Regional Monitoring of Nonnative Plant Invasions With the Forest Inventory and Analysis Program

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Abstract.—Monitoring nonnative plant invasions by the Forest Inventory and Analysis Program includes (1) assembly of regional lists of nonnative invasive plant species in forest land, (2) observations at systematic intervals equivalent to a 5-km grid with traditional forest resource measurements, and (3) growing-season observations of all vascular introduced and native plant species at 1/16th of those locations (a 22-km grid) with additional forest health measurements. Strengths and limitations of this collective effort are discussed. This report provides lists of species to be monitored, preliminary results that rank infestation probability and severity in southern United States forest land, and highlights from studies of earlier surveys in selected States.

Introduction

To be effective, management of nonnative plant invasions in forest land requires a strategy that includes regional monitoring to determine the presence and extent of such invasions and the effects of local management activities on pest populations. Such monitoring will make it possible to prioritize management efforts at appropriate spatial scales. Many view plant invasions mainly as a problem affecting agricultural and urban land, but such invasions significantly affect forest land. Invasive plants considered problems are the ones that damage forest resources and transform ecological processes. For example, kudzu (*Pueraria montana*) suppresses tree regeneration and the wood volume growth of established trees by reducing the amount of light into the forest. Other impacts include modification of habitat for native wildlife, replacement of native forest species, alteration of soil properties, reduction in species diversity, and rapid biomass accumulation that increases the risk of wildfire.

The U.S. Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) program conducts a national forest resource survey that provides a means of studying the problem of plant invasions in forest land. FIA conducts a systematic, sample-based inventory over a large area to provide baseline estimates of representative conditions with a stated range of confidence. These estimates constitute strategic information to guide decisions about the efficient regional allocation of conservation, management, procurement, and production activities.

We report on progress in using FIA surveys for the conterminous United States, share highlights of preliminary findings in addressing the problem of plant invasions, and discuss weaknesses and opportunities for the future. Examples show that FIA survey data can (1) supplement existing knowledge of distributions of nonnative and potentially invasive plant species, (2) provide a sound basis for allocation of increased prevention efforts, (3) be used to identify and map large invasions, or regional hot spots, on forest land, (4) explore plausible correlated relationships among associated attributes, and (5) facilitate calibration of satellite imagery and obtain finer-scaled, mapped estimates of canopy-dominant invasive species.

Background

Several terms used in this discussion must be defined. *Forest land* is land at least 37 m wide; 0.4-ha in size; covered, or formerly

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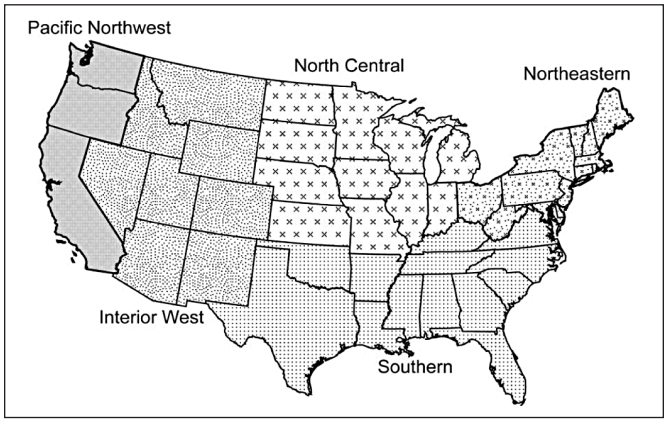
covered, by trees; capable of tree-growth; and not developed for nonforest uses. *Timberland* is forest land excluding areas restricted from timber production, such as wilderness, and forest land too wet or too dry to support commercial wood production. A *nonnative* plant species is one that is alien or exotic to the ecosystem under consideration.

In this report, an *invasive species* is a nonnative plant species whose introduction causes or is likely to cause economic or environmental harm. Infested land is land represented by a sampled area in which an invasive plant species is present. Each sampled location represents a portion of the study region. If infested, that portion is the *area of infestation*. The *severity* of the infestation is the portion of the sample covered by the species, and calculated as *total cover* (area of infestation multiplied by the proportion of severity).

The USDA Forest Service has a national strategy for addressing invasive species management (Ries *et al.* 2004), but adaptation of the FIA forest land monitoring effort in the conterminous United States has, thus far, been driven primarily by interested parties in FIA's five research work unit regions (fig. 1).

Figure 1.—*FIA survey regions of the conterminous United States: Interior West (Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming), Northeastern (Connecticut, Delaware, Maine, Massachusetts, Maryland, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, West Virginia), North Central (Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Wisconsin), Pacific Northwest (California, Oregon, Washington), and Southern (south central States—Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas—and southeastern States—Florida, Georgia, North Carolina, South Carolina, and Virginia).*



Methods

Collectively, the efforts of FIA work unit regions to monitor plant invasions may be viewed as a three-tiered task. The first tier is the assembly of a target list of plant species deemed potential problems in one or more FIA regions or States. The second is a survey by Federal and state forest resource survey crews with added training to identify the listed species or taxa from samples of plots on a 5-km grid (a P2 grid) and located on forest land (USDA Forest Service 2001). A third is documentation of the occurrence of introduced species, estimation of their cover, and approximation of the ratio of introduced plant species to all vascular plant species. This third task involves growing-season observations by botanists on a subset of P2 plots, typically 1/16th of P2 sample plots and located at 22-km intervals (on a P3 grid), along with other attribute observations (Burkman 2005). The P3 observations include a census of all vascular plant species on three, 1-square-meter areas within each subplot, and cover estimates by species for the subplot (Schulz 2003).

FIA forest resource surveys today operate on a random, systematic sampling grid, with each panel representing a subset of samples from all portions of the grid. Field crews complete a panel without major revisions to a sample protocol, and generally complete a panel in a single year. Thus, the sample design and operational logistics permit observations and analyses with the completion of a panel in a given state. Samples are located at random in a grid cell, which permits calculation of confidence intervals for area estimates by the random sampling formula (O'Brien *et al.* 2003). At each forest land sample location, inventory crews estimate cover by target species on four equidistant 7.3-m radius subplots in a 0.6-ha plot sample area (Burkman 2005). The area of the four subplots, 0.067 ha, is fixed, and crews record observations only on forest land. Forest land may be characterized for a single sample location as those associated with the *forest interior*—none of the subplots are positioned on nonforest land and those associated with *forest edge*—a portion of the subplots is positioned on nonforest land.

Target Lists and Measurement Protocols

Each FIA region confers with State agencies and staff from the USDA Forest Service and assembles a target list of potential problem species to be inventoried on forest land. Published lists of problem species are consulted; these may include those on the Federal Noxious Weed List (Federal Register 2004), State noxious weed lists, and national forest district or region lists of species of concern, species discouraged for restoration, or prohibited from introduction (Southeast Exotic Pest Plant Council 2001; USDA Forest Service, Pacific Northwest Region 2004; USDA Forest Service, Pacific Southwest Region 2001). The USDA Natural Resources Conservation Service (NRCS) PLANTS Database (USDA NRCS 2004) also is referenced to confirm that the species selected are documented as occurring in the region.

A regional consensus on what nonnative species are potential problems sufficient to warrant monitoring is not always possible. Some State and other Federal agencies collect FIA field observations themselves and have an influence on the selection of species. In the Eastern United States, each FIA region's staffs typically shorten the list to those that are easily identifiable and known to occur in forest land. FIA regions in the West place formally designated noxious species on their target lists on request by interested groups, such as State forestry agencies and national forest districts.

FIA assigns a unique national code to each nonnative and potentially invasive tree species. By consensus, FIA regions designate several of these as "core-required" (USDA Forest Service 2004). Crews that encounter core-required tree species must uniquely identify the species in the national FIA Database and record its stem attributes for volume, growth, and mortality estimation. Mimosa (*Albizia julibrissin*), a nonnative and reportedly invasive tree species, is an example of a recent addition.

If no consensus exists among FIA regions, the tree species is "core-optional." Each FIA region may identify these uniquely, record other attributes, or ignore the species altogether. Examples include saltcedar (*Tamarix* spp.), which may be of variable form under Western United States moisture regimes, and camphortree (*Cinnamomum camphora*), which typically is a tree only in subtropical and tropical climates. FIA records the cover of saltcedar without stem attributes primarily in the Interior West. FIA records camphortree and its stem attributes in Florida, but ignores this species in other States.

For species designated as nontree species, crews record observations by subplot, but the species (see the appendix) and procedures vary by FIA region (table 1). Identification of nontree species is established by consensus primarily in, rather than among, FIA regions. Procedures for estimating cover are often more compatible with existing or historical protocols for

Table 1.—*Protocol for inventories of invasive plant species by FIA region.*

Attribute	Western regions		Eastern regions		
	Interior West	Pacific Northwest	North Central	Northeastern	Southern
States implemented	All	All	All	Pennsylvania only	All currently surveyed
Noxious species selected for inventory	All listed by State	National forests and likely on forest land	Regionwide and likely on forest land	By State and likely on forest land	Regionwide and for Florida, likely on forest land
Cover category estimates	Presence (noxious), 1% above 5% (invasive)	≥ 1% (noxious), 1% above 3% (invasive)	< 1, 1–5, 6–10, 11–25, 26–50, 51–75, 76–100%	10% classes	< 1, 1–10, 11–50, 51–90, 91–100
Measurement tolerance	1–5, 6–10, 11–20, 21–40, 41–60, 61–80, 81–100%	1–5, 6–10, 11–20, 21–40, 41–60, 61–80, 81–100%	No error 80% of time	No error 85–90% of time	No error 90% of time

collection of vegetation data. As demand for national information grows, collaborative standardization for nontree species likely will follow.

Status of P2 Efforts

The narrative below summarizes the status of FIA's P2 efforts as of September 2004:

- The Northeastern FIA Region conducts a year-round survey. Crews inventory invasive nontree invasive species only during the growing season and only in Pennsylvania. About 300 randomly selected P2 samples are surveyed as part of a special study of tree regeneration. Crews estimate percent cover for 10 taxa and estimate presence or absence for a total of 33 taxa.

- The North Central FIA Region conducts a year-round survey. Crews estimate percent cover for 25 invasive nontree taxa. A 2003 pilot study conducted in Wisconsin during both the growing and dormant seasons indicated that crews could readily identify these species in leaf-off condition. For field identification, crews are using local guides as well as an invasive plant species manual designed to distinguish between similar species (Huebner *et al.* 2004). Informal testing suggested that species identification was consistent across seasons. Assignment of species to categories of growing-season cover is assumed to be consistent from season to season, but this assumption has not been tested.

- The Interior West FIA Region sometimes conducts surveys year-round, but never when snow is on the ground. The understory vegetation survey estimates cover by four life forms and up to four of the most abundant species, including some invasive taxa, with 5 percent or more cover per forested subplot. Crews also record presence of State-listed noxious species, with lists varying in species composition and number between 18 (Idaho) and 71 (Colorado). The ecosystems are diverse, consensus is limited, and observations insufficient at this time to establish a more consistent noxious species list. Identification and assignment of species to categories of growing-season cover are assumed to be consistent from season to season, but this assumption has not been tested.

- The conterminous Pacific Northwest FIA Region conducts surveys primarily during months with no snowfall. Crews record cover for abundant ($\geq$ 3 percent cover), easily identifiable taxa. These include about 20 invasive nontree taxa. For national forests in California, crews document presence to 1 percent for each of 11 species deemed noxious. Identification and assignment of species to categories of growing-season cover are assumed to be consistent from season to season, but this assumption has not been tested.

- The Southern FIA Region conducts a year-round survey. Invasive nontree surveys have not yet been initiated in Mississippi, Oklahoma, or west Texas. Crews use a four-season invasive species manual (Miller 2003) for field identification and tally up to four of the most abundant species per forested subplot. Crews estimate percent cover in classes for 33 taxa, plus some 20 species unique to Florida (USDA Forest Service 2001, 2003). Identification and assignment of species to categories of growing-season cover are assumed to be consistent from season to season, but this assumption has not been tested.

Example Results

The following are examples of early findings and preliminary analyses based on various FIA surveys that have documented the presence of invasive plants. Some of this information is taken from upcoming reports of P2 and P3 nonnative vegetation surveys for selected areas of the United States. We also include selected information from FIA survey data archives dating from the 1990s and earlier.

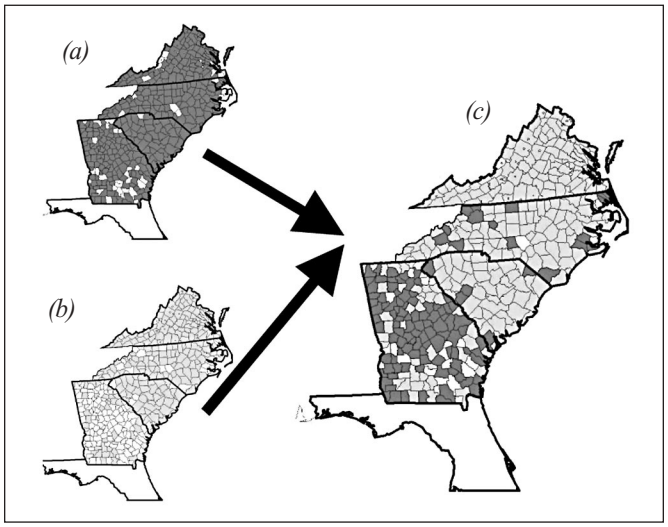
Distributions of Invasive Species

Managers and scientists derive their knowledge of distributions of invasive plant species from observations for a range of earth cover types. At present, inferences about species distributions typically rely on information stored at state and national herbaria, which contain physical records for an array of earth cover types. These records, unlike FIA records, rarely reference periodic, systematic observations or comprehensive environmental, spatial, or temporal details for broad areas. Inferences from FIA obser-

vations of invasive species, however, are generally limited to forest land. FIA's sampling design and measurement protocols have been adapted to nonforest areas (O'Brien *et al.* 2003, Riemann 2003), but cost and the logistical difficulties in collaborating with agencies responsible for nonforest land assessments are impediments to wider adoption of these methods.

Combining FIA data with data from other sources can increase our knowledge of invasive plant species distributions. Figure 2a illustrates P2 FIA data from county surveys of forest land from four southern States (Georgia, North Carolina, South Carolina, and Virginia) that are infested with Japanese honeysuckle. (Note that the FIA data represented in the example is for only about 1/5 of the sample plots.) Figure 2b shows corresponding county-level data from the PLANTS Database of herbarium records (USDA NRCS 2004). By combining the two sources, one obtains a more comprehensive account of the range and counties occupied (fig. 2c).

Figure 2.—*Japanese honeysuckle distribution by county in Georgia, North Carolina, South Carolina, and Virginia: (a) FIA phase 2 field observations, 2001–04, (b) PLANTS Database 2002, largely from herbarium specimens, and (c) both combined: information from (b), with additions from (a).*



P2 Infestation and Severity Estimates

The summary of invasive plant occurrences on P2 forest land plots includes information about infestations by one or more selected species for the States represented (table 2). Without accounting for sample size and observer variability by State, species, and infestation severity, regional differences in the frequency of plots with invasive plants appear large. For example, 72 percent of forest land is infested in Kentucky, while 23 percent of forest land is infested in Arkansas. The preliminary conclusion is that varying climate and forest disturbance regimes favor one or more species in the target species list. To suggest that forest land in Arkansas is less susceptible to plant invasions, and Kentucky is more susceptible, is tempting, but not valid without an assessment of all vascular species.

In the areas surveyed for invasive plant species on the South's target list, Japanese honeysuckle infests the most forest land, with Chinese and European privet (*Ligustrum sinense, L. vulgare*) ranked a distant second (table 3). Kudzu is ranked 14th in overall frequency, but kudzu outranks the other 13 taxa in the

Table 2.—*Sampled locations with forest land and percent infested by State, 2001–04, as of September 2004.*[a]

Attribute	All States	Arkansas	East Texas	South Carolina	Louisiana	North Carolina	Georgia	Virginia	Tennessee	Alabama	Kentucky
Number of forest land plots	10,368	639	2,202	484	955	711	597	638	1,552	1,681	909
Percent infested with one or more of 33 taxa	49	23	40	41	42	47	50	51	53	63	72

[a] Data are from completed panels in the South (as of September 2004) and represent a portion of the final 5-km sample grid intensity. States, panel numbers, and approximate proportions are: Arkansas, 3, 0.20; East Texas, 1 through 5, 1.00; South Carolina, 4, 0.20; Louisiana, 4 and 5, 0.40; North Carolina, 5, 0.20; Georgia, 3, 0.14; Virginia, 4, 0.20; Tennessee, 3, 4, and 5, 0.60; Alabama, 3 and 4, 0.40; and Kentucky, 3 and 4, 0.33.

Table 3.—*Relative frequency of infested forest land subplots by taxa and State, 2001–04, for panels completed as of September 2004.*[a]

Attribute	All States	Arkansas	East Texas	South Carolina	Louisiana	North Carolina	Georgia	Virginia	Tennessee	Alabama	Kentucky
					Relative frequency						
Japanese honeysuckle	50	77	41	62	25	58	62	50	54	66	31
Chinese and European privet	11	1	11	10	13	14	25	6	5	19	0
Chinese tallowtree	7	0	31	2	26	0	1	0	0	1	0
Tall fescue	6	0	0	3	0	0	0	15	5	0	25
Nonnative roses	6	2	1	0	0	9	0	8	7	0	20
Japanese/glossy privet	5	14	5	8	8	6	2	3	8	6	0
Japanese climbing fern	3	0	5	0	23	0	1	0	0	2	0
Bush honeysuckles	3	0	0	0	0	2	0	3	2	0	11
Tree-of-heaven	2	0	0	1	0	1	0	7	4	0	3
Chinese lespedeza	2	3	0	5	0	3	6	2	2	0	2
Nepalese browntop	1	0	0	0	0	1	0	0	6	0	1
Mimosa	1	2	2	0	1	1	1	0	1	2	0
Chinaberry	1	0	2	1	1	0	2	0	0	1	0
Kudzu	1	1	0	1	0	0	1	0	0	2	0
15 other taxa	4	0	1	6	2	6	1	5	6	2	6
All taxa	100	100	100	100	100	100	100	100	100	100	100
Number of infested subplots $\sum(\#\text{subplots})_{\text{taxa}}$	17,362	343	2,473	598	1,329	1,049	1,014	1,195	2,909	3,726	2,726

[a] Data are from completed panels in the South (as of September 2004) and represent a portion of the final 5-km sample grid intensity. States, panel numbers, and approximate proportions are: Arkansas, 3, 0.20; East Texas, 1 through 5, 1.00; South Carolina, 4, 0.20; Louisiana, 4 and 5, 0.40; North Carolina, 5, 0.20; Georgia, 3, 0.14; Virginia, 4, 0.20; Tennessee, 3, 4, and 5, 0.60; Alabama, 3 and 4, 0.40; and Kentucky, 3 and 4, 0.33.

severity of its infestations (fig. 3). Thirty-one percent of kudzu-infested subplots have greater than 50 percent coverage, which means that kudzu is the dominant species in these subplots.

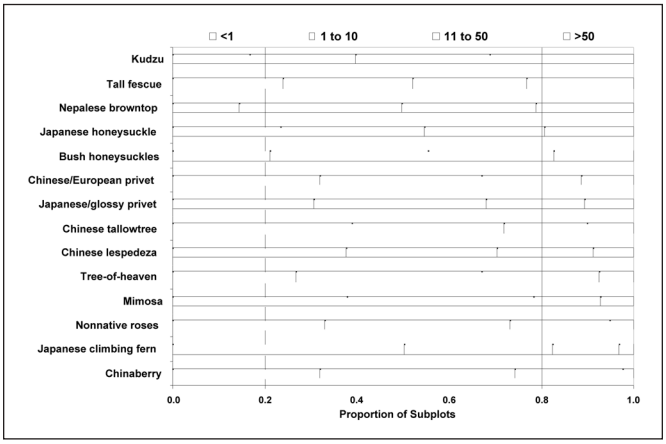
The strength of FIA's probability-based sampling design is that one is able to make inferences about the extent of infestations and their severity on forest land. An east Texas example shows that Japanese honeysuckle infests 2,774,900 acres, which make up 23 percent of the region's 12 million forest land area in 2003. Statistically, one may be 95 percent confident that the area is between 2,838,600 and 2,711,200 acres, or 2,774,900 $\pm$ 63,700. Confidence in estimates is strong for the common species and weak for rarely occurring species such as kudzu (table 4). In general, estimates of total cover represent less than 10 percent of the infected area of forest land. Japanese honeysuckle infests a million more acres than Chinese tallowtree (*Triadica sebifera*), a canopy-dominant tree species, but the two species are statistically similar in terms of total cover.

Table 4.—*Top 12 invasive species infesting forest land and their severity, east Texas, 2001–03 surveys.*

Species	Infested forest land			Severity (total cover)	
	% of total forest land	Acres (1,000s)	95% confidence interval	Acres (1,000s)	95% confidence interval
Japanese honeysuckle	22.9	2,774.9	±63.7	154.7	±15.0
Chinese tallowtree	14.1	1,715.3	±50.1	160.0	±15.3
Chinese/European privet	5.8	701.3	±32.0	39.1	±7.6
Japanese/glossy privet	3.4	413.4	±24.6	17.7	±5.1
Japanese climbing fern	3.0	369.1	±23.2	12.6	±4.3
Chinaberry	2.3	281.6	±20.3	8.5	±3.5
Mimosa	1.5	182.9	±16.4	1.7	±1.6
Chinese lespedeza	0.5	54.6	±8.9	0.1	NA
Nonnative roses	0.4	52.6	±8.8	1.9	±1.7
Bush honeysuckles	0.3	40.5	±7.7	1.7	±1.6
Nandina	0.3	39.2	±7.6	0.5	NA
Kudzu	0.3	33.4	±7.0	0.4	NA

NA = Confidence interval includes zero.

Figure 3.—*Proportion of infested subplots by species and severity class (< 1, 1–10, 11–50, and > 50 percent cover) for panels completed as of September 2004, southern United States.*



P3 Sampling

The census of all vascular species from P3 forest land observations provides information that is being used to develop indicators of forest health. Part of this development includes documenting their legitimacy, e.g., assurance in species identification (Gray and Azuma 2005). At present, funding for full implementation of all vascular vegetation on P3 plots is uncertain. The 1,300 plot observations of all vascular vegetation on forest land between 2001 and 2003 have been made only in selected States and survey years (table 5).

Table 5.—*Number of sampled plots on forest land in the conterminous United States for 2001–03 in which an all-vascular species inventory was conducted, by FIA region, State, and year. Unless otherwise noted, sampling was at the P3 (22-km) grid density.*

FIA region and State	2001	2002	2003
		Number	
Interior West			
Utah	40	45	50
Northeastern			
Delaware[a]	19	19	21
Ohio	16	21	26
Pennsylvania[a]	136	99	33
New Jersey[a]	9	6	0
New York[a]	21	10	0
North Central			
Illinois	14	8	17
Indiana	12	6	7
Iowa	7	9	5
Kansas	8	6	6
Michigan	41	43	43
Minnesota[a]	70	70	42
Missouri	36	32	35
Nebraska	4	5	2
North Dakota	3	0	1
South Dakota	4	3	4
Wisconsin	34	32	29
Pacific Northwest			
Oregon	62	0	0
Southern			
South Carolina	0	31	0
Total	536	445	321

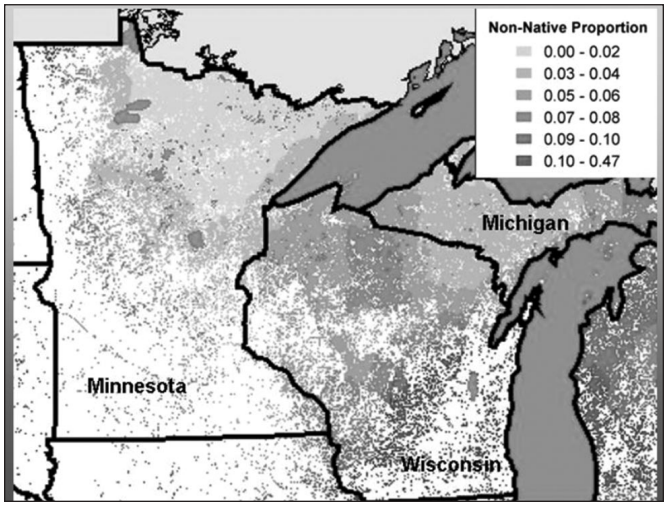
[a] Included samples at the P2 (5-km) grid density for special study areas, such as the Allegheny National Forest.

P3 sampling serves to corroborate species ranking from P2 plot observations, includes vouchered specimens deposited at regional herbaria for future study, and fills in information gaps associated with narrower target lists. In South Carolina, a pilot study of P3 data collection notes nonnative species occurred in an average of 5 percent of 31 forest land plots (Oswalt, in press). As with P2 observations, Japanese honeysuckle is the overall dominant invasive species by frequency, and kudzu is relatively rare. Included among recorded invasive species are the less easily identifiable life forms such as grasses, e.g., Bermudagrass (*Cynodon dactylon*), and species such as alligatorweed (*Alternanthera philoxeroides*), which are problems only in uncommon, specialized habitats, such as forested wetlands with limited tree cover.

Analysis of P3 indicators include the proportions of species richness and cover in introduced species, and these estimates serve as measures of relative impact (Stapanian *et al.* 1998). For example, Gray and Azuma (2005) note that the proportions of nonnative to native-and-introduced vascular plant species richness and cover differed significantly by ecoregion in forest land of western Oregon.

An illustration comes from a preliminary examination of P3 observations for the North Central FIA region (fig. 4) which suggests that the proportion of nonnative plant species varies by ecoregion (Olson *et al.* 2003). Large blocks of forest land—predominantly evergreen forest types—are associated with lower nonnative proportions. One interpretation is that the proportion varies directly with landscape-scale disturbances, such as forest fragmentation, and regional soil fertility. Another is that regions predominantly in deciduous forest land may be more susceptible to invasion by semi-evergreen species with longer growing cycles than regions predominantly in evergreen forests. Elsewhere, preliminary data appear to corroborate these patterns (Olson *et al.* 2003; Oswalt, in press; Schulz and Gray 2004).

Figure 4.—*Percent nonnative species on forest land by ecoregion, Michigan, Minnesota, and Wisconsin (Source: Olson* et al. *2004).*



Opportunities for Further Analysis

On forest land, future analysis of P2 and P3 observations will increase when monitoring of invasive plant species is fully implemented and standardized across FIA regions. Such analyses will permit a broader national understanding of pest species populations and their potential threat across all regions.

Robust risk assessments require national coordination, augmented interagency cooperation, and transdisciplinary collaboration with other monitoring efforts. These include national programs responsible for areas outside forest land, e.g., the USDA NRCS National Resources Inventory, State and local monitoring for management operations (Carpenter *et al.* 2002), and invasive species observations by volunteers (e.g., Brown *et al.* 2001).

In Alaska, one coordinated approach includes the establishment of an interagency memorandum of understanding, a strategy for cooperative inventories (Shephard *et al.* 2002), and an associated Web site (Alaska Committee for Noxious and Invasive Plants Management 2004). Another is the report from The H. John Heinz III Center for Science, Economics and the Environment (2002) and a newly launched Web site that focuses on invasive species (National Institute of Invasive Species Science, n.d.). The institute is in the process of gathering knowledge about invasive plant species from various agencies and land cover types, and analysts may one day be able to use the Web site's assembled data to supplement FIA forest land observations when developing risk prediction models with wider applicability.

Analyses With Older Survey Data

Before establishment of the P3 national sampling protocol for vascular plants and regional P2 sampling protocols for invasive plant species, a few FIA regions surveys estimated vegetation structure on timberland by easily distinguished plant taxa. These surveys happened to include a few invasive plant species in their tally. We highlight ongoing and recently completed analyses of these older data as example information products that could be developed from data currently being collected. The FIA program could generate similar information for all forest land if national P2 standard protocols for species selection and field measurement were established, and if the national form of P3 sampling were implemented across the United States.

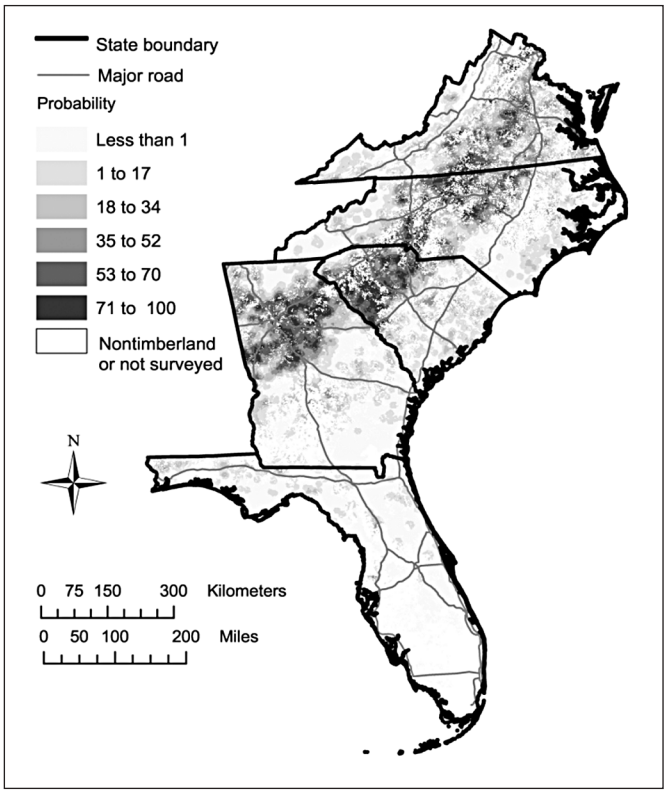
One example analysis provides estimates of Himalayan (*Rubus discolor*) and cutleaf blackberry (*R. lacinatus*) based on the 1998 western Oregon forest survey of non-federal land. Gray (2005) used stepwise logistic regression of these species' distributions to construct a model with correlated variables and thereby obtain an understanding of likely causal variables. Although model predictability was generally less than 50 percent, analyses and associated maps supported hypotheses that invasions were more likely at low elevations and in timberland with limited overstory cover (tree basal area, crown cover).

Another analysis yields maps of infestation probabilities for a few well-known species and is based largely on interior forest surveys of understory species in Southeastern United States timberland during the 1990s. Findings noted infestation probabilities are greater for Japanese honeysuckle in the Southern Mixed Forest than Coastal Plain provinces (fig. 5). For more details about the interpolation, see Jacobs and Rudis (2005).

Data came from interpolations of presence-absence observations recorded in a 1989 –95 survey of 26,882 timberland sample locations[2]. About 20 percent of the forest sample locations were infested with Japanese honeysuckle, 3.5 percent with privet (*Ligustrum* spp.), 0.9 percent with multiflora rose (*Rosa multiflora*), and 0.2 percent with kudzu. The odds of infestation probability were greatest with the absence of prescribed fire. Trends based on matched locations (timberland for both the 1980s and 1990s surveys) indicated a statistically significant decline in infestation probability over the decade for Japanese honeysuckle, no change in kudzu, and an increase in privet.

A third example characterizes forest fragmentation and the odds of infestation relative to the forest edge by employing the fixed configuration of the current plot design. Of 6,761 sampled forest locations in the 1997 survey of Georgia's timberland, 9 percent contained forest-nonforest edges[2]. The odds of an infestation by Japanese honeysuckle were two times greater, for privet three times greater, and for kudzu seven times greater at the forest edge than in forest interior locations. Forest land in nonforest-dominated neighborhoods may be particularly vulnerable to invasion due to the close proximity to anthropogenic activities and likely larger invasive plant populations on nonforest land (Franklin *et al.* 2003).

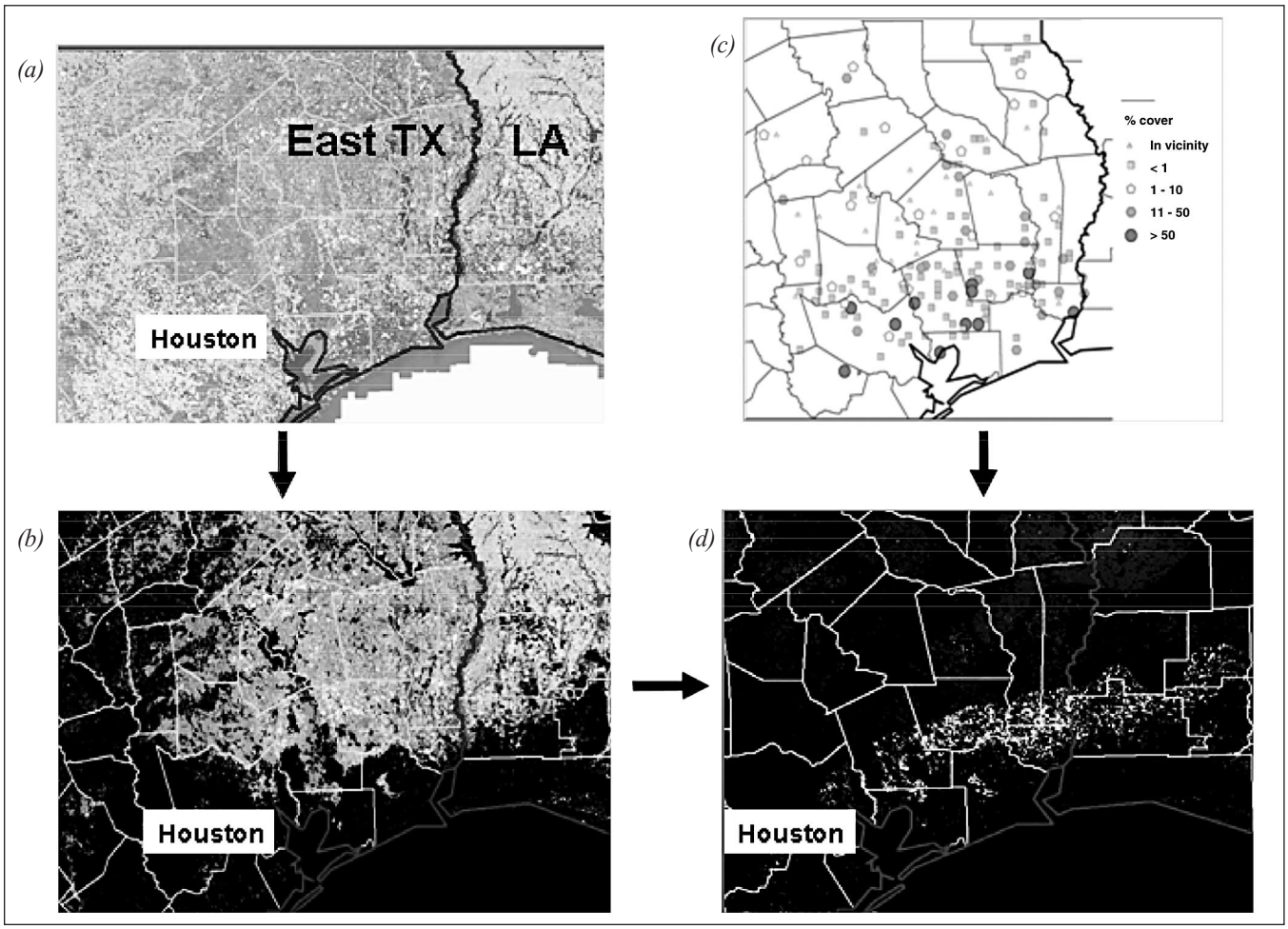
Figure 5.—*Infestation probability of Japanese honeysuckle on timberland, southeastern United States.*



[2] Data on file with: USDA Forest Service, FIA Program, 4700 Old Kingston Pike, Knoxville, TN 37919.

Fine-scaled, spatially referenced estimates of invasive species often are the data of most interest to county and other local land managers. This fourth example describes a protocol for obtaining fine-scale, spatially-registered estimates for Chinese tallowtree, a species noted in surveys conducted in the south central United States beginning with 1990s surveys. Figure 6 illustrates portions of the protocol. Initial efforts require geographic registration of satellite imagery to FIA plot locations containing a single condition, and all four subplots are completely forested or completely nonforested. The next step develops a model that predicts forest land and nonforest land based on sampled values; secondary data from other sources also are employed as predictors. Figure 6b illustrates results using Moderate Resolution Imaging Spectroradiometer (MODIS) imagery to predict forest land at 250-m resolution. The third step develops a predictive model of invasive species presence and biomass volume for standing trees. In addition to FIA plot and forest condition information, the model may include other geographically registered data, such as generalized ecoregion boundaries, specific climate attributes from the National Weather Service, slope and elevation estimates from the U.S. Geological Survey, and soil properties from the NRCS Natural Resources Inventory. The final model yields a map of satellite image spectral values that estimate the species' biomass volume at 250-m resolution. For Chinese tallowtree, biomass values may appear something like those displayed in figure 6d.

Figure 6.—*Steps in the process of fine-scaled estimation of Chinese tallowtree biomass: (a) MODIS satellite imagery at 250-m resolution for east Texas and west Louisiana; (b) spectral value classification of forest and nonforest land; (c) Chinese tallowtree-infested FIA forest land sample locations in east Texas by presence and infestation severity (percent total cover); and (d) depiction of Chinese tallowtree biomass at 250-m resolution.*



Analysts can test the underlying predictions against other FIA observations withheld from initial model development. The final map product, together with associated reliability statistics, provides sufficient spatial resolution for more detailed planning by county-level managers.

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Appendix

This list contains the inventoried invasive species on Forest Inventory and Analysis (FIA) forest plots in the conterminous United States.

Trees

National (Core-required)

- Tree-of-heaven[†b] *Ailanthus altissima*
- Tung-oil tree *Aleurites fordii*
- Mimosa, silktree[†] *Albizia julibrissin*
- European alder *Alnus glutinosa*
- Eucalyptus *Eucalyptus* spp.
- Melaleuca[‡] *Melaleuca quinquenervia*
- Chinaberry[*] *Melia azedarach*
- Royal paulownia *Paulownia tomentosa*
- Mesquite[‡] *Prosopis* (selected species, not *P. glandulosa*, *P. pubescens, P. velutina*)
- European mountain ash *Sorbus aucuparia*
- Chinese tallowtree[†] *Triadica sebifera* (*Sapium sebiferum*)
- Siberian elm *Ulmus pumila*

National (Core-optional)

- Norway maple *Acer platanoides*
- Camphortree[†] *Cinnamomum camphora*
- Russian olive[*b] *Elaeagnus angustifolia*
- Saltcedar[a, b] *Tamarix* spp.

Shrubs

North Central

- Japanese barberry[†] *Berberis thunbergii*
- Glossy buckthorn *Frangula alnus*
- Common buckthorn *Rhamnus cathartica*

North Central, Southern

- Autumn olive[†] *Elaeagnus umbellata*
- European privet[†c] *Ligustrum vulgare*
- Bush honeysuckles[†] *Lonicera* spp.
- Multiflora rose[†] *Rosa multiflora*

Pacific Northwest

- English holly[c] *Ilex aquifolium*
- Himalayan blackberry[b, c] *Rubus discolor*
- Cutleaf blackberry[c] *Rubus lacinatus*
- Scotch broom[b, c] *Cytisus scoparius*
- Gorse[b, c] *Ulex europaeus*

Southern

- Silverthorn[*] *Elaeagnus pungens*
- Winged euonymus, burning bush, *Euonymus alata*
- Chinese privet[†] *Ligustrum sinense*, Japanese privet[†] *L. japonicum*, glossy privet[†] *L. lucidum*
- Nandina, sacred bamboo[*] *Nandina domestica*
- Nonnative roses *Rosa spp.*

Ferns—Southern

- Japanese climbing fern[†] *Lygodium japonicum*

Forbs/Herbs/Other Herbaceous

Interior West

- Russian knapweed[b, c] *Acroptilon repens*
- Hoarycress[b, c] *Cardaria draba*
- Diffuse knapweed[b, c] *Centauria diffusa*

Interior West, North Central

- Leafy spurge[b, c] *Euphorbia esula*

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[*] Species introduction on national forest land discouraged (Southeast Exotic Pest Plant Council 2001).
[†] Species introduction on national forest land prohibited (Southeast Exotic Pest Plant Council 2001).
[‡] Species on the Federal Noxious Weed List (Federal Register 2004).
[a] Surveyed as a tree only in the Interior West.
[b] Species present and representing a potential threat to the Sierra Nevada National Forest (USDA Forest Service, Pacific Southwest Region 2001).
[c] Species introduction on national forest land prohibited (USDA Forest Service, Pacific Northwest Region 2004).

Interior West, North Central, Pacific Northwest

- Thistle[*b, c] *Circium* spp.

North Central

- Common burdock *Arctium minus*
- Japanese knotweed[†c] *Polygonum cuspidatum*
- Mile-a-minute weed[*] *P.perfoliatum*

North Central, most of Interior West

- Spotted knapweed[c] *Centauria bierbersteinii*

North Central, Southern

- Garlic mustard[†] *Alliaria petiolata*

Pacific Northwest

- ***NFS California:***
  - Musk thistle[*b, c] *Carduus nutans*
  - Knapweed[b, c] *Centauria diffusa, C. solstitialis, C. maculosa*[*]
  - Rush skeleton weed *Chonrilla juncea*
  - Spurge[b, c] *Euphorbia esula, E. oblongata*
  - French broom[b, c] *Genista monspessulana*
  - Medusa head[b, c] *Taeniatherum caputmedusa*
- Foxglove[c] *Digitalis purpurea*
- Wall lettuce *Mycelis muralis*

Pacific Northwest Unites States and Colorado, Montana, Nevada, and Wyoming

- St. Johnswort[b, c] *Hypericum perforatum*

Southern

- Shrubby lespedeza *Lespedeza bicolor*

Southern United States and Arizona

- Chinese lespedeza[†] *Lespedeza cuneata*
- Tropical soda apple[‡] *Solanum viarum*

Grasses

North Central

- Reed canary grass[c] *Phalaris arundinacea*
- Common reed *Phragmites australis*

North Central, Southern

- Nepalese browntop[†] *Microstegium vimineum*

Southern

- Giant reed *Arundo donax*
- Tall fescue[†] *Lolium arundinaceum*
- Cogongrass[‡] *Imperata cylindrica*
- Chinese silvergrass[*] *Miscanthus sinensis*
- Nonnative bamboos *Phyllostachys* spp., *Bambusa* spp

Vines

Pacific Northwest, Southern

- English ivy[*c] *Hedera helix*

North Central

- Porcelainberry[*] *Ampelopsis brevipedunculata*
- Black swallowwort *Cynanchum louiseae*

North Central, Southern

- Oriental or Asian bittersweet[†] *Celastrus orbiculatus*
- Nonnative climbing yams –air yam/Chinese yam/water yam[†] *Dioscorea bulbifera/D. oppositifolia/D. alata*
- Wintercreeper[†] *Euonymus fortunei*
- Japanese honeysuckle[†] *Lonicera japonica*
- Kudzu[†] *Pueraria montana*

Southern

- Periwinkles[c] *Vinca minor, V.major*
- Chinese/Japanese wisteria[*] *Wisteria sinensis/W. floribunda*

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[*] Species introduction on national forest land discouraged (Southeast Exotic Pest Plant Council 2001).
[†] Species introduction on national forest land prohibited (Southeast Exotic Pest Plant Council 2001).
[‡] Species on the Federal Noxious Weed List (Federal Register 2004).
[b] Species present and representing a potential threat to the Sierra Nevada National Forest (USDA Forest Service, Pacific Southwest Region 2001).
[c] Species introduction on national forest land prohibited (USDA Forest Service, Pacific Northwest Region 2004).

Florida Supplement

Florida Trees

- Australian-pines *Casuarina spp.*
- Carrotwood *Cupaniopsis anacardioides*
- Schefflera *Schefflera actinophylla*
- Java plum *Syzygium cumini*

Florida Subshrubs

- Coral ardisia† *Ardisia crenata*
- Lantana *Lantana camara*

Florida Shrubs

- Surinam cherry *Eugenia uniflora*
- Guava spp. *Psidium* spp.
- Downy rose myrtle† *Rhodomyrtus tomentosa*
- Brazilian pepper† *Schinus terebinthifolius*
- Wetland nightshade‡ *Solanum tampicense*

Florida Vines

- Rosary pea *Abrus precatorius*
- Cat's-claw vine* *Macfadyena ungis-cati*
- Skunk vines† *Paederia spp*.

Florida Grasses

- Napier grass *Pennisetum purpureum*

Florida Ferns

- Smallleaf climbing fern† *Lygodium microphyllum*
- Sword fern *Nephrolepis cordifolia*

Florida Forbs/Herbs/Other Herbaceous

- Hairy indigo *Indigofera hirsuta*

Not included are lists used in special studies supported in part by cooperating agencies. For example, the Northeastern FIA uses an extended list of nonnative tree species in special surveys of urban and other nonforest land (Riemann 2003), and conducts an ongoing, growing-season survey to assess cover for 12 invasive species, and occurrence for 38 others in Pennsylvania. In the West, special surveys in selected western national forest districts and regions include noxious species surveys on nonforest land, e.g., Bridger-Teton National Forests (O'Brien *et al.* 2003).

* Species introduction on national forest land discouraged (Southeast Exotic Pest Plant Council 2001).
† Species introduction on national forest land prohibited (Southeast Exotic Pest Plant Council 2001).
‡ Species on the Federal Noxious Weed List (Federal Register 2004).