195 species recorded, 2007–2016

Scientific name	Common name	Area	SE	Cover	SE
		- - - *Hectares* - - -		- - - *Percent* - - -	
Bromus tectorum[a]	Cheatgrass	212 082	11 022	0.85	0.04
Phleum pratense	Timothy	36 365	3502	0.15	0.01
Centaurea stoebe ssp. *micranthos*[a]	Spotted knapweed	18 969	2443	0.08	0.01
Agropyron cristatum	Crested wheatgrass	16 538	2384	0.07	0.01
Cirsium arvense[a]	Canada thistle	14 098	1082	0.06	0.00
Eragrostis lehmanniana	Lehmann lovegrass	14 047	3202	0.06	0.01
Bromus rubens	Red brome	12 027	1806	0.05	0.01
Dactylis glomerata	Orchardgrass	11 852	2124	0.05	0.01
Bromus arvensis	Field brome	11 456	1751	0.05	0.01
Melilotus officinalis	Yellow sweetclover	5266	1266	0.02	0.01
Tamarix ramosissima[a]	Saltcedar	5250	1859	0.02	0.01
Elymus repens[a]	Quackgrass	5134	1302	0.02	0.01
Cynoglossum officinale[a]	Gypsyflower	4368	391	0.02	0.00
Erodium cicutarium[a]	Redstem stork's bill	4256	1167	0.02	0.00
Thinopyrum intermedium	Intermediate wheatgrass	4184	1159	0.02	0.00

SE = standard error.
[a] Species on one or more Forest Inventory and Analysis state invasive species lists.

Table 8.3—The 15 nonnative plants that cover the most forest land in the Pacific Coast states out of 259 species recorded, 2007–2016

Scientific name	Common name	Area	SE	Cover	SE
		- - - *Hectares* - - -		- - - *Percent* - - -	
Bromus tectorum[a]	Cheatgrass	256 164	11 810	1.87	0.09
Rubus armeniacus[a]	Himalayan blackberry	137 002	9 603	1.00	0.07
Bromus diandrus	Ripgut brome	97 941	8 869	0.71	0.06
Cynosurus echinatus	Bristly dogstail grass	61 914	5 212	0.45	0.04
Bromus hordeaceus	Soft brome	52 072	5 558	0.38	0.04
Torilis arvensis	Spreading hedgeparsley	46 876	4 358	0.34	0.03
Avena fatua	Wild oat	45 582	6 032	0.33	0.04
Taeniatherum caput-medusae[a]	Medusahead	42 790	4 936	0.31	0.04
Erodium botrys	Longbeak stork's bill	28 636	4 446	0.21	0.03
Poa bulbosa[a]	Bulbous bluegrass	26 999	3 356	0.20	0.02
Brachypodium distachyon	Purple false brome	25 508	4 692	0.19	0.03
Erodium cicutarium	Redstem stork's bill	22 633	4 387	0.17	0.03
Cytisus scoparius[a]	Scotch broom	17 493	3 137	0.13	0.02
Holcus lanatus	Common velvetgrass	15 760	2 608	0.11	0.02
Hypochaeris radicata	Hairy cat's ear	14 695	3 166	0.11	0.02

SE = standard error.
[a] Species on the proposed Forest Inventory and Analysis invasive species list.

Table 8.4—The nine nonnative plants recorded on forest land in coastal Alaska, 2006–2015

Scientific name	Common name	Area	SE	Cover	SE
		- - *Hectares* - -		- - *Percent* - -	
Taraxacum officinale[a]	Common dandelion	292	210	0.00	0.00
Phalaris arundinacea[a]	Reed canarygrass	265	128	0.00	0.00
Trifolium[a]	Clover	43	24	0.00	0.00
Rumex crispus	Curly dock	18	21	0.00	0.00
Vicia cracca ssp. *cracca*[a]	Bird vetch	7	7	0.00	0.00
Matricaria discoidea[a]	Disc mayweed	5	6	0.00	0.00
Phleum pratense[a]	Timothy	5	6	0.00	0.00
Plantago major[a]	Common plantain	5	6	0.00	0.00

SE = standard error.
[a] Species on the Forest Inventory and Analysis invasive species list.

Table 8.5—The 10 nonnative plants that cover the most forest land in Hawaii, out of 136 species recorded, 2010–2015

Scientific name	Common name	Area	SE	Cover	SE
		- - - *Hectares* - - -		- - - *Percent* - - -	
Psidium cattleianum [a]	Strawberry guava	55,858	7,586	9.39	1.27
Urochloa maxima	Guinea grass	18,040	4,614	3.03	0.78
Clidemia hirta [a]	Soapbush	16,873	2,983	2.84	0.50
Pennisetum clandestinum	Kikuyugrass	16,577	4,867	2.79	0.82
Melastoma candidum [a]	Asian melastome	10,213	2,738	1.72	0.46
Schinus terebinthifolius [a]	Brazilian peppertree	10,191	2,973	1.71	0.50
Microlaena stipoides	Weeping grass	9,919	3,239	1.67	0.54
Psidium guajava [a]	Guava	9,088	3,024	1.53	0.51
Ardisia elliptica [a]	Shoebutton	6,973	2,934	1.17	0.49
Dodonaea viscosa	Florida hopbush	6,945	1,582	1.17	0.27

SE = standard error.
[a] Species on the Forest Inventory and Analysis invasive species list.

The abundance of nonnative plants varied among forest types. In the RM states, the nonstocked forests (forest land where current tree stocking was <10 percent) had the highest mean cover of nonnative plants at 3.8 ± 0.25 percent (fig. 8.2). Among remaining forest types, mean nonnative cover was between 0.5 and 1.0 percent in hardwood and low-elevation and dry conifer types (e.g., pinyon/juniper, ponderosa pine), and <0.5 percent for high-elevation and moist conifer types (e.g., true fir/Engelmann spruce and western hemlock/redcedar). In the PC states, mean nonnative plant cover was highest in oak-dominated forest types at 14.0 ± 0.57 percent (fig. 8.2). As found in the RM states, nonnative plant cover was

Nonnative plants were most abundant in dry forest types and stages of stand development with sparse tree cover.

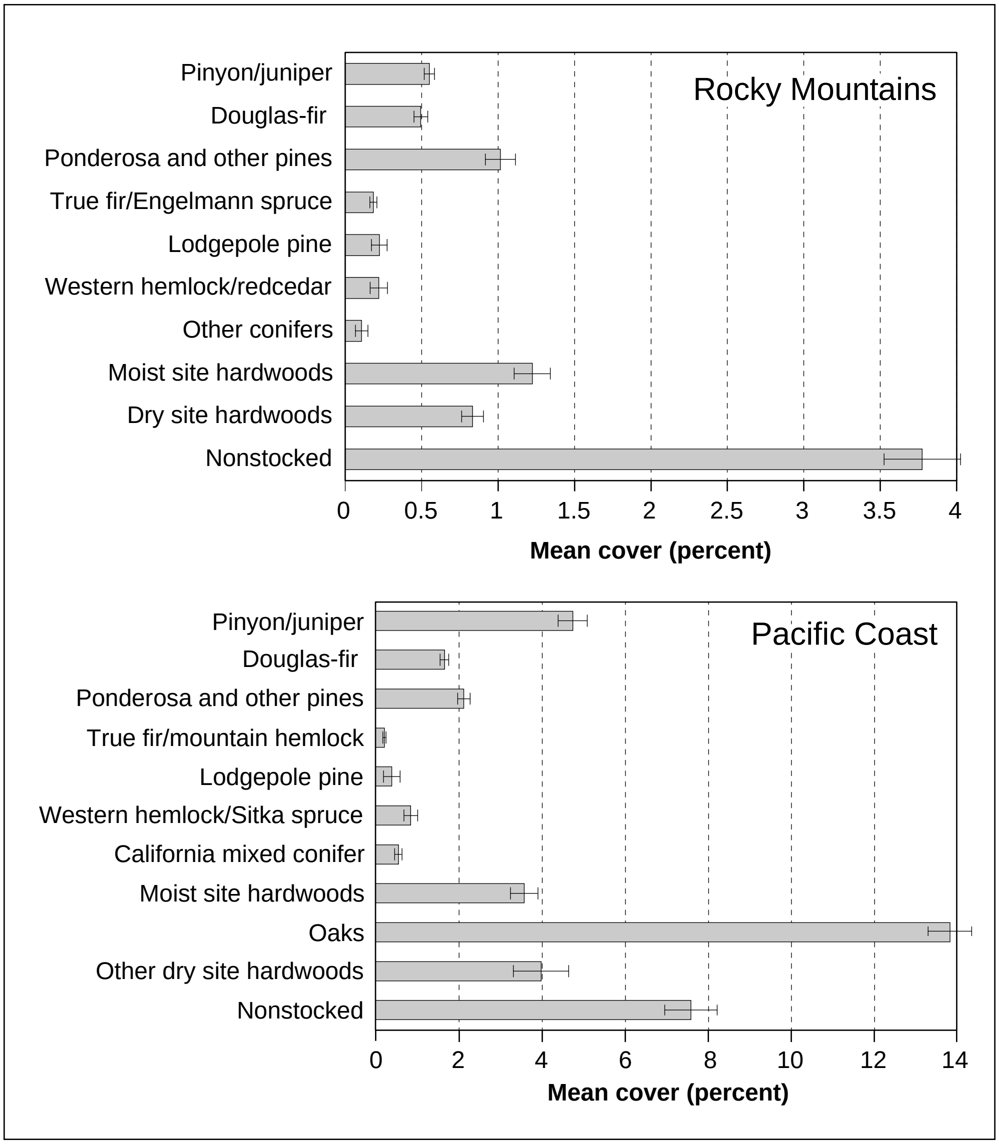

Figure 8.2—Forested area covered by nonnative plants (with standard errors) by forest type group in Rocky Mountain and Pacific Coast states, 2007–2016. Scale of *x*-axis differs between regions.

higher in hardwood and dry conifer forest types than in high-elevation and moist conifer types. Similarly, in coastal Alaska, most of the sites where nonnative plants were found were either nonstocked or hardwood types, and close to roads (data not shown). In Hawaii, mean cover was similar (>40 percent) in all forest types except for cloud forest, where mean cover was 7.8 ± 2.5 percent.

Mean cover of nonnative plants varied by stand age. For both the RM and PC regions, mean cover of nonnative plants in the oldest stands (>200 years) was less than one-fifth the cover of nonnative plants in the youngest stands (0 to 50 years) (fig. 8.3). Although stand age is clearly related to time since severe disturbance, the incidence of disturbance in the previous 10 years was not a definitive explanation of nonnative plant cover. Although nonnative cover was higher on sites experiencing fire than other disturbances (or no disturbance) in RM states, differences were less among disturbance types in PC states (fig. 8.4).

Proximity to nonforest land conditions, which tend to be preferred habitat for many nonnative species or frequently disturbed (e.g., roads), was significantly associated with cover of nonnative species. Mean nonnative plant cover was significantly lower on plots that were entirely forest than on forested portions of plots that contained both forest and nonforest land, except for coastal Alaska, where low abundance of nonnatives led to a relatively high standard error (table 8.6).

National forests in the Northern Rocky Mountains (U.S. Forest Service Northern Region), coastal Alaska (Alaska Region), and the Pacific Coast (Pacific Southwest and Northwest Regions) measure vegetation on nonforest land on FIA plots. Although cover of nonnative plants was similarly low on forest and nonforest lands on national forests in coastal Alaska, mean cover of nonnative plants on RM and PC national forests was more than five times greater on nonforest conditions than on forested conditions (2.1 ± 0.4 vs. 0.32 ± 0.03, and 5.5 ± 0.4 vs. 0.96 ± 0.06 percent, respectively) (table 8.7). Cheatgrass covered the most area on both forest and nonforest lands on RM and PC national forests (tables 8.8 and 8.9). Two of the top five species on nonforest land in both the RM and PC regions were relatively uncommon on forest land, covering less than 2,000 ac [809 ha]; those species were crested wheatgrass and field brome in the RM region, and North Africa grass and field brome in the PC region.

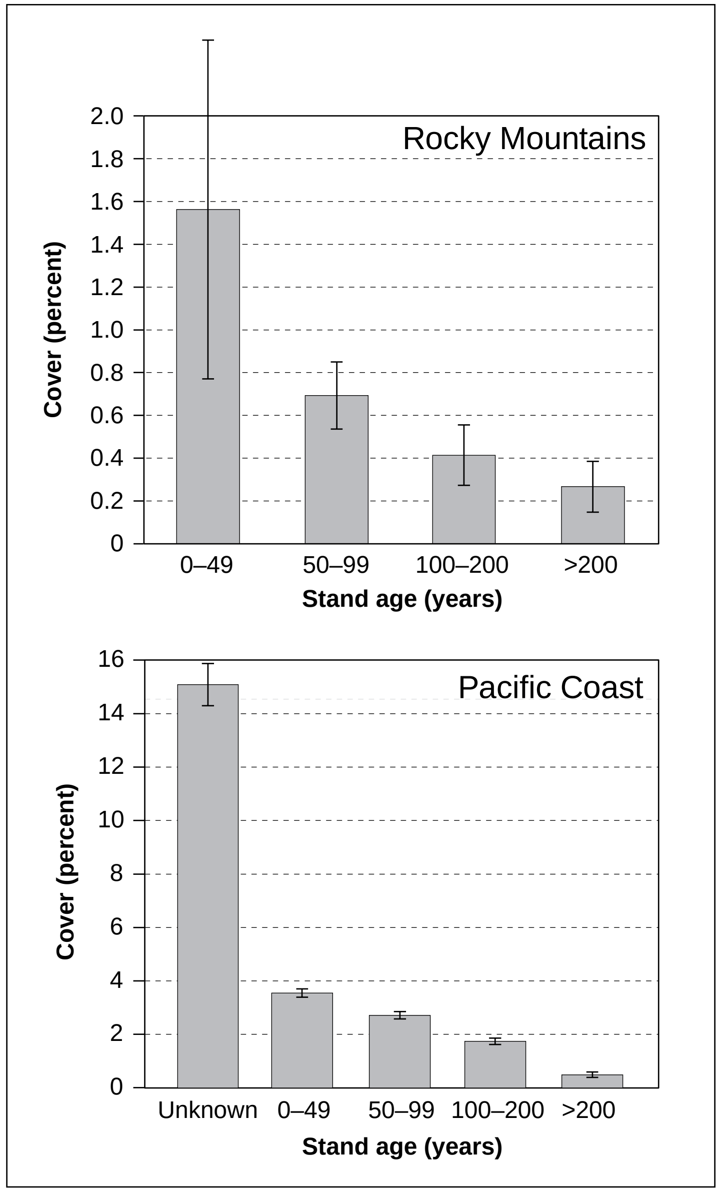

Figure 8.3—Mean cover of nonnative plants by stand age class and region, 2007–2016. The unknown stand ages in the Pacific Coast states are primarily oak-dominated stands where trees were not increment-cored for age.

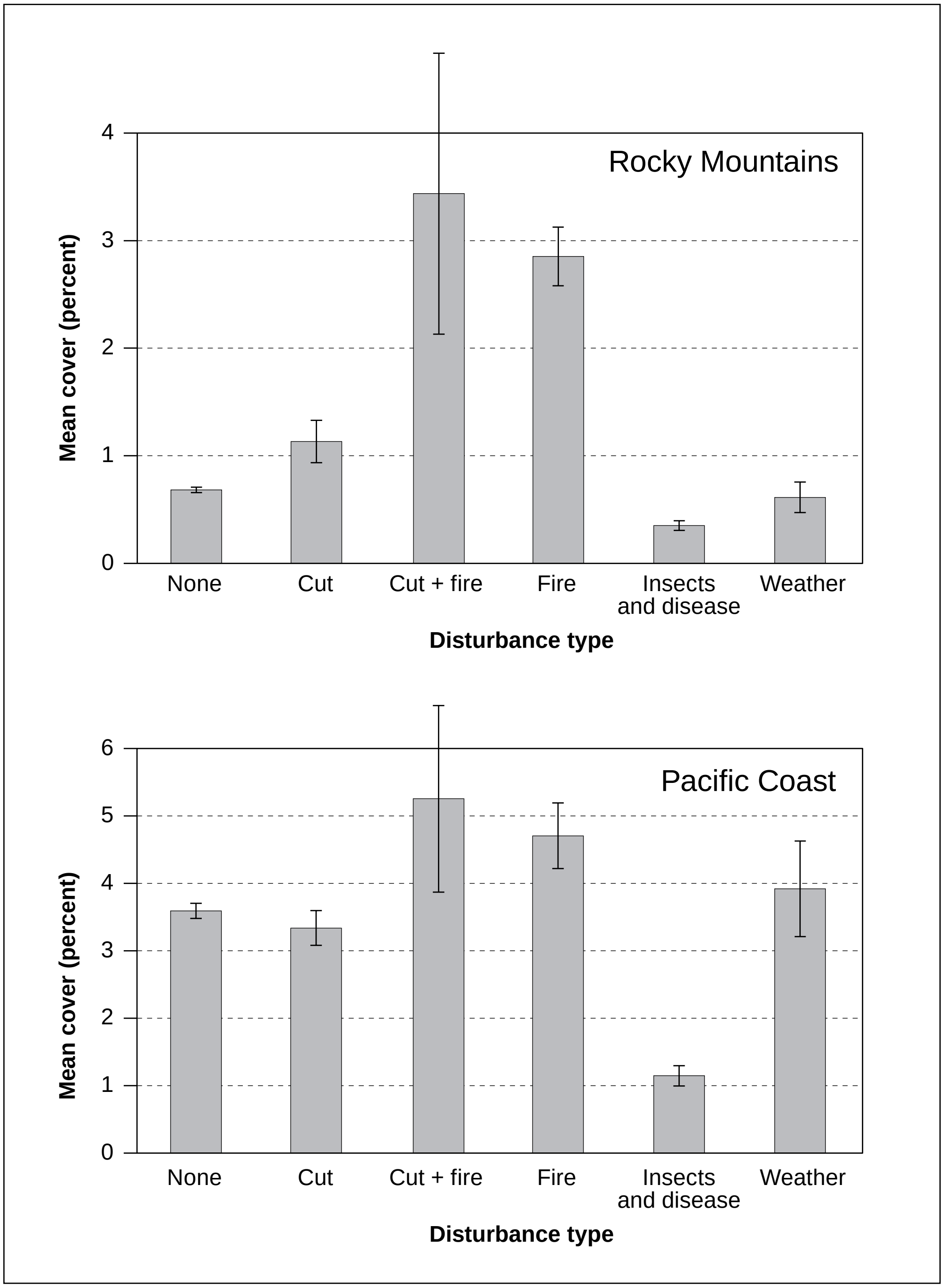

Figure 8.4—Mean cover of nonnative plants by disturbance type occurring in the 10 years prior to measurement, by region, 2007–2016. Insect and disease impacts are grouped under “insectdis”; *y*-axis scale differs between regions.

Table 8.6—Mean cover of nonnative plants comparing fully forested plots to forested portions of plots with forest and nonforest conditions, by region, 2007–2016

	Fully forested		Partially forested	
Region	Cover	SE	Cover	SE
	- - - - - - - - - - - Percent - - - - - - - - - - -			
Rocky Mountain	0.69	0.03	1.36	0.09
Pacific Coast	2.86	0.09	6.26	0.30
Alaska	0.01	0.00	0.15	0.10
Hawaii	44.67	2.66	59.86	7.62

SE = standard error.

Table 8-7—Comparison of nonnative cover on forest and nonforest lands where measured on national forests by region, showing land area, nonnative area, and mean percentage of cover, 2007–2016

	Forest		Nonforest	
Region	Estimate	SE	Estimate	SE
Land area:				
	- - - - - - - - - - - - - - - Hectares - - - - - - - - - - - - - - -			
Rocky Mountain	8 907 242	88 500	882 962	42 838
Pacific Coast	15 076 562	59 856	1 551 951	44 173
Coastal Alaska	2 694 493	100 271	862 130	58 497
Nonnative area:				
	- - - - - - - - - - - - - - - Hectares - - - - - - - - - - - - - - -			
Rocky Mountain	28 635	2 929	18 305	3 435
Pacific Coast	145 093	9 061	85 039	6 632
Coastal Alaska	161	102	16	18
Nonnative cover:				
	- - - - - - - - - - - - - - - Percent - - - - - - - - - - - - - - -			
Rocky Mountain	0.32	0.03	2.07	0.38
Pacific Coast	0.96	0.06	5.47	0.41
Coastal Alaska	0.01	0.00	0.00	0.00

SE = standard error.

Table 8.8—The five nonnative plants that cover the most forest or nonforest land on U.S. Forest Service Northern Region national forests (Montana and northern Idaho), 2007–2016

	Common name	Area	SE	Mean cover	SE
		- - - Hectares - - -		*- - - Percent- - -*	
Forest:					
Bromus tectorum	Cheatgrass	7 864	1 573	0.09	0.02
Phleum pratense	Timothy	6 032	1 451	0.07	0.02
Centaurea stoebe ssp. *micranthos*	Spotted knapweed	3 616	793	0.04	0.01
Hypericum perforatum	Common St. John’s wort	1 251	577	0.01	0.01
Cirsium arvense	Canada thistle	1 091	442	0.01	0.00
Nonforest:					
Bromus tectorum	Cheatgrass	3 977	1 042	0.45	0.12
Phleum pratense	Timothy	3 679	1 110	0.42	0.12
Agropyron cristatum	Crested wheatgrass	2 118	2 101	0.24	0.24
Bromus arvensis	Field brome	1 900	775	0.22	0.09
Centaurea stoebe ssp. *micranthos*	Spotted knapweed	1 262	523	0.14	0.06

SE = standard error.

Table 8.9—The five nonnative plants that cover the most forest or nonforest land on Pacific Coast national forests, 2007–2016

Scientific name	Common name	Area	SE	Mean cover	SE
		- - - Hectares - - -		*- - - Percent - - -*	
Forest:					
Bromus tectorum	Cheatgrass	74 201	5 795	0.49	0.04
Bromus diandrus	Ripgut brome	8 068	1 967	0.05	0.01
Torilis arvensis	Spreading hedgeparsley	5 603	1 609	0.04	0.01
Cynosurus echinatus	Bristly dogstail grass	5 200	1 267	0.03	0.01
Avena fatua	Wild oat	4 723	1 918	0.03	0.01
Nonforest:					
Bromus tectorum	Cheatgrass	50 509	4 252	3.25	0.26
Ventenata dubia	North Africa grass	4 771	1 184	0.31	0.08
Bromus diandrus	Ripgut brome	3 152	1 540	0.20	0.10
Bromus arvensis	Field brome	2 785	637	0.18	0.04
Taeniatherum caput-medusae	Medusahead	2 101	712	0.14	0.05

SE = standard error.

Changes in nonnative plant cover suggest significant increases over a 10-year period (fig. 8.5). However, some of the apparent increases may not be real, because rates of plant identification to the species level improved between the first and second measurements. Crews could assign genus or general growth form codes if they were not sure of the correct species, but identification to the species level is needed to determine whether a species is nonnative. For PC states, 83 percent of species cover was coded to the species level at time 1 and 90 percent at time 2. However, in the case of graminoids in California, the change was 20 to 48 percent. Species identification rates were better for the RM states, but still increased from 87 to 96 percent.

Complete vascular plant sampling found that 60 percent or more of the forested plots had at least one nonnative plant on them.

The full vascular plant sample from the P3 protocol indicated that at least 60 percent of forested plots in Utah, Oregon, and Washington had at least one nonnative present, compared to 10 to 20 percent from the P2 protocol (fig. 8.6). The P3 estimates of forested area covered by nonnatives were more than twice the estimates from P2, primarily because of the cover of forbs and graminoids. Fewer differences were seen in relative cover; both the nonnative and total cover estimates differ among protocols. The more complete sample of species in P3 could be part of the reason for greater levels of cover, but species identification rates could be a factor as well; for P3, 95.6 percent of the cover was identified to species (the proportion of those identified to genus was 0.70), while the rate for P2 in the same states was 93.3 percent. Identification rates were lowest for graminoids (87.7 vs. 83.5 percent of cover identified to species for P3 and P2, respectively). Even for P3, identification rates were quite low for forbs in Utah as

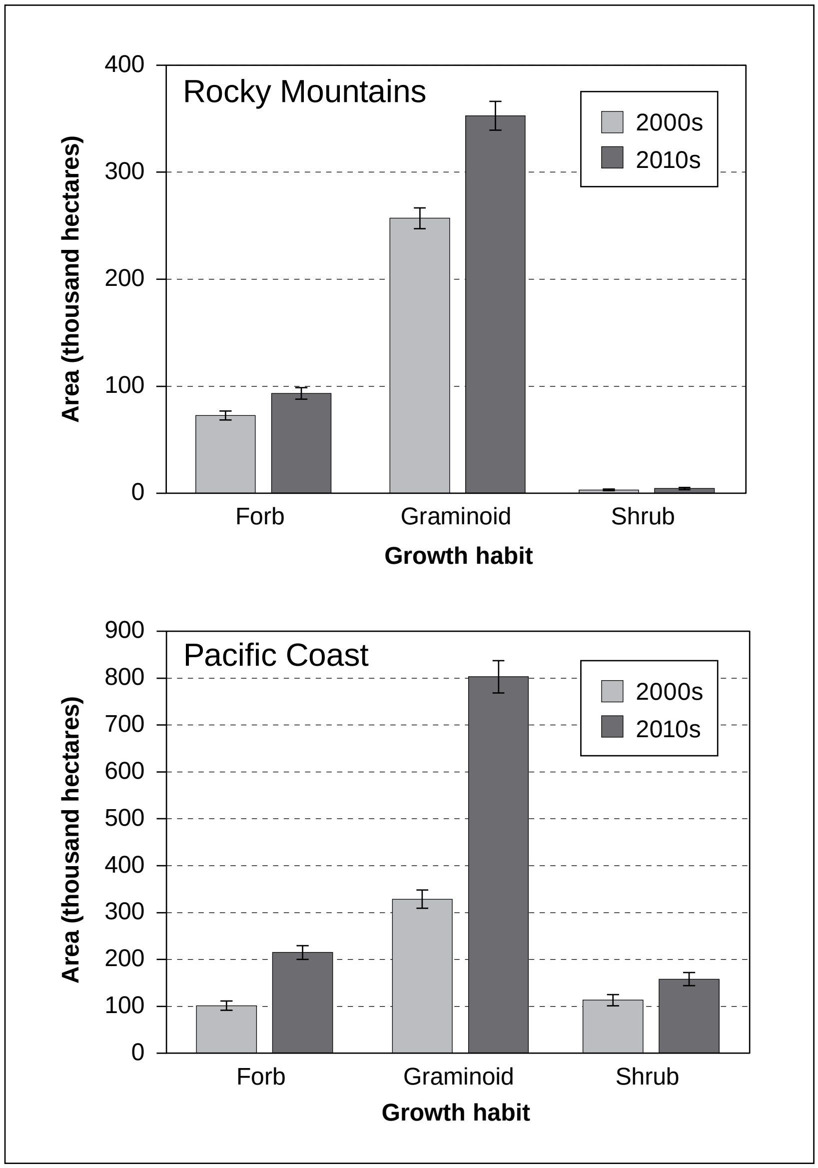

Figure 8.5—Mean change (with standard error) in estimated area covered by nonnative plants between the 2000s and 2010s, by growth habit and region. Some of the increase may be due to better plant identification at the second measurement, particularly for graminoids in the Pacific Coast states.

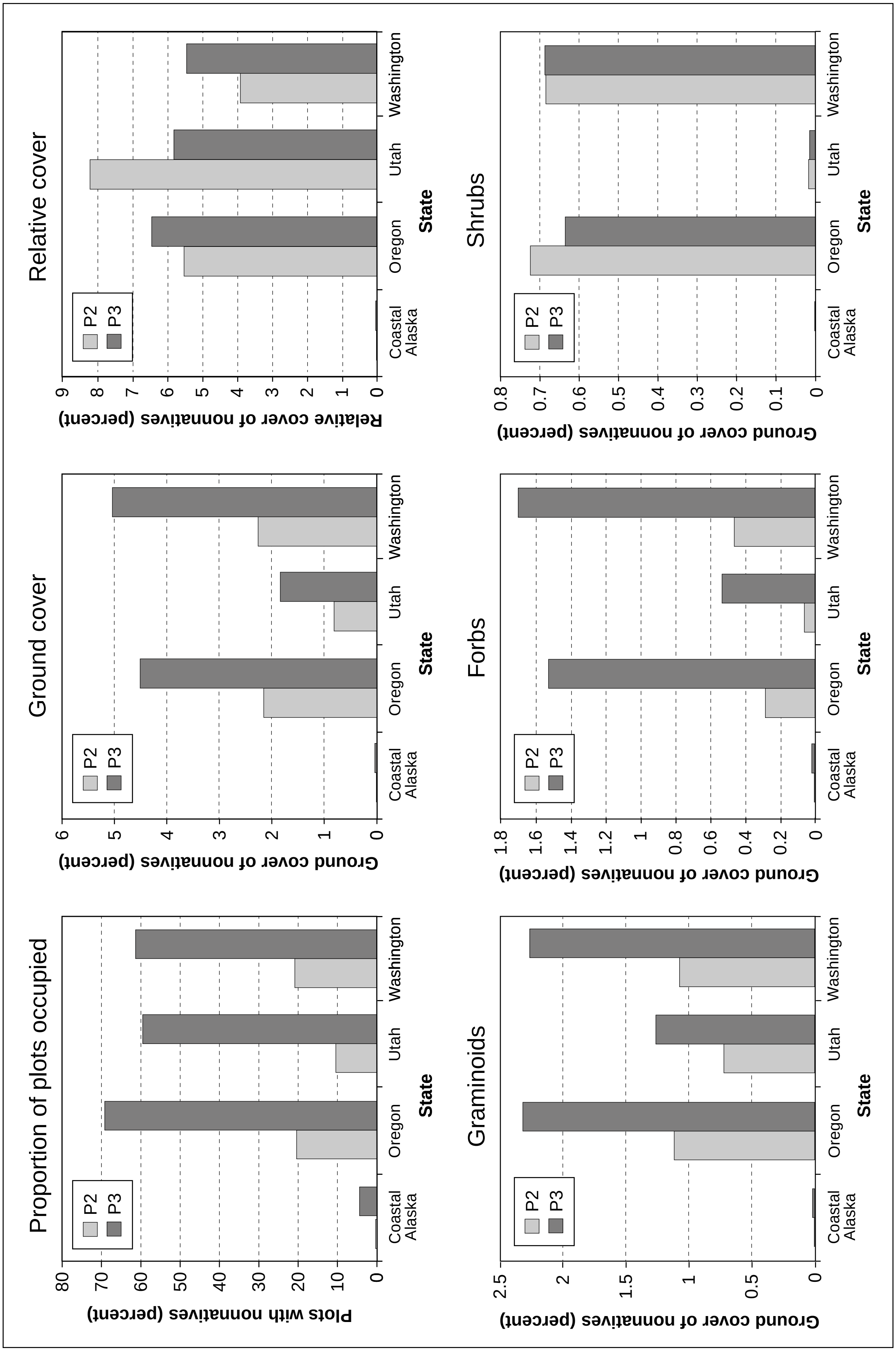

Figure 8.6—Comparison of measures of nonnative plant abundance by Forest Inventory and Analysis protocol type (P2 or P3), illustrating the proportion of plots occupied by at least one nonnative, and mean cover and relative cover (top row), and cover by growth habit (bottom row), by state.

well (76.4 percent); in dry open forest types, many plants are only readily observable and identifiable during short periods.[4] The nonnative species with the most cover from the P3 protocol (table 8.10) were similar to those from the P2 protocol, except that nonnative grasses tended to be ranked with greater abundance in the P3 measurement, and a few species that tended to occur as scattered individuals at low cover were ranked abundant in P3 but were rarely recorded in P2 (e.g., yellow salsify in Utah and wall-lettuce in Washington).

Key Findings

The area of forest covered by invasive plants ranged from 46 percent in Hawaii to 3.3 percent on the Pacific Coast, to 0.75 percent in the Rocky Mountains, to 0.01 percent in Coastal Alaska (table 8.1). Except for Hawaii, the impact of invasive plants is substantially lower than has been found in eastern forests (Oswalt et al. 2015, Schulz and Gray 2013). The best data available from a subset of the region suggest that the area covered by invasives on the Pacific Coast and Rocky Mountains could be twice those values. Nonnative cover appears to have increased substantially from the 2000s to the 2010s.

Most of the invasive species in western forests are early-seral and associated with stands that are nonstocked, young, or fragmented. Roads, in particular, fragment forest land and create suitable sites for invasive plant establishment, thereby providing vectors for invasion into forest land (e.g., Kerns and Day 2017, Lovtang and Riegel 2012). Streams and rivers may also serve as conduits for the dispersal of seeds and plant fragments of invasive plants into resource-rich riparian habitats (Parendes and Jones 2000).

Annual grasses are particularly abundant in dry western forests and woodlands. Because these grasses dry out earlier and more completely than native perennial vegetation, they often increase the spread, severity, and frequency of fire when it occurs, thereby perpetuating conditions ideal for annual grasses (e.g., Balch et al. 2013, D'Antonio and Vitousek 1992).

Invasive plants tolerant of full or partial shade are found in moist western forests and can invade intact stands or those that are partially cut (e.g., Gray 2005). Forests of the Northeastern United States, which have been exposed to nonnative plants longer than Western States, tend to be invaded by many shade-tolerant species. A similar fate may await western forests.

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[4] **O'Brien, R. 2004.** Personal communication. Ecologist (retired), U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 507 25th Street No. 301, Ogden, UT 84401.

Table 8.10—The 10 nonnative plant species with the greatest mean cover in the P3 sample by state, 2001–2010

Scientific name	Common name	Cover
		Percent
Alaska:		
Taraxacum officinale	Common dandelion	0.02
Schedonorus phoenix[a]	Tall fescue	0.01
Phalaris arundinacea	Reed canarygrass	0.01
Vicia cracca ssp. *cracca*	Bird vetch	0
Erysimum cheiranthoides	Wormseed wallflower	0
Oregon:		
Bromus tectorum	Cheatgrass	0.99
Geranium lucidum[a]	Shining geranium	0.57
Rubus armeniacus	Himalayan blackberry	0.46
Holcus lanatus	Common velvetgrass	0.25
Poa bulbosa	Bulbous bluegrass	0.22
Dactylis glomerata	Orchardgrass	0.14
Cytisus scoparius	Scotch broom	0.13
Phleum pratense	Timothy	0.10
Arrhenatherum elatius	Tall oatgrass	0.10
Digitalis purpurea	Purple foxglove	0.08
Utah:		
Bromus tectorum	Cheatgrass	1.06
Lepidium latifolium[a]	Broadleaved pepperweed	0.10
Tragopogon dubius	Yellow salsify	0.07
Agropyron cristatum	Crested wheatgrass	0.06
Galinsoga parviflora[a]	Gallant soldier	0.06
Cirsium arvense	Canada thistle	0.05
Bromus rubens	Red brome	0.04
Tamarix chinensis[a]	Five-stamen tamarisk	0.03
Poa bulbosa	Bulbous bluegrass	0.03
Sisymbrium altissimum	Tall tumblemustard	0.02
Washington:		
Holcus lanatus	Common velvetgrass	0.88
Bromus tectorum	Cheatgrass	0.60
Mycelis muralis	Wall-lettuce	0.26
Hedera helix	English ivy	0.25
Cirsium arvense	Canada thistle	0.24
Rubus armeniacus	Himalayan blackberry	0.21
Hypochaeris radicata	Hairy cat’s ear	0.21
Bromus racemosus[a]	Bald brome	0.21
Cirsium vulgare	Bull thistle	0.18
Rubus laciniatus	Cutleaf blackberry	0.17

[a] These species are based on large cover measurements on only one plot, so statewide abundance is less clear.

Discussion

The area of forest covered by nonnative plants is outside the range of natural variation almost by definition (Montréal Process criterion 3.15). Quantifying how far outside the natural range of variation invasive plants have moved forests, and which ecosystem functions are affected, is more challenging. The outcome of invasion by nonnative plants is highly dependent upon both the identity of the invader and the biotic and abiotic environmental context of the invaded site (Pyšek et al. 2012). Presumably the space taken up by invasive plants results in less space occupied by native species. Invasive plants can also alter the physical properties of ecosystems. For example, tamarisk trees might promote sediment deposition, resulting in narrower river channels and less frequent but more severe floods (Graf 1978). Invasive grasses that increase fire incidence or intensity can cause conversion of forest to savannah or grassland (D'Antonio and Vitousek 1992). This has been found in Hawaii, but the extent to which it occurs in the continental Western United States is not clear (although cheatgrass conversion of sagebrush ecosystems to annual grasslands is well documented). Invasive plants can change nutrient cycling in a variety of ways. In the case of the nitrogen-fixer Scotch broom, soil nutrients increase at some sites (Slesak et al. 2016), and its presence can transform the species composition of the plant community (Shaben and Myers 2009). Invasive plants can alter the pollination of native plants, affecting reproductive success and the composition of insect communities (Bartomeus et al. 2008). Invasive plant species can also affect the success of herbivores, seed predators, soil organisms, and higher trophic levels (e.g., Knapp 1996, Litt and Pearson 2013).

Once an invasive plant like cheatgrass becomes widespread, managers by necessity reprioritize their efforts from eradication to long-term management.

Although it is clear that invasive plants can affect ecosystems and communities they invade in many ways, this is not necessarily true for all introduced species, or even all invasive plants. Many are not expected to have any appreciable long-term impacts upon invaded sites. Even where invasive plants have been reliably shown to have significant impacts on native ecosystems and plant and animal communities, there is a lack of convincing evidence for extinctions attributable to invasives (Gurevitch and Padilla 2004). Once an invasive plant like cheatgrass becomes widespread, managers by necessity reprioritize their efforts from eradication to long-term management that attempts to reduce negative effects and take advantage of the positive ones (Kitchen 2014). On the other hand, preventative measures could be effective at maintaining the currently low abundance of nonnative species in boreal forests (Sanderson et al. 2012).

Much of the literature on invasive plants focuses on impacts in nonforested environments like rangeland, grasslands, or wetlands. The presence of nonnative plants in a forest dominated by native trees is less obvious, and the impacts perhaps more subtle, than occurs in nonforest environments, although examples like kudzu in the Southeastern United States, English ivy in the Northwest, or strawberry guava in Hawaii are certainly available. The greater abundance of nonnative plants in forests of the Eastern United States could be a result of greater disturbance (including recovery from widespread agriculture in the 1900s), higher human population density, or longer exposure to introduced species. Given the propensity of many invasive plants to occupy disturbed sites, their impact on tree regeneration through competition or other effects (e.g., promoting fire) may be the most significant from an economic perspective (e.g., The Research Group 2014). Most state forestry regulations in the West require prompt tree seedling establishment after regeneration harvesting. In many forest types, site preparation in the form of prescribed burning or herbicide application (only on nonfederal lands for the latter) has been traditionally used after harvest. It is not clear whether the presence of nonnative plants has required greater use and expense of site preparation than would be undertaken to control native plants, or whether some plantations have failed because of the dominance of nonnative plants in western forests. Nonetheless, abundant evidence exists for negative impacts of invasive plants on tree recruitment, via either direct competition or their ability to promote higher rates of seed predation (e.g., Gorchov and Trisel 2003, Meiners 2007, Stinson 2006).

Mechanical and chemical control are usually employed in initial attempts to control or eradicate early and localized infestations. Biological control by introducing the predators of invasive plants from their regions of origin (e.g., nonnative insects) is an attractive option for widespread plant invasions because it can be relatively cheap and effective, as in the case of St. John's wort in western rangelands (Crompton et al. 1988). Despite years of research and rigorous testing in controlled environments, unintended consequences from introduction of biological control agents can occur, however. For example, the introduction of gall flies to control spotted knapweed increased deer mouse populations, which could result in increased exposure of humans to hantavirus (Pearson and Callaway 2008). A significant challenge with targeted control measures is that in many cases, secondary invaders respond to the newly available space better than the natives (Pearson et al. 2016).

In this chapter, we summarized the major impacts of invasive plants on indicators of sustainable forestry and quantified the abundance of those plants in western forests. Identified research priorities for sustainable forestry include (Chornesky et al. 2005):

- More taxonomists in the field, because accurate species identification is a key challenge in detection and monitoring

- Integration of invasive plant control considerations into all aspects of management, from transportation and travel corridors to silviculture, because the connections between disturbances, activities, and land types can either accelerate or retard invasions
- Landscape consideration and planning, with models that integrate different types of activities with the probabilities of invasion.

Better quantification of invasive plant impacts on sustainable forests could involve linking site-specific research on the impacts of particular species to broad-scale estimates of species' abundance in different habitat types.

The impacts of nonnative plants on forest lands will most likely increase in the future, as suggested by our change analysis. Although there are active efforts to prevent arrival of new invaders, increasing global trade makes it likely that new introductions will continue to occur (Moser et al. 2009). Many species do not appear to occupy all habitat that is currently available, or may become available with climate change (e.g., Gray 2005, Kerns et al. 2009). Given the importance of ruderal and graminoid invaders in western forest lands, every disturbance creates an opportunity for invasive plants to become established, become part of the local seed bank, and increase the propagule pressure on the landscape. Species that become abundant can have sufficient propagule pressure to colonize and affect otherwise marginal habitats (e.g., cheatgrass in closed forest). The increase of shade-tolerant invasive plants in our moister western forests will probably continue as well, as there appear to be large areas of climatically suitable land available (e.g., Gray 2005). Many of the shade-tolerant nonnative species that have become abundant in temperate forests of the Eastern United States are also being found in the West (e.g., garlic mustard) and are likely to become important here as well. The expected increase in the extent of plant invasions in Western U.S. forests suggests the utility of successful monitoring strategies in these areas.

Monitoring of Invasive Plants in Western U.S. Forests

Monitoring approaches can be split into early detection, tactical, and strategic categories. Early detection and rapid response is often viewed as the most effective means of controlling an invasion and minimizing its impacts (Sharov and Liebhold 1998, Simberloff 2003). Nevertheless, early detection of burgeoning invasions is uncommon owing to challenges inherent in detecting a relatively rare invasive within a native-dominated community (Hulme 2006). Early detection is often serendipitous but involves having people with the proper taxonomic skills observing likely locations for invasion (Reichard and Hamilton 1997).

Tactical monitoring may also be serendipitous but often involves identifying particular species in specific habitats of concern. Standardized protocols exist for documenting the location and extent of infestation (e.g., North American Weed Management Association), often with the objective of determining change over time or the response to eradication and control efforts. Although vital to land management, the targeted nature of tactical monitoring, tied to the landowner's particular objectives, makes comprehensive assessment of invasive plant impacts difficult.

Strategic monitoring is based on a statistical design that samples a defined area with consistent procedures such that the probabilities of detection are known (Bechtold and Patterson 2005). The FIA currently covers all the forests in the nation with a common set of procedures and a consistent remeasurement cycle. Yet the standard grid density and vegetation plot size samples only 1/36,000th of the landscape, making FIA ineffective for early detection and tactical monitoring. The Western States implement a P2 understory vegetation protocol that quantifies cover of the four most abundant vascular plant species per lifeform present at >3 percent cover on each of four subplots, and most states across the country record any observation on the plot (regardless of cover) from a targeted list of invasive plants. As seen in our comparison of P2 and P3 in the states where both are available, the P2 measurement underestimates the prevalence and abundance of nonnative plants. The P2 focus on dominant species, use of personnel with moderate botanical expertise, and long field seasons and varied phenological stages over which sampling occurs probably all contribute to the underrepresentation. However, for species that are readily identified and abundant, the large number of P2 plots (16 times the standard density of P3) make the P2 data useful for modeling abiotic and biotic attributes related to their distribution (Baer and Gray, n.d., Lovtang and Riegel 2012). Training to identify a targeted set of invasive list species, and their measurement on P2 plots, is useful even though the scope is often limited to the regions or states for which they are listed. The P3 all-species measurement with experienced botanists during the peak phenological period on a subset of plots can be logistically challenging to integrate in an annual inventory, but the data provide the best assessment of nonnative species composition and make it possible to assess both native and invasive species richness and a more refined view of community dynamics over time.

Table 8.11—Scientific and common of plants identified in this chapter

Scientific name	Common name
Achillea millefolium L.	Common yarrow
Agropyron cristatum (L.) Gaertn.	Crested wheatgrass
Alliaria petiolate (M. Bieb.) Cavara & Grande	Garlic mustard
Ardisia elliptica Thunb.	Shoebutton
Arrhenatherum elatius (L.) P. Beauv. ex J. Presl & C. Presl	Tall oatgrass
Avena fatua L.	Wild oat
Brachypodium distachyon (L.) P. Beauv.	Purple false brome
Bromus arvensis L.	Field brome
Bromus diandrus Roth	Ripgut brome
Bromus hordeaceus L.	Soft brome
Bromus racemosus L.	Bald brome
Bromus rubens L.	Red brome
Bromus tectorum L.	Cheatgrass
Centaurea stoebe L. ssp. *micranthos* (Gugler) Hayek	Spotted knapweed
Cirsium arvense (L.) Scop.	Canada thistle
Cirsium vulgare (Savi) Ten.	Bull thistle
Clidemia hirta (L.) D. Don	Soapbush
Cynoglossum officinale L.	Gypsyflower
Cynosurus echinatus L.	Bristly dogstail grass
Cytisus scoparius (L.) Link	Scotch broom
Dactylis glomerata L.	Orchardgrass
Digitalis purpurea L.	Purple foxglove
Dodonaea viscosa (L.) Jacq.	Florida hobbush
Elymus repens (L.) Gould	Quackgrass
Eragrostis lehmanniana Nees	Lehmann lovegrass
Erodium botrys (Cav.) Bertol.	Longbeak stork's bill
Erodium cicutarium (L.) L'Hér. ex Aiton	Redstem stork's bill
Erysimum cheiranthoides L.	Wormseed wallflower
Galinsoga parviflora Cav.	Gallant soldier
Geranium lucidum L.	Shining geranium
Hedera helix L.	English ivy
Holcus lanatus L.	Common velvetgrass
Hypericum perforatum L.	Common St. John's wort

Table 8.11—Scientific and common of plants identified in this chapter (continued)

Scientific name	Common name
Hypochaeris radicata L.	Hairy cat's ear
Lepidium latifolium L.	Broadleaved pepperweed
Matricaria discoidea DC.	Disc mayweed
Melastoma candidum D. Don	Asian melastome
Melilotus officinalis (L.) Lam.	Yellow sweetclover
Microlaena stipoides (Labill.) R. Br.	Weeping grass
Mycelis muralis (L.) Dumort.	Wall-lettuce
Pennisetum clandestinum Hochst. ex Chiov.	Kikuyugrass
Phalaris arundinacea L.	Reed canarygrass
Phleum pratense L.	Timothy
Plantago major L.	Common plantain
Poa bulbosa L.	Bulbous bluegrass
Psidium cattleianum Sabine	Strawberry guava
Psidium guajava L.	Guava
Pueraria montana (Lour.) Merr.	Kudzu
Rubus armeniacus Focke	Himalayan blackberry
Rubus laciniatus Willd.	Cutleaf blackberry
Rumex crispus L.	Curly dock
Schedonorus phoenix (Schreb.) Dumort., nom. cons.	Tall fescue
Schinus terebinthifolius Raddi	Brazilian peppertree
Sisymbrium altissimum L.	Tall tumblemustard
Taeniatherum caput-medusae (L.) Nevski	Medusahead
Tamarix chinensis Lour.	Five-stamen tamarisk
Tamarix ramosissima Ledeb.	Saltcedar
Taraxacum officinale F.H. Wigg.	Common dandelion
Thinopyrum intermedium (Host) Barkworth & D.R. Dewey	Intermediate wheatgrass
Torilis arvensis (Huds.) Link	Spreading hedgeparsley
Tragopogon dubius Scop.	Yellow salsify
Trifolium spp.	Clover
Urochloa maxima (Jacq.) R. Webster	Guinea grass
Ventenata dubia (Leers) Coss.	North Africa grass
Vicia cracca L. ssp. *cracca*	Bird vetch

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