CHAPTER 15.

The Invasion of Southern Forests by Nonnative Plants: Current and Future Occupation, with Impacts, Management Strategies, and Mitigation Approaches

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KEY FINDINGS

- Invasive plants continue to escape into and spread through southern forests to eventually form exclusive infestations, and replace native communities to the detriment of forest productivity, biodiversity, ecosystem services, and human use potential.
- Over a 300-year period, invasive plants have been increasingly imported into the South, despite public policies and warnings by professional ecologists and plant experts of long-term irreversible ecosystem damage.
- The invasion process is accelerated by greater forest disturbance, fragmentation, parcelization, and urbanization needed to accommodate and support an increasing population and is being accelerated by climate warming. Approximately 9 percent of southern forests or about 19 million acres are currently occupied by one or more of the 300 invasive plants in the region.
- The annual spread of invasive plants in southern forests is conservatively estimated at a 145,000 forested acres; accelerated by a warming climate and by increasing numbers of forest disturbances that accommodate and support growing human populations.
- Given the current occupation and spread of invasive plants and the increasingly common infestations by multiple species, eradication appears only probable on specific lands unless awareness and strategic programs are greatly enhanced.
- Over a 20 year period, research has developed effective control treatments and integrated approaches that can eradicate or replace invasive plants, while a more robust, coordinated, and focused effort will be required to stem and turn the tide of invasion.
- Model projections show high-threat invasive plants have not reached their potential range or density limits within the region under current conditions. A predicted warming climate will permit northward range extensions for some, while range extensions can be restricted by a simultaneous drier climate. Losses in forest production, recreation, and wildlife habitat would have quality-of-life implications for future generations that would continue to be exacerbated if not mitigated.
- Increased occupation by invasive plants would diminish the variety and abundance of current wood-based products from the “wood basket” of the United States. Some invasive species may find use in biomass and composite products if harvesting and processing become more efficient.
- Most plants escaping into southern forests have been imported, hybridized, sold, and planted for yard and garden beautification, soil stabilization, wildlife habitat enhancement, and livestock production.
- Stricter controls for importing species are pending, but their effectiveness will be hampered as long as garden centers continue to market invasive plants as ornamentals.
- Limiting the degree of occupation and impact depends on the development of adaptive management programs and actions that are coordinated across political boundaries and engage all ownerships. Piecemeal and splintered actions by agencies and ownerships, if continued, cannot dwarf the destructive impacts of this invasion.
- Public awareness campaigns, cooperative spread abatement networks, collaborative programs of detection and eradication, dedicated research and extension programs, and employment of new land restoration options have been found to slow the spread of invasive plants and prevent them from destroying critical habitats.

INTRODUCTION

Invasive plants pose one of the most immediate threats and socio-ecological challenges we face to present and future forests, especially in the South (Miller and others 2010b, Moser and others 2009). These alien plants increasingly infiltrate landscapes to erode and replace native communities while irreversibly degrading critical human-sustaining ecosystems (Mack and others 2000, Pimentel 2002, U.S. Congress OTA 1993). The replacement of diverse native plant communities by dense infestations with limited

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species is becoming widespread—altering forest ecosystem structure and function, threatening all forest communities and agricultural systems, and imposing human economic and cultural costs (Holmes and others 2009, Mack and others 2000, Pfeiffer and Voeks 2008).

The U.S. Congress Office of Technology Assessment (1993) reported that the need for a more restrictive national policy on introductions of nonnative species was widely acknowledged but impeded by historical divisions among agencies and constituencies. Most plants that have escaped into wildlands have gained entry into the United States through the vast and complex plant production industry or by other deliberate introductions (Bryson and Carter 2004, Drew and others 2010). Invasive species continue to be both accidentally and intentionally introduced through relatively porous entry points (Carrete and Tella 2008, Conn and others 2008, Mack and others 2000). The ever increasing volume of trade, including international Internet sales, will continue this trend unless surveillance improves (Britton and others 2005, Mack and others 2000, Simberloff and others 2005). Of the 20,000 species of nonnative plants now living in the United States, about 4,500 have invasive tendencies (Devine 1989), and thousands more reside in gardens, moving with the expanding urban fringe, with unknown consequences to adjoining lands (Pimentel 2002).

Of the 380-plus recognized invasive plants in southern forests and grasslands (more than 330 terrestrials and 48 aquatics) 53 are ranked as high-to-medium risk to natural communities (Morse and others 2004, USDA Forest Service 2008b). Only recently has the extent of invasive plant occupation in the Southern United States and elsewhere in the world been realized (Colton and Alpert 1998, Miller 2003). Colton and Alpert (1998) report that the extent and spread of nonnative plant species over the past several decades has taken most people by surprise, and is still not comprehended by most citizens and policymakers.

In 1999, President Clinton issued Executive Order 13112 defining an “invasive species” as a species: (1) that is nonnative (or alien) to the ecosystem under consideration (such as the South) and (2) whose introduction causes or is likely to cause economic or environmental harm or harm to humans. Thus, a plant invader is a species that occurs outside its area of origin and has become established, can reproduce, and can spread without cultivation to cause harmful impacts. The Executive Order established the National Invasive Species Council to coordinate a counter offensive and instructed Federal agencies to direct available funding toward prevention, detection, response, monitoring, restoration, research, and public awareness efforts.

The National Invasive Species Council involves Federal agency heads as members. They were mandated to establish the National Technical Advisory Council and to write a national invasive species strategic plan with reviews and revisions every five years (National Invasive Species Council 2001). Since then, most agencies have drafted their own strategic plans (such as those prepared by the USDA Forest Service and its Southern Region). As instructed by the Executive Order, agency implementation of invasive programs has been in collaboration with regional efforts and subject to the availability of appropriated funding. Much networking among Federal and State agencies has occurred owing to the Executive Order along with non-governmental partners. Control activities and treatments have been initiated during this period, while these efforts in every Southern State are only coordinated in Florida, with formal partnerships among governmental and non-governmental collaborators.

Not all nonnative plants are invasive. Some 128 crop species have been intentionally introduced and a few are among our most valued crops, including wheat, barley, rice, oats, and corn, which was a Native American introduction from Mesoamerica (Pimentel 2002). Other nonnative grasses are mainstays for forage; however, many of them are often invasive in regenerated forests or forest openings. For example, pasture grasses are highly competitive when invading loblolly pine (*Pinus taeda*) plantings, reducing early survival and growth (Smith 1989). Plant breeding programs over the past 150 years have yielded numerous crop and forage varieties that have improved productivity, useable yields, and tolerance to a wider range of growing conditions and predators. And over the past 50 years, the rapid increase in turf, ornamental and horticultural species and varieties has improved many aspects of modern life, such as landscape beautification and fast growing shade trees and shrubs. But the accumulation of all these introductions and “improved” varieties have taken its toll on our natural ecosystems (Burton and Samuelson 2008, Mack and others 2000); as well as in parks, green spaces, and rights-of-way, where the cost of controlling invasive species has skyrocketed (Perrings and others 2002, Pimentel 2002, U.S. Congress Office of Technology Assessment 1993).

Invasive plants can in general outcompete native species and reproduce rapidly in the absence of predators from their native lands to form dense infestations that exclude most other plants (Randall and Marinelli 1996). These infestations decrease forest productivity, threaten forest health and sustainability, and limit biodiversity and wildlife habitat on millions of acres including protected habitats (Westbrooks 1998). Alterations to forest structure and natural succession result in changes in functions and processes that threaten vital ecosystem services, like soil formation, water yield, and air rejuvenation (Ehrenfeld and others 2001, Gomez-Aparicio and Canham 2008, Martin and others 2009). Some invasives alter natural fire regimes and increase risk of wildfire

Existing Collaborative Invasive Plant Efforts in the South

Nonnative invasive plant collaboration networks in the South are presently organized for horizontal connectivity, usually State centered. The leading collective efforts involved in managing nonnative invasive plants are voluntary State exotic pest plant councils linked via the Internet through university centers with State land management agencies, individual and corporate land owners, and vegetation management associations. Fledgling cooperative weed management areas are becoming organized within States and among groups of counties. The first council was established in 1984 to bring together numerous agencies combating severe outbreaks in the Everglades and tropical Florida. With significant State and Federal funding, strong leadership, a dedicated and inclusive membership, and a focus on natural areas, the Florida council has developed a mission statement, bylaws, invasive list with threat categories, and identification and control publications (Langeland and others 2008).

The Tennessee council was established in 1994 with assistance from Florida council members and support from the Great Smoky Mountains National Park, which has had an invasive plant control program under way since the 1970s. The Tennessee Council's mission and goals, like Florida's, focuses on raising public awareness, facilitating the exchange of information on identification and control, convening forums and workshops to share information, advising on all aspects of nonnative invasive plants, and launching campaigns to prevent future introductions. Among its accomplishments has been an exotic plant management manual for the State (Tennessee Exotic Pest Plant Council 1996) and leadership in organizing both a South-wide council to fulfill a regional mission to one that now includes a national council in 1997. From 1999 to 2008, exotic plant councils were organized in Georgia (1999), Kentucky (2000), Alabama (2002), Mississippi (2002), South Carolina (2003), North Carolina (2005) and Texas (2008). Most of these broadened the scope of their partnerships to include right-of-way managers, gardeners, native plant enthusiasts, and stakeholders from all components of the intricate modern landscape. State and regional annual meetings share current developments in research, policy, new nonnative invasive plant arrivals, and council activities that have helped to propel invasive management efforts in the region. Although their 501(c)(3) Federal tax status allows some collaborative lobbying, this avenue has not yet been pursued.

The South-wide and State Web sites are hosted at the Center for Invasive Species and Ecosystem Health (an offshoot of the Bugwood Network organized in 1994), which was given official status by the University of Georgia in 2007. In cooperation with Federal agencies, the Center provides critical information and services such as the invasive plants listed by each State, identification and control guides for these invasive plants, details and Web hosting for cogongrass (www.cogongrass.org) and other severe invasive plants, and annual meeting proceedings. The Center maintains an image database system containing over 145,000 high-resolution images of native and nonnative species (Bargeron and others 2006) and with The Invasive Plant Atlas of the United States provides identification, distribution, and management methods for most recognized invasive plants of the United States (Bargeron and others 2007). Regional connectivity for council members on nonnative invasive plant matters is also being provided by the Center's managing a listserv, blog, Facebook page, and Twitter site. The Center also hosts a national reporting and mapping Web site entitled EDDMapS, Early Detection and Distribution Mapping System (Bargeron and Moorhead 2007). It is publically accessible, provides for voluntary inputs by State councils, and assigns a verifier to review data submitted on invasive species infestations and distribution. This mapping site has in 2010 been expanded to cover the entire United States. In 2008, the Woodrow Wilson School at Princeton University created another voluntary mapping database—the Invasive Species Mapping Program—that focuses on the southern distribution of Chinese privet, kudzu, and cogongrass (Marvin and others 2008). Additionally, a parallel mapping project, the Invasive Plant Atlas of the MidSouth, is under construction at the Mississippi State University GeoSpatial Institute. It will combine information from the U.S. Geological Survey and other agencies with the Invasive Plant Atlas of New England; and it will incorporate mechanisms and procedures to transmit data both upward (nationally) and downward to the local level for rapid assessment and response. These databases are being linked and projected to map most nonnative invasive plants in the region and eventually provide an effective and efficient early detection and rapid response network for identifying and locating new high-risk introductions (Westbrooks 2004).

State vegetation management associations and societies focused on right-of-way management and their regional and national organizations represent potentially invaluable collaborative partners for pest plant councils. These associations recently added nonnative invasive plant management to their certified training curriculum. Because rights-of-way are major conduits for some invasive plant spread, this increased awareness and added management approaches should greatly aid further containment. Most pest plant councils have a transportation department employee on their boards and many professional right-of-way managers are members of pest plant councils. These interactions have contributed to new regulations ensuring that right-of-way projects use fill-dirt and rock uncontaminated by invasive plant seeds and plants.

occurrence and damage (Brooks and others 2004, Lippincott 2000). Exotic plant bio-pollution is one of the greatest threats to biodiversity, second only to habitat destruction, and continues to attack our highly valued nature preserves and wetlands (Wilcove and others 1998).

To date, successful efforts to combat and contain invasive nonnative plants have taken an integrated approach to vegetation management (Miller 2003, Miller and others 2010b). This approach incorporates all effective control methods, which may include preventive measures (such as quarantines, border inspections, and embargoes), biocontrol using natural predators, herbicide technology, prescribed fire, and mechanical and manual removal. Most preventive measures and biocontrol programs are only effective when organized on a regional basis because cooperation among States is necessary for their success (Moran and others 2005, Pimentel and others 2000, Westbrooks 2004).

This chapter summarizes pertinent information for the most damaging trees, shrubs, vines, grasses, and forbs that have invaded forests and natural areas as well as pastures, rights-of-way, orchards, grasslands, wetlands, and yards in the South (Langeland and others 2008, Miller and others 2010a). Our objective is to provide useful information on species descriptions, traits that make them invasive, and current management procedures and strategies for 56 threatening invasive plants in 31 groups. The chapter also covers principles of invasion and the value of organization, planning, prevention, and management programs in slowing their spread (with the caveat that eradication of widespread invasions appears only possible on specific lands). Finally, the current occupation and impacts of the invasive plants are presented, with projections of potential spread for the next 50 years.

METHODS AND DATA SOURCE

Biological and ecological traits are summarized from the literature for the major invasive plants in the South to guide specific and general management actions. Recognized concepts, impacts, strategies, policies, and program elements regarding invasive plants and their management are synthesized from the literature. The influences and impacts relative to the other meta-issue areas are discussed using current literature and inputs derived from their chapters. Linear regression was used to calculate the mean annual spread rate in forests using the approximate date of introduction, major planting campaigns or escape documented in the literature, and current occupation estimates from Forest Service survey results. The linear regression models provided conservative estimates of future occupation under past and current climate conditions and no expected major control programs. Other modeling approaches used the climate change cornerstones and landscape data bases to forecast current and future potential habitat for five high-threat species.

In 2001, the Southern Research Station of the Forest Service, U.S. Department of Agriculture began surveying 53 invasive plant groups on all forest ownerships in partnership with State forestry agencies (USDA Forest Service 2008a). This survey of 33 regional species (Miller 2003) and 20 species particular to Florida (Langeland and Burks 1998) has become part of the traditional timber data collections that have been conducted by the Station's Forest Inventory and Analysis unit (FIA) since the 1930s. Maps of occupation for the most occupying species and tabular coverage estimates were derived from these data.

The species selected for survey are regionally recognized nonnative plants known to invade interior forest stands, some forest edges, gaps, roadsides, and stream-sides less than 120 feet wide. The 13 State inventories commenced in different years; although they have varying rates of progress and cycle completions, the expectation is that at least a fifth of the plots within a State will be inventoried every year (Oklahoma's data has yet to be verified for posting). Percent cover by species is recorded on existing FIA clusters of four permanent 1/24-acre subplot that are located across forested landscapes on an approximately 3-mile grid. Each subplot represents about 1,500 acres. Invasive plant cover is recorded in five categories: 1 = trace to <1 percent; 2 = 1 to 10 percent; 3 = 11 to 50 percent; 4 = 51 to 90 percent; and 5 = 91 to 100 percent. For each category, midpoint values are used to calculate an estimate of cover by species for the region and for each county within a State. Our methods combine analyses of FIA data to display current occupation by county, State, and subregion, and then follow up with analyses to understand the nature of occupations.

We focused our predictive modeling on five species of high concern in the South using the Cornerstone Futures. These species were selected because they had sufficient datasets, represented a range of plant growth forms and invasion patterns, and varied by subregional occurrence. The modeled species were Japanese climbing fern (*Lygodium japonicum*), Nepalese browntop (*Microstegium vimineum*), nonnative roses (*Rosa* spp.), silktree (*Albizia julbrissin*), and tallowtree (*Triadica sebifera*). Human and environmental landscape variables were extracted from available digital information for each FIA datapoint, including national resource inventory land-use categories, distance to roads and rivers, human population census with projections, elevation, and climate information (Gesch and others 2002, PRISM Group 2008, U.S. Census Bureau 2000). All variables were converted into 295 feet by 295 feet (90 m by 90 m) cells across the South.

Two modeling techniques, logistic regression (Hosmer and Lemeshow 2000) and maximum entropy (Phillips and others 2006), were used to develop a potential distribution for each species. Logistic regression is a generalized linear model that is used to investigate the relationship between a set of explanatory variables for prediction of the probability of occurrence of an event by fitting data to a logistic curve. It makes use of several predictor variables that may be either numerical or categorical. Logistic regression makes no assumptions about the distribution of the independent variables. MaxEnt (Phillips and others 2006) is based on maximum entropy probability distribution. It is a probability distribution whose entropy is at least as great as that of all other members of a specified class of distributions. The MaxEnt approach is to estimate the probability distribution, such as the spatial distribution of a species that is the greatest extent subject to constraints such as the known locations of the species. It is a machine learning technique that predicts species distributions using detailed geospatial data sets together with species occurrence information, conducted using a specialized program package of MaxEnt (Phillips and others 2006). It generally performs as well or better than other algorithms in tests of model performance (Elith and others 2006, Phillips and others 2006). The important difference between the two techniques is that logistic regression uses information on both presence and absence to estimate a predictive linear model, whereas maximum entropy (MaxEnt) uses information from presence-only and is a nonparametric approach. In developing models for species, variables were eliminated using a manual backward selection method to delete those having little or no impact. Impact on the model was measured as percent contribution and with a jackknife test on gain and influence on area under the curve (AUC). This allowed identification of key variables in determining the occurrence of each species.

To identify the key variables in determining each species occurrence, we calculated the contribution of each variable to the model. The omission rate and area under the Receiver Operator Characteristic (AUC) were used to assess the reliability and validity of models. To assess models, FIA data were split spatially with 50 percent used as a test dataset and 50 percent used as a training dataset. The omission rate is the false negative or the proportion of sites where the species was present but the model predicted absence. To calculate this, a cut-off criterion is required to convert continuous model predictions to binary classifications. We used a threshold value that maximized the sum of sensitivity and specificity. The *sensitivity* is the proportion of actual presence correctly identified and the *specificity* is the proportion of absences correctly identified. Sensitivity and specificity for each potential cut-off were added together and the cut-off with the greatest combined number was selected for further work. This has the advantage of giving equal weights to the probability of success of both presences and absences (Manel and others 2002). This is one of the most appropriate methods to correctly derive a binary variable from continuous probabilities when species presence-absence distribution data are unbalanced (Jiménez-Valverde and Lobo 2006, Liu and others 2005). AUC provides a single measure of model performance, independent of any particular choice of threshold but is sensitive to the method in which absences in the evaluation data are selected (Lobo and others 2008). It is most applicable to data with true absences (Jiménez-Valverde 2011), thus it needs to be used with caution with datasets that do not have absence data. The models run with FIA data were measured absences, but as invasions are not at their full potential, these were not necessarily true absences. We used the following classes of AUC to assess model performance: 0.50 to 0.75 = fair, 0.75 to 0.92 = good, 0.92 to 0.97 = very good, and 0.97 to 1.00 = excellent (Hosmer and Lemeshow 2000). AUC is useful when used in conjunction with other validation statistics because invasive species are often not at equilibrium with their environment and their current realized distribution is much smaller than their potential distribution, thus even field absence data can be temporary with a time dimension.

Although logistic and MaxEnt models may be compared individually to select the best overall model for a particular dataset, combining the two (Araújo and New 2007) can reduce the uncertainty associated with dependence on one or the other. We identified areas where both models predict high potential of invasion, areas where just one model predicts moderate potential of invasion, and areas where both models predict low potential of invasion. Variable contribution to the models was calculated as an average of the two models and direction was assessed in combination. The directions were either a linear positive or negative, or a binomial (two peaks) or polynomial (one valley) relationship. The percentage of forest invaded was calculated by overlaying the final occurrence map with a binary layer of forest for each Cornerstone (chapter 2), producing percentages at high and moderate potential levels. For comparison, each was converted to a current and future percentage of forested FIA plots invaded for each species and for each Cornerstone, based on projected forest acreage (chapter 5). Using these same models, a likewise probability for nonforested lands was calculated for display on the same maps. Because the datasets of landscape variables used for modeling were extracted for the entire South and FIA from forested area, predictions for nonforest lands using forest plot occurrence may be less accurate. However, because all invasive species have large populations on nonforested lands, their projected occupation on nondeveloped lands provides a depiction of interconnectivity that has been lacking. This interconnectivity of the forest and nonforest land invasions under way and projected should not be ignored, however limited the strength of the models on the nonforested portion may be.

RESULTS

The South's Most Pervasive Invasive Plants

The 31 groups (taxa) discussed here qualify as the first targets for proactive management because they account for much of the lands occupied by invasive plants. Although they cumulatively pose the greatest threat for the region, priorities vary for specific subregions, depending on current and potential occupations. Most are able to spread from one subregion to another if not contained, because most are limited by spread vectors and not environmental factors (Pattison and Mack 2009). In this section we summarize invasive plant descriptions, current and future occupation with country of origin (table 15.1), and the community layers they mostly impact (table 15.2) in five categories: trees, shrubs, vines, grasses and bamboos, and forbs. Descriptions are mostly derived from Miller and others (2010a) and Langeland and others (2008), while specific traits that lead to their success as invasives are derived from the wider literature.

Invasive Trees

In addition to dramatically altering habitats, nonnative trees hinder reforestation and management of rights-of-way and natural areas. Some species occur initially as scattered individuals and then eventually form dense stands if not controlled. Almost all invasive trees are hardwoods. Most spread by prolific seed production and abundant root sprouts, and all are still sold as ornamentals unless prohibited by State laws. Because they tolerate an exceptionally wide range of soil and site conditions, they are popular as low maintenance ornamentals. Depending on conditions, invasive trees can be eliminated with herbicides by stem injection, cut-treat, soil spots, basal sprays, and foliar sprays (Miller and others 2010b). Although bulldozers with root rake blades, mulchers, chainsaws, and prescribed burning will eliminate or reduce standing trees, only herbicides are effective in controlling roots. Total elimination requires surveillance and treatment of resprouts and plant germinants that originate from the soil seed bank.

Tallowtree—Tallowtree or popcorntree (*Triadica sebifera*) forms nearly pure stands in former wet prairies and is more likely on low and flat lands, areas adjacent to water and roadways, sites recently harvested or disturbed, young stands, and private forestlands (Bruce and others 1995, Gan and others 2009). Tallowtree was originally introduced from China presumably through France into coastal South Carolina near Charleston and Georgia as early as the 1770s (Hunt 1947). It is a deciduous tree growing to 60 feet tall with leaves that are broadly ovate to diamond-shaped and turn bright yellow and scarlet in the autumn, which makes it an attractive and widely planted yard tree (Jubinsky and Anderson 1996). Also, the plant has a high tolerance to insect defoliation (Rogers and Siemann 2003) and all parts of the plant are considered toxic to humans, especially the inner seeds (Everest and others 1996). Although not pollinated by bees (but wind), the tree is prized and planted by honey producers because of its abundant nectar glands (Lieux 1975). Bundles of white waxy popcorn-like seeds appear on branchlets in the autumn and remain into winter. Seeds are high in fat and protein, and birds and possibly mammals consume the waxy seed coat and then pass and spread the seeds (Conway and Smith 2002; Renne and others 2000, 2002). Because they float, seeds are also spread by water around lake and bog margins as well as along drainage ditches, streams, and rivers. Tallowtree is shade intolerant, which limits seedling establishment in intact forests (Pattison and Mack 2009). Trees as young as 3 years can produce viable seed and remain reproductive for 100 years, capable of producing 100,000 seeds per year (Bruce and others 1997, Gray 1950). Seed viability in the soil is 2 to 7 years, and germination rate varies by State from 6 to 52 percent reported (Cameron and others 2000). Infestations intensify seeding and surface root sprouts, and foliage and roots release chemicals that inhibit other vegetation, causing an eventual collapse of biodiversity following invasion (Conway and others 2002).

Occupation occurs mostly in the Coastal Plain along the Gulf of Mexico and Atlantic Ocean, with the greatest concentration on invaded coastal prairies surrounding Houston (fig. 15.1). Reports of China's fourteen centuries of uses prompted the U.S. Department of Agriculture to establish trials and promote Gulf Coastal Plain plantings in Texas during the early 1900s, resulting in the current Texas epicenter (Howes 1949). Tallowtree has the highest regional occupation of any nonnative tree invader, with more than a half million acres covered and a 45 percent increase projected during the next 50 years (table 15.1) under current climate conditions. Floodwaters from multiple hurricanes in the past two decades have facilitated spread into damaged forests, wetlands, and wet prairies (Chapman and others 2008). Oswalt (2010) reported that the numbers of Chinese tallowtree in Louisiana, Mississippi, and eastern Texas increased by about 370 percent from the 1990s to 2005. Because its sole limitation is dispersal vectors, this invasive has yet to occupy the full extent of its range in North America (Pattison and Mack 2008, 2009). Increases in both range and severity have been predicted with a warming climate (Gan and others 2009), and we investigated this further and provide results in a later section.

Tree-of-heaven—Tree-of-heaven (*Ailanthus altissima*) or ailanthus occurs mostly along forest roads where it spreads into recently harvested or disturbed sites and displays exceptional competitive capabilities as a new player in stand development (Landerberger and others 2007, Miller 1990). Tree-of-heaven was imported into the Eastern U.S. as an

Table 15.1—High-priority invasive plants of southern forests: their origin, date of introduction or extensive planting, current cover, annual rate of spread, and projected cover in 2060 (absent control programs)

Species	Origin	Date of introduction or extensive planting	Current cover	Average annual rate of spread	Projected cover 2060
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Invasive Trees					
Tallowtree	Asia	About 1900	596,239	5,420	867,257
Tree-of-heaven	China	1784	243,111	1,076	296,897
Chinaberrytree	China/India	1830	101,426	563	129,600
Silktree, mimosa	Asia	1785	90,055	400	110,067
Brazilian peppertree	South America	1898	83,434	745	120,681
Melaleuca	Australia	1934	61,631	811	102,178
Princesstree	China	1844	27,009	163	35,144
Total			**1,202,905**	**9,178**	**1,661,824**
Invasive Shrubs					
Invasive privets	China/Europe/Japan/Korea	Ave 1875	3,180,488	23,559	4,358,447
Invasive roses	Japan/Korea/China	Ave 1877	693,618	5,215	954,377
Invasive lespedezas	Japan	Ave 1863	532,235	3,621	713,267
Bush honeysuckles	Asia	About 1950	345,622	5,760	633,640
Invasive elaeagnus	China/Japan/Europe/Asia	Ave 1930	96,421	1,205	156,684
Sacred bamboo	Asia/India	1960	24,595	492	49,190
Tropical soda apple	Brazil/Argentina	1988	9,570	435	31,320
Winged burning bush	Asia	1980	8,710	290	23,227
Total			**4,891,259**	**40,578**	**6,920,152**
Invasive Vines					
Japanese honeysuckle	Eastern Asia/Japan	About 1850	10,342,030	64,638	13,573,914
Japanese climbing fern	Asia/Australia	About 1918	314,758	3,421	485,822
Kudzu	Japan/China	About 1920	226,889	2,521	352,938
Invasive wisterias	Japan/China	Ave 1873	57,129	417	77,979
Invasive ivies	England/Europe/Asia	Ave 1762	29,328	118	35,241
Vincas, periwinkles	Europe	Ave 1780	25,255	110	30,745
Invasive climbing yams	Asia/Africa	Ave 1900	20,691	188	30,096
Wintercreeper	Asia	1907	11,860	115	17,617
Old World climbing fern	Africa/Asia/Australia	1960	9,369	187	18,738
Oriental bittersweet	Asia	1860	8,654	58	11,539
Total			**11,045,963**	**71,773**	**14,634,630**
Invasive Grasses and Canes					
Nepalese browntop	Tropical Asia	1919	935,529	10,281	1,449,556
Tall fescue	Europe	1940	767,208	10,960	1,315,214
Cogongrass	Japan/Phillipines	About 1935	60,107	801	100,178
Invasive bamboos	China	1882	56,581	442	78,683
Chinese silvergrass	Asia	1957	10,130	191	19,687
Total			**1,829,555**	**22,675**	**2,963,318**
Invasive Forbs					
Garlic mustard	Europe	About 1900	5,991	54	8,714
GRAND TOTAL			**18,975,673**	**146,947**	**26,658,728**

Table 15.2—Forest community layers and edges prone to be replaced by these species of invasive plants

Overstory replacers	Midstory replacers	Understory and ground-layer replacers	Edge and gap eroders	Persistent infestations in openings (disturbed areas)
Tallowtree	Silktree	Japanese honeysuckle	Silktree	All invasive plants readily establish in openings and disturbed areas
Princesstree	Privets	Bush lespedeza	Chinaberrytree	
Tree-of-heaven	Bush honeysuckles	Scared bamboo	Privets	
Melaleuca	Invasive elaeagnus	Winged burning bush	Invasive roses	
Brazilian peppertree	Oriental bittersweet	Japanese climbing fern	Tropical soda apple	
Chinaberrytree	Japanese climbing fern	Winter creeper	Invasive lespedezas	
Kudzu	Wisterias	Vincas, Periwinkles	Kudzu	
Wisterias		Invasive ivies	Japanese climbing fern	
Cogongrass		Nepalese browntop	Wisterias	
Bamboos		Cogongrass	Invasive climbing yams	
Old World climbing fern		Garlic mustard	Oriental Bittersweet	
			Nonnative ivies	
			Invasive Bamboos	
			Cogongrass	
			Nepalese Browntop	
			Chinese Silvergrass	

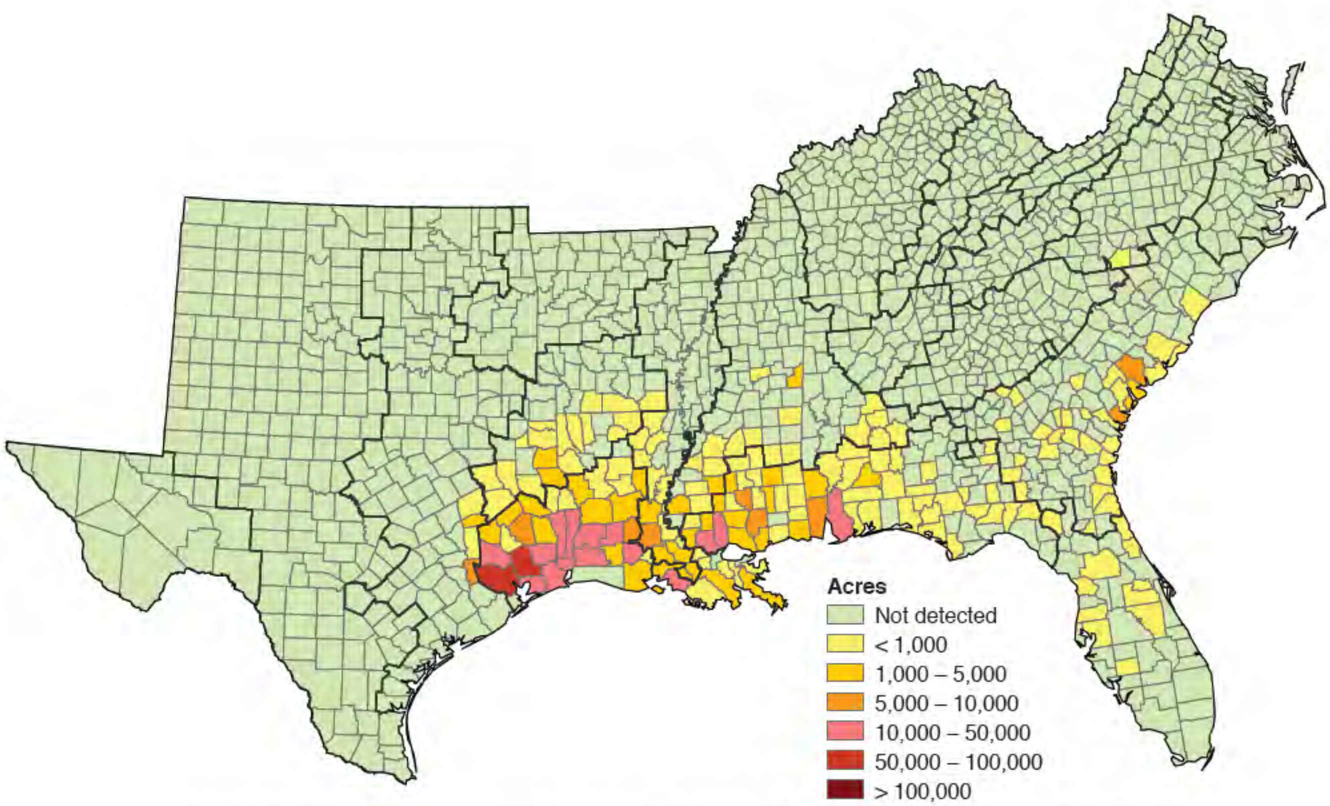

Figure 15.1—Tallowtree: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

ornamental in 1785 and was a common nursery species by the mid-1800s (Davies 1942, Hu 1979). Favorable early tests paved the way for widespread plantings on surface mined lands in Appalachia (Plass 1975). Tree-of-heaven is a shallow-rooted deciduous tree that can grow to 80 feet tall. It has long compound leaves that have rows of non- opposing leaflets on both sides of the stalk with two circular glands under small lobes at leaflet bases (Miller and others 2010a). Large terminal clusters of tiny greenish flowers in early summer yield persistent clusters of wing-shaped fruit with twisted tips on female trees. Viable seeds are produced at 2 to 3 years, and mature trees can produce more than 100,000 seeds per year (Renne and others 2002). Even light-green seeds in midsummer are capable of germination. Renne and others (2002) reported that 40 percent of a seed crop was dispersed by 16 bird species in coastal South Carolina. Seeds can be also blown up to 330 feet from a parent tree (Landenberger and others 2007) and can also float causing long-distance dispersal and infestations along streams and rivers (Kowarik and Saumel 2008). If the main stem is deadened, root sprouts will appear afterward, and root segments left in soil after pulling treatments will sprout (Miller and others 2010b). Sprouts can grow 10 to 14 feet tall the first year (Swingle 1916). This vigorous growth can continue for 4 or more years. Leaves and roots release allelopathic chemicals that inhibit other plants, decreasing biodiversity (Gomez-Aparicio and Canham 2008, Lawrence and others 1991).

The area of highest occupation is around Nashville in the Cumberland Plateau of Tennessee, followed by another one along the Shenandoah Valley where the Piedmont meets the Northern Ridge and Valley Province in Virginia (fig. 15.2). Southward spread is expected since scattered infestations occur even as far south as Florida, with a predicted increase of 24 percent more cover in 50 years (table 15.1).

Chinaberrytree—Chinaberrytree (*Melia azedarach*), a traditional widely escaped ornamental introduced into South Carolina and Georgia from Asia in 1830 (Gordon and Thomas 1997), is increasingly becoming established within forests. It is deciduous, growing to about 50 feet tall with multiple trunks that tend to arch outward. It has lacy, many divided leaves that are dark green, sometimes turning bright yellow in autumn (Miller and others 2010a). Showy panicles of tiny blue flowers in spring yield abundant round yellow pulpy fruits that persist during winter. Some seeds will germinate even when the fruit coats are green. If the main stem is deadened, stump sprouts, root sprouts, and seedlings will eventually emerge. Viable seed can be produced at 4 to 5 years, while the longevity of seed viability in the soil has not been reported. This species spreads by abundant bird- and animal-dispersed seeds (Vines 1960), which are toxic to humans and some mammals (Everest and others 1996). Occupation is highest across the Coastal Plains with scattered outliers elsewhere in the South (fig. 15.3). Occurrences in the cooler climates of northern Virginia indicate that range is not limited by temperature and that further spread can be expected. Chinaberrytree is the third most abundant invasive tree in the region (table 15.1). Region-wide spread has already occurred (USDA Natural Resource Conservation Service 2010), and an additional 28 percent of occupation is forecasted by 2060.

Silktree—Silktree or mimosa (*Albizia julbrissin*) is a small legume tree 10 to 50 feet tall imported into the South from central Asia (Cothran 2004) and traditionally planted as an ornamental owing to abundant showy pink and white flowers in spring and throughout summer. It reproduces by abundant seeds and root sprouts. It has feathery deciduous leaves and smooth light-brown bark. Profuse dangling flat pods containing 5 to 10 seeds are released during winter and can float to spread along waterways and ditches, where seeds remain viable for many years. All subregions have scattered silktree stands, mostly along highways, with the heaviest infestations in north central Alabama surrounding Birmingham (fig. 15.4). Silktree is currently the fourth most abundant invasive tree (table 15.1). Forest occupation is expected to increase by 22 percent over the next 50 years under current climate, resulting in extra roadside maintenance costs to prune jutting limbs. Various diseases attack silktree and may restrict future range and density (Dirr 1998). Estimates of spread rates with climate change scenarios are reported in a later section.

Brazilian peppertree—Brazilian peppertree (*Schinus terebinthifolius*) was initially imported in the mid- and late 1800s (Barley 1944), while it was made popular as an ornamental near Miami in the 1930s where it initially escaped (Morton 1978). Brazilian peppertree completely replaces native vegetation with its tangled infestations that reach heights of 40 feet (Langeland and others 2008). It is an evergreen shrub or small tree and has many short trunks or arching stems of contorted branches. Drooping, odd pinnately-compound leaves smell of turpentine when crushed. It produces many multi-branched clusters of small whitish flowers in summer and autumn that yield abundant clusters of spherical red pepper-smelling fruit in winter (only on female plants). Plants can produce seeds as early as 3 years. Germination mainly occurs from November to April, with seed viability ranging from 30 to 60 percent. Drought appears to be the main cause of seedling mortality. Allelopathic chemicals are released by fallen leaves that inhibit other plants, decreasing biodiversity (Morgan and Overholt 2005). Chemicals are produced in leaves, flowers, fruits, and sap that can irritate human skin and respiratory passages (Morton 1978).

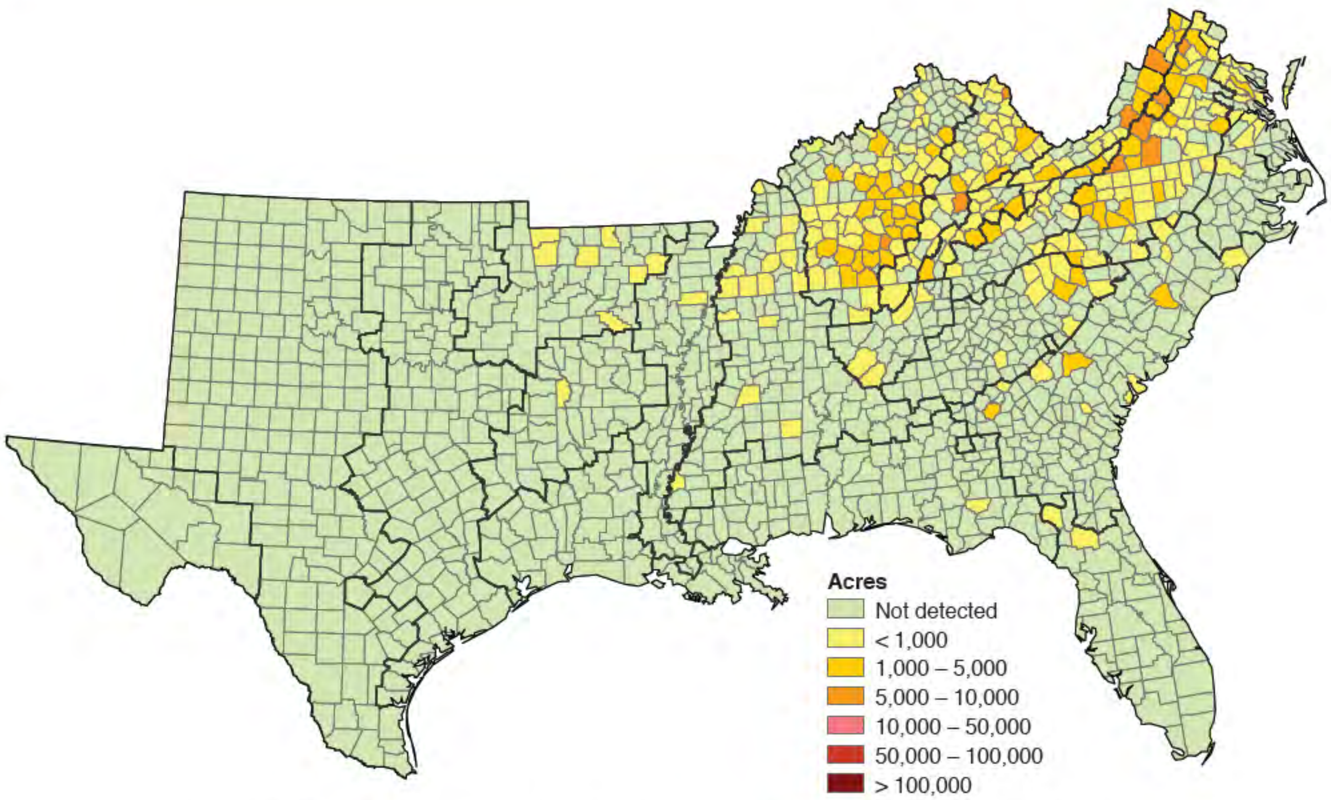

Figure 15.2—Tree-of-heaven: current regional cover, 2010.(Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

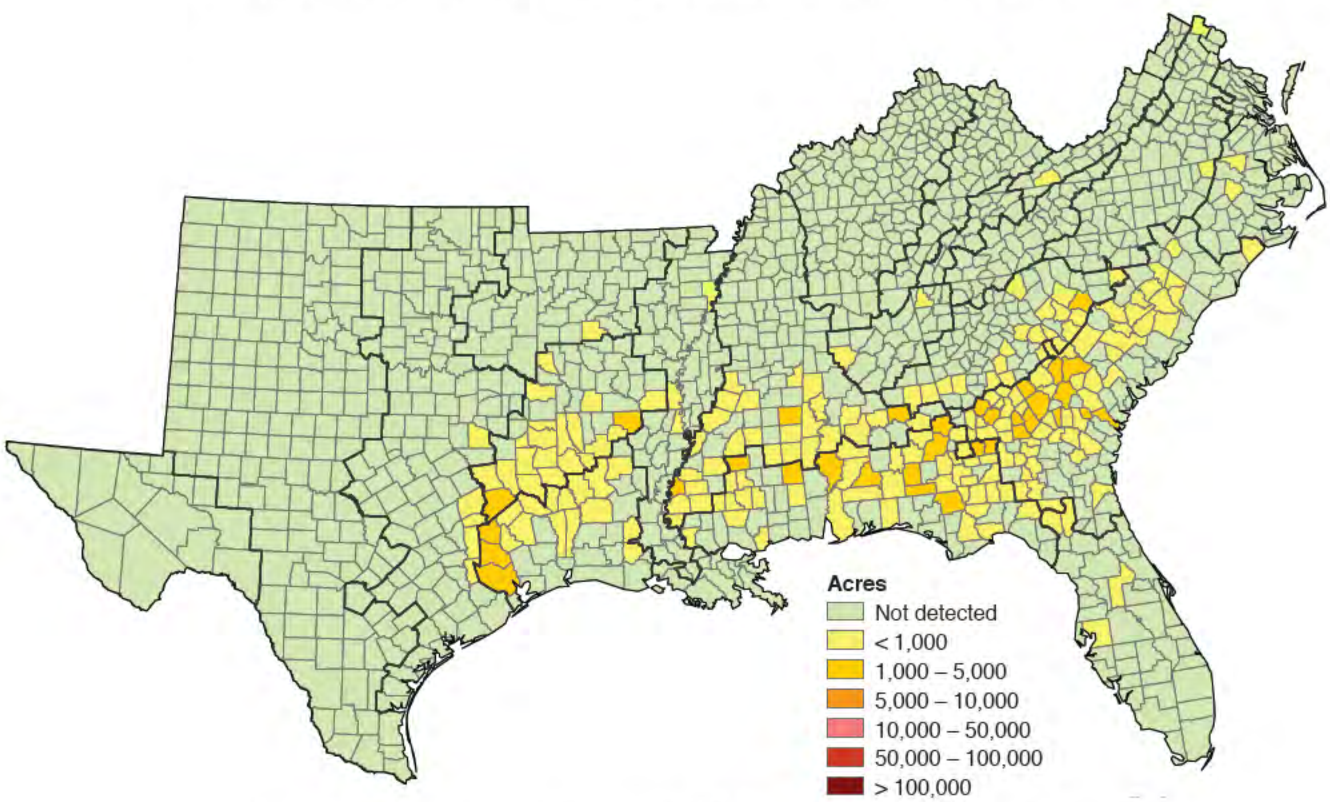

Figure 15.3—Chinaberrytree: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

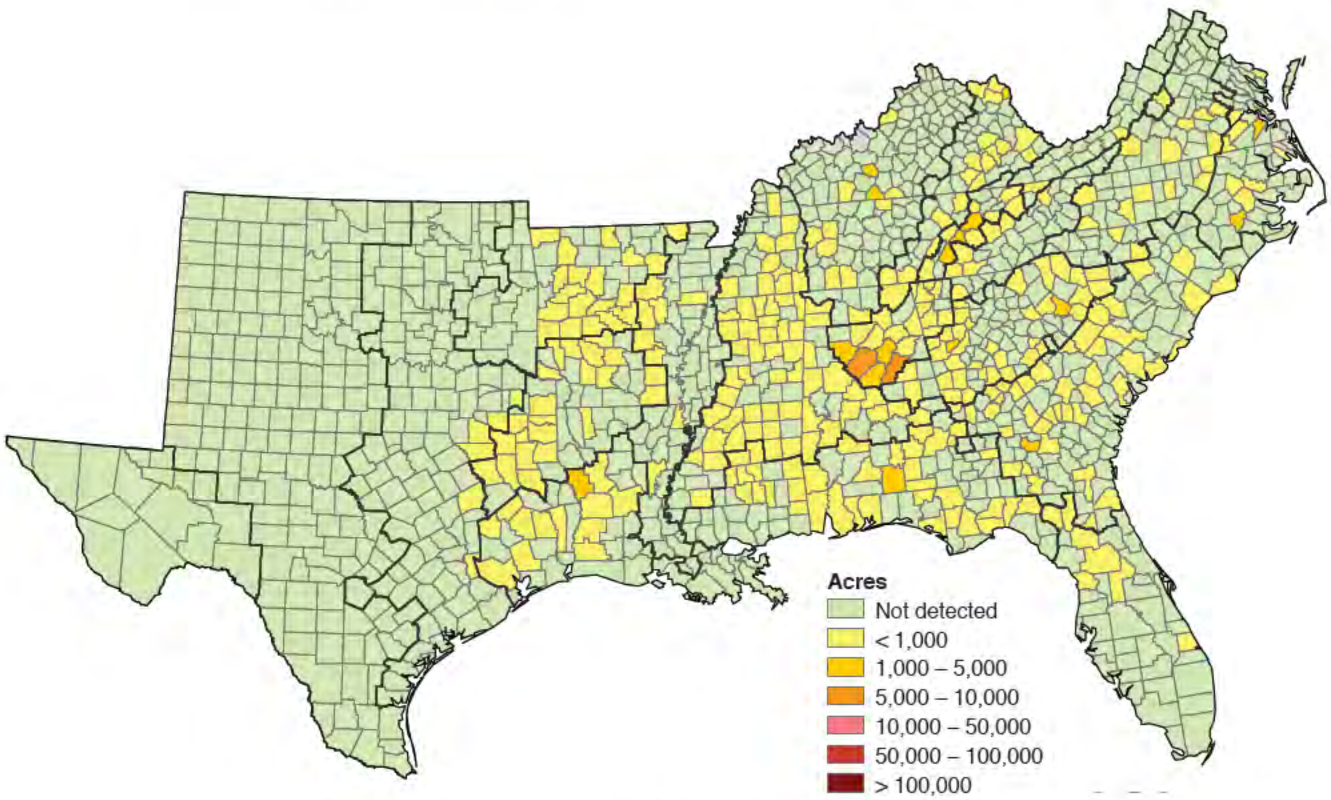

Figure 15.4—Silktree: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

Brazilian peppertree is confined to Florida and the southern tip of Texas. Because of the extensive dense infestations in Florida, it is fifth in forest occupation by invasive trees. It has recently extended its range northward to the Panhandle of Florida with an expansion rate projected at 30 percent in 50 years (table 15.1). It can be expected to spread northward even with the current climate.

Melaleuca—Melaleuca (*Melaleuca quinquenervia*) is a widely recognized invasive tree that continues to threaten the biological integrity of the unique ecosystems in Florida's Everglades (Dray and others 2006, University of Florida Institute of Food and Agricultural Sciences 2007). It was introduced to Florida from Australia in about 1887 and promoted by the nursery industry as an ornamental (Dray and others 2006, Langeland and others 2008). In the 1930s it was aerially scattered over the Everglades to create forests and is currently invasive only in the southern and central areas of the State. It is an evergreen tree to 100 feet tall that occurs in vertically dense stands with slender crowns of alternate, grayish-green, lance-shaped leaves to 4 inches long that smell of camphor when crushed (Langeland and others 2008). The bark consists of soft whitish layers that peel and drop, thus the common name, paper-bark. Flowers are whitish, bottlebrush-like spikes to 6 inches long. Tightly clustered around young stems, the fruit are round, woody capsules that release 200 to 300 tiny seeds for windborne distribution. The trees grow exceedingly fast in dense stands that diminish wildlife food and habitat. Aggressive application of herbicides has greatly reduced infestations in the Everglades, but melaleuca continues to spread into pine flatwoods, marshes, and cypress swamps (Nelson 1994). A cooperative management program has coordinated prevention and eradication programs since 1990 (University of Florida Institute of Food and Agricultural Sciences 2007). In addition, three insect biological control agents have been released, two of which are available by mail order, and research is under way on a fourth (University of Florida Institute of Food and Agricultural Sciences 2007).

Surveys indicate dense infestations in southern Florida forests with known outliers in central Florida (Ferriter 2007), where the actual coverage on all lands of this invasive exceeded half a million acres by 1993 (University of Florida Institute of Food and Agricultural Sciences 2007). Also it has been recorded as an escape along the south shores of Lake Pontchartrain near New Orleans (USDA Natural Resource Conservation Service 2010). This species could spread northward with warming climate at an estimated rate of 65 percent more coverage in 50 years, being the highest percentage increase for an invasive tree (table 15.1).

Princesstree—Princesstree or paulownia (*Paulownia tomentosa*) was introduced from Europe to America for ornamental purposes in about 1844, although originally from China (Hu 1961). It was considered naturalized in Georgia by 1896 (Harper 1900). Princesstree is a deciduous tree to 60 feet tall with large heart-shaped leaves that are fuzzy on both surfaces. Before leaves appear in spring, trees are covered with showy pale-violet flowers that produce persistent pecan-like capsules in clusters in autumn and winter. Each capsule splits to release thousands of tiny winged seeds that are spread by wind and water. Abundant flower buds are present on erect stalks over winter. Plants can produce viable seed at 5 to 7 years. In the mountains, seeds can be dispersed as far as 2 miles by wind (Langdon and Johnson 1994). Because germination requires bare soil, princesstree invades widely after wildfire, timber harvesting, and other disturbances, forming colonies from prolific root sprouts (Langdon and Johnson 1994). This ornamental is still widely marketed as royal paulownia or royal empress and planted as an "instant" shade tree. Princesstree occurs as scattered forest infestations in all States except Texas. Heaviest infestations are associated with surface mine plantings (Tang and others 1980) and those cities with numerous ornamental plantings, such as Lexington-Lynchburg (TN), Forest City (NC), Florence and Tuscaloosa (AL), and Vicksburg (MS) (fig. 15.5). Some occurrences are probable escapes from commercial princesstree plantations owing to the promotion by the American Paulownia Association, Inc. The relatively few straight trees produced by these plantations have a high value in Japan but nowhere else (Tang and others 1980). Because of continued sales and plantings along with a naturalized range that covers all Southern States (USDA Natural Resource Conservation Service 2010), spread and intensification is expected to increase by at least 31 percent over the next 50 years (table 15.1).

Invasive Shrubs

Nonnative shrubs often occur as dense understory layers that prevent natural regeneration of the native overstory trees (table 15.2). Herbicide control options resemble those for trees, with a few exceptions: foliar sprays are more often the control of choice for shrubs; cutting shrub stems close to the soil surface and treating the stump with an herbicide is easier with shrubs; and because shrub stems are smaller, basal sprays are usually more effective (Miller and others 2010b). All invasive shrubs are shade tolerant and are spread by bird-dispersed seeds, initially resulting in scattered plants under existing forest canopies that require interior surveillance strategies. All species described below are still produced, sold, and planted as ornamentals and wildlife food plants, except tropical soda apple.

Invasive privets—There are at least eight species of invasive privets (*Ligustrum* spp.) that have been introduced from Asia and Europe into the South as ornamentals from 1794 to 1899 (Dirr 1998, Maddox and others 2010, USDA Natural Resource Conservation Service 2010). They are the second most abundant invasive plants in the South and they form dense stands in the understory of bottomland hardwood forests and exclude most native plants and replacement regeneration (Merriam and Feil 2002). These privets are also increasing in upland forests, fencerows, rights-of-way, and special habitats throughout the region. They drastically change habitat and critical wetland processes. Abundance of common birds is sustained in privet thickets, but abundance of specialist birds and diversity of native plants and bees is decreased (Hanula and others 2009, Wilcox and Beck 2007). Chinese privet (*L. sinense*) is the most common invasive privet across the South, while European privet (*L. vulgare*), Amur privet (*L. amurense*), California privet (*L. ovalifolium*), waxyleaf privet (*L. quihoui*), and border privet (*L. obtusifolium,* only in VA, KY, TN, and NC) are confined to subregions (USDA Natural Resource Conservation Service 2010). These privet species are most often semi-evergreen to evergreen being multi-stemmed shrubs to 30 feet tall and just as wide due to arching tops. They are difficult to distinguish to species since all have leafy stems with opposite leaves less than 3 inches long. The evergreen privets include Japanese privet (*L. japonicum*) that grows to 12 feet tall and just as wide and glossy privet (*L. lucidum*) that grows up to 50 feet in height, with an upward spreading canopy. They have thick leathery opposite leaves 4 to 6 inches long that are glossy, and stems that are hairless. Terminal sprays of small showy white flowers bloom on all privets in spring, except waxyleaf in autumn; abundant clusters of small, green-turning-purple fruit appear in autumn and often persist through winter. Birds spread seeds (Greenberg and Walter 2010), which produce abundant seedlings and are thought to be viable for only a year (Shelton and Cain 2002). Privets also increase in density by stem and root sprouts. If the parent shrub is deadened, many shallow surface roots will produce sprouts (Harrington and Miller 2005). In Georgia, privet has been reported as an important autumn and winter browse for white-tailed deer (*Odocoileus virginianus*) (Stromayer and others 1998).

Occupation is widespread throughout the South, with the most occurrences in an epicenter around Birmingham, AL (fig. 15.6) and the least in Kentucky, Florida, and western Texas (USDA Natural Resource Conservation Service 2010). Thirty-seven percent more privet cover is predicted by 2060, which would amount to 1.2 million more acres, second only to Japanese honeysuckle for potential spread (table 15.1).

Invasive roses—There are over 21 nonnative roses (*Rosa* spp.) invading ecosystems in the South, while multiflora rose (*R. multiflora*) is the most pervasive in the Eastern United States (Miller and others 2010a, USDA Natural Resource Conservation Service 2010). With their dense infestations

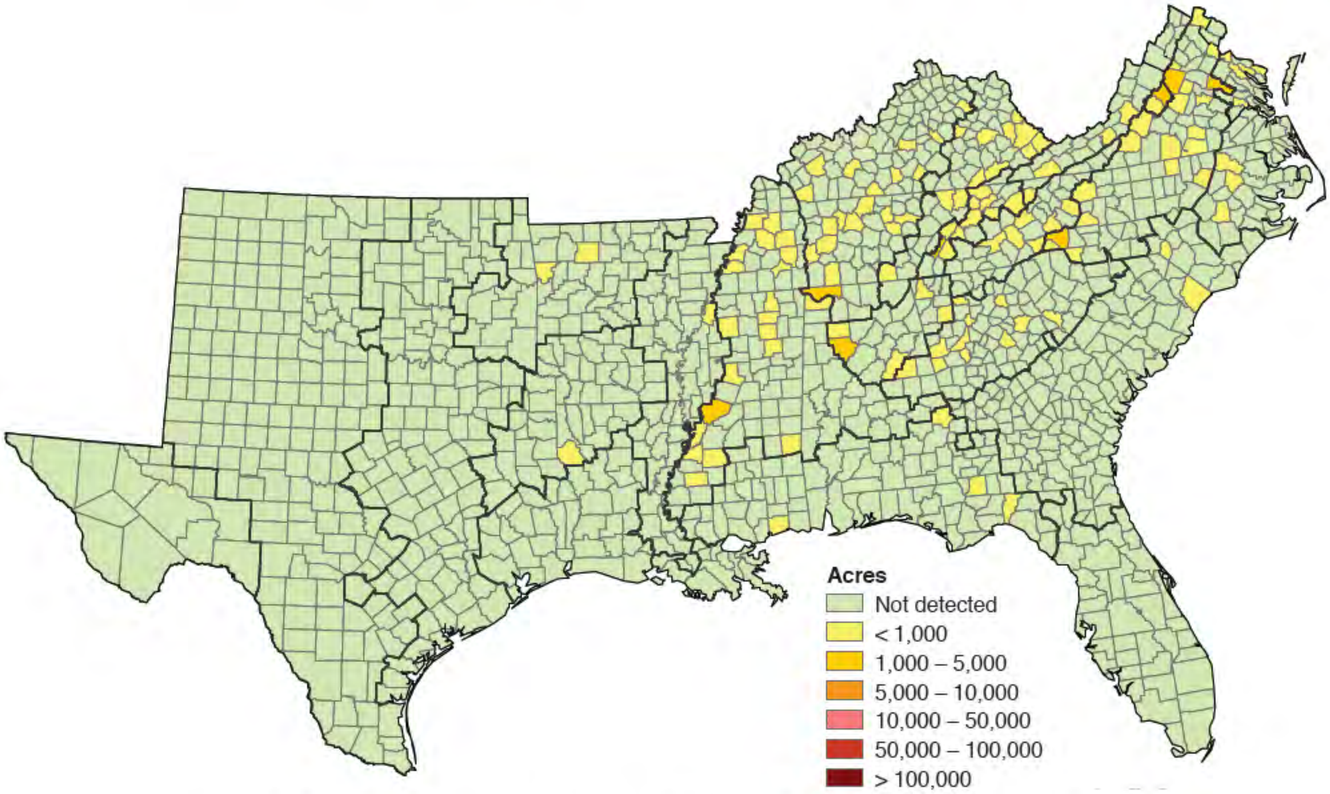

Figure 15.5—Princesstree: current regional cover map, 2010.(Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

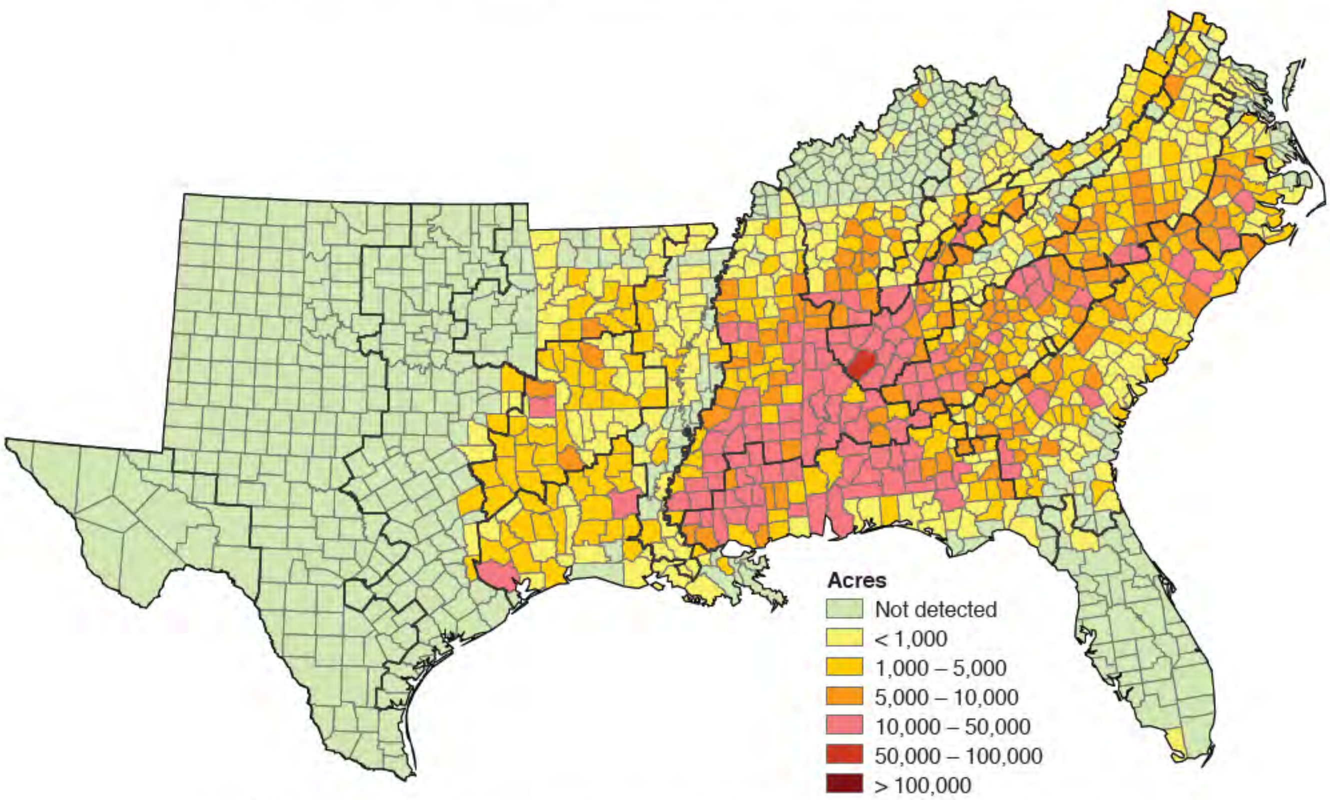

Figure 15.6—Invasive privets: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

of thorny shrubby entanglements, invasive roses occur increasingly along forest margins, within interior forests, and along stream banks where they disrupt forest regeneration, wildlife movement, and land access (Honu and Gibson 2008, Merriam 2003). With the exception of multiflora, all invasive roses are evergreen. Multiflora was imported from Japan and Korea in 1886 (Dirr 1998). Roses can be erect, arching, or trailing shrubs to 30 feet in height or long and clump forming. They have compound leaves with three to nine leaflets and frequent recurved or straight thorns along the stems. Clustered or single white-to-pink flowers appear in early summer to yield red rose hips in autumn to winter. The fruit are consumed by birds resulting in wide seed dispersal (Greenberg and Walter 2010). Roses colonize by prolific sprouting and rooted trailing stems. It has been estimated that an average multiflora rose plant may produce a million seeds per year, which may remain viable in the soil for up to 20 years (Bergmann and Swearingen 2009). Nonnative roses invade along stream banks and forest road edges to extend into open forests. Nonnative roses resemble native Carolina rose (*R. carolina*), swamp rose (*R. palustris*), and climbing rose (*R. setigera*), all of which have pink flowers in spring and nonbristled leafstalk bases, but none form extensive infestations except swamp rose.

Occupation varies by species (fig. 15.7). Supported by government programs that promoted and funded plantings until the 1950s, multiflora rose has been planted for "living fences" to confine livestock, wildlife habitat, and in highway medians as a crash barrier (Bergmann and Swearingen 2009). Its range is the entire Eastern United States and Canada, although declines have been reported in central New Jersey as a forest stand developed over a 40-year period (Banasiak and Meiners 2009). Multiflora occurs in most Southern States with heaviest infestations in Kentucky and Virginia throughout the Cumberland Plateau and Mountains and the Appalachian Mountains. Other infestations are common in the Ozark-Ouachita Highland, while Cherokee rose (*R. laevigata*) principally occurs across the Coastal Plain most notably in the Black Belt Prairie area of southern Alabama. Together, invasive roses occupy almost 700,000 acres of forests—making them the second most common invasive shrub—and they are predicted to increase their coverage by 37 percent over the next 50 years (table 15.1) because of continued spread along highway-forest margins, which go largely untreated. Estimates of spread rates with climate change scenarios are reported in a later section.

Invasive lespedezas—Invasive lespedezas (*Lespedeza* spp.) were introduced in the United States from 1837 to 1896, originally from China, Japan, or Korea (Dirr 1998, Donnelly 1954). All three species have been widely planted for wildlife food plots and forage for more than a century and continue to be used for soil stabilization projects along highways and on surface mines. All were reported to have escaped from plantings in the 1940s (Allard and Leonard 1943, Davison 1945, Gunn 1959). If allowed to escape from planted stands, they form dense exclusive infestations that remain standing during winter dormancy to prevent forest regeneration, wildlife movement, prescribed burning, and land access. All have nitrogen-fixing bacteria on root nodules. Shrubby lespedeza (*L. bicolor*) and its look-alike, Thunberg's lespedeza (*L. thunbergii*), are perennial much-branched semi-woody shrubs 3 to 10 feet in height. Chinese lespedeza (*L. cuneata*) occupies the most lands of the invasive lespedezas and has already spread westward into the Great Plains. A subshrub that grows to 6 feet in height with allelopathic chemicals in the foliage that inhibit other plants (Kalburtji and Mosjidis 1992), it has many tiny cream-colored flowers during summer compared to the pinkish-to-white flowers of shrubby and Thunberg's lespedeza. All three species yield abundant single flat seeds in autumn and winter that are spread by birds, ants, and rodents. Seeds have low germination, but because they are long-lived in the soil seed bank control treatments must be followed by long-term monitoring (Logan and others 1969). These invasives resemble two native species, the slender lespedeza (*L. virginica*) that grows in tufted clumps instead of infestations and the native roundhead lespedeza (*L. capitata* Michx.) that has similar leaves but whitish flowers in round-topped clusters. Superior strains of invasive lespedezas that were developed at Federal plant materials centers (Pieters 1950) have the potential to take over diminishing native grasslands and prairie communities to the detriment of biodiversity (Brandon and others 2004). Chinese lespedeza varieties were developed with lower lignin and tannin concentrations to overcome forage limitations (Donnelly 1954, Hawkins 1955).

All subregions have invasive lespedeza infestations, with an epicenter around Greenville and Spartanburg, SC, while the least are along the Mississippi River Delta and in Florida (figs. 15.8). Occurrence appears to be matched to areas of past planting programs for soil stabilization and wildlife food plots. Region-wide spread mainly along highways and roads is occurring at an estimated annual rate of 7,600 acres, and 71 percent more cover is predicted over the next 50 years (table 15.1).

Bush honeysuckles—There are at least six species of invasive bush honeysuckles (*Lonicera* spp.) that have been repeatedly imported from eastern Asia into the United States over a 100-year period from 1752 to 1860 followed by plant breeding programs. Widespread distribution has occurred through continued nursery sales and Federal programs from 1960s to 1984 (Dirr 1998, Luken and Thieret 1996). They are still planted as ornamentals and for wildlife habitat and soil stabilization, while botanists proclaim their biological threat. Bush honeysuckles now occur as frequent shrubs along forest margins and in openings in many Southern States, and as solid understory

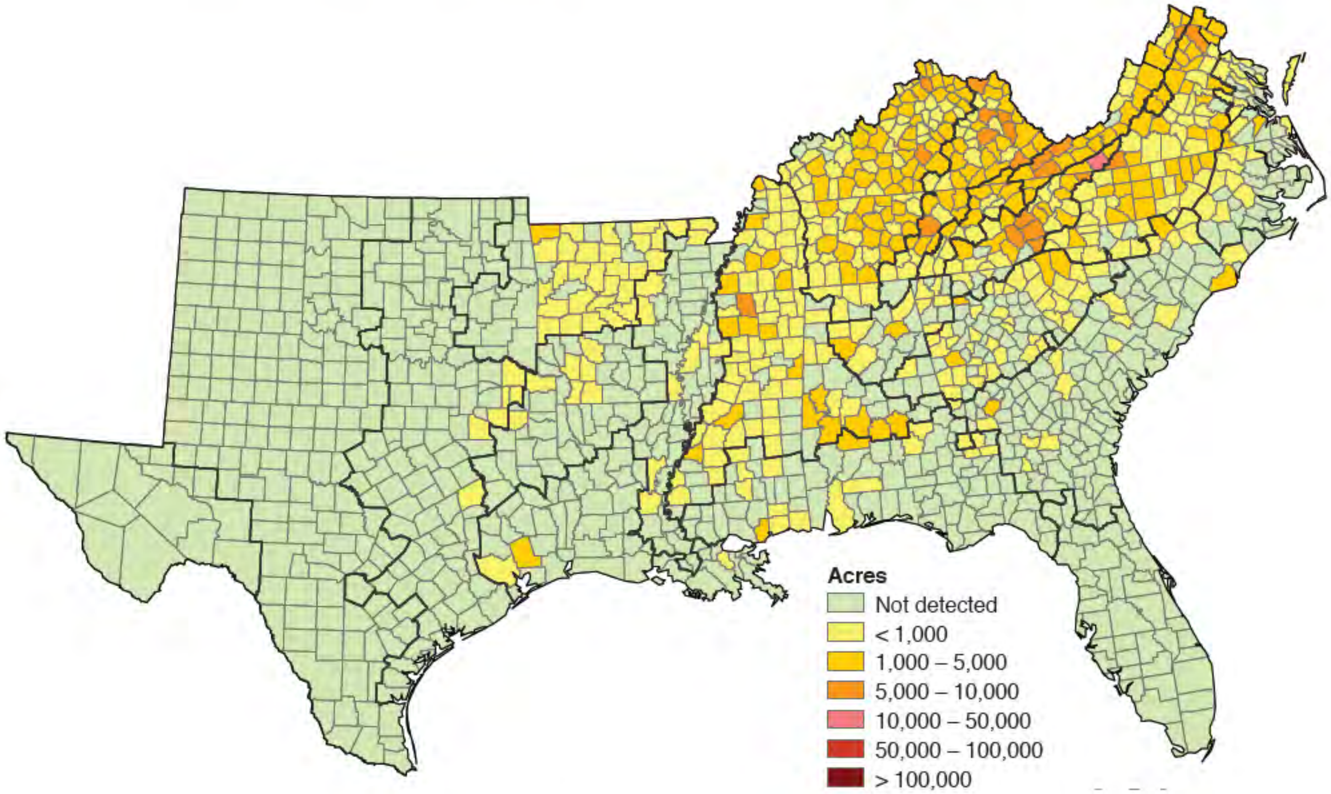

Figure 15.7— Invasive roses: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

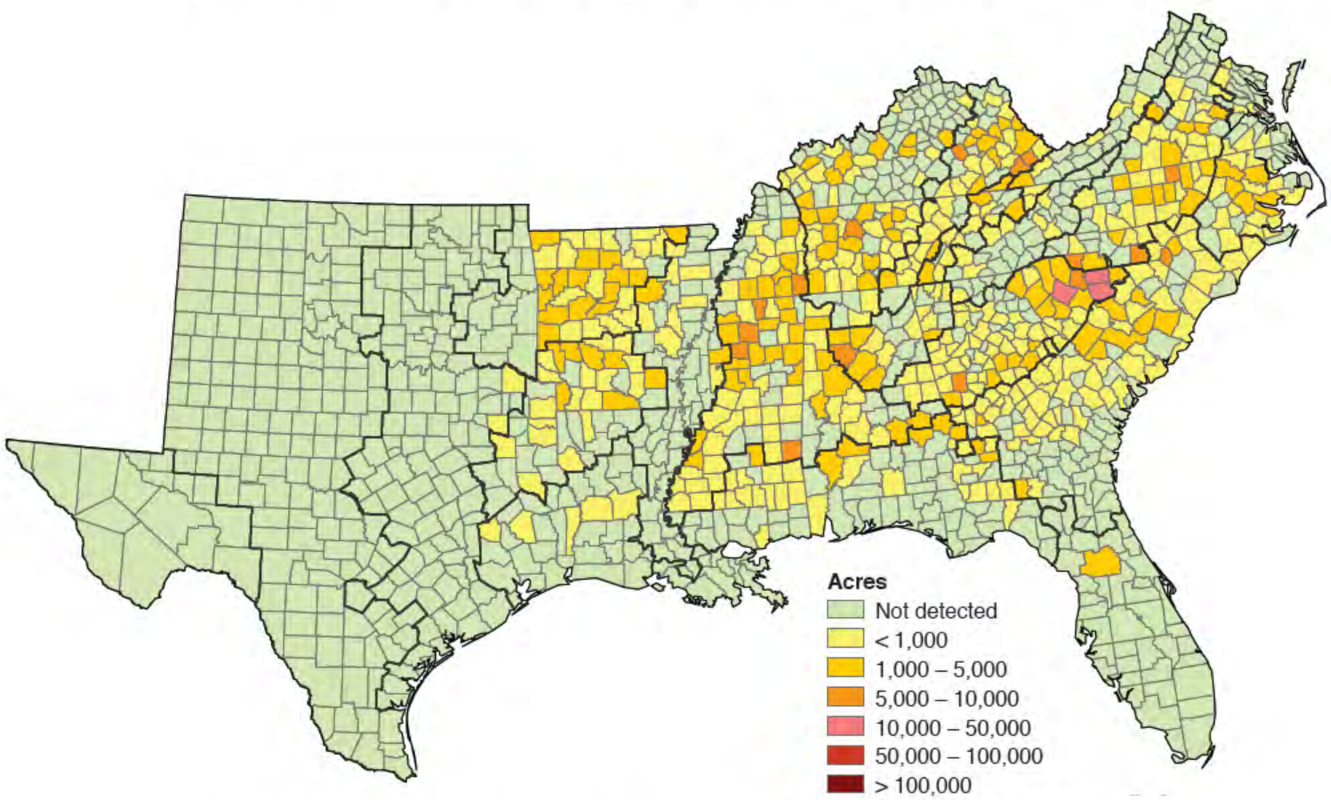

Figure 15.8— Invasive lespedezas: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

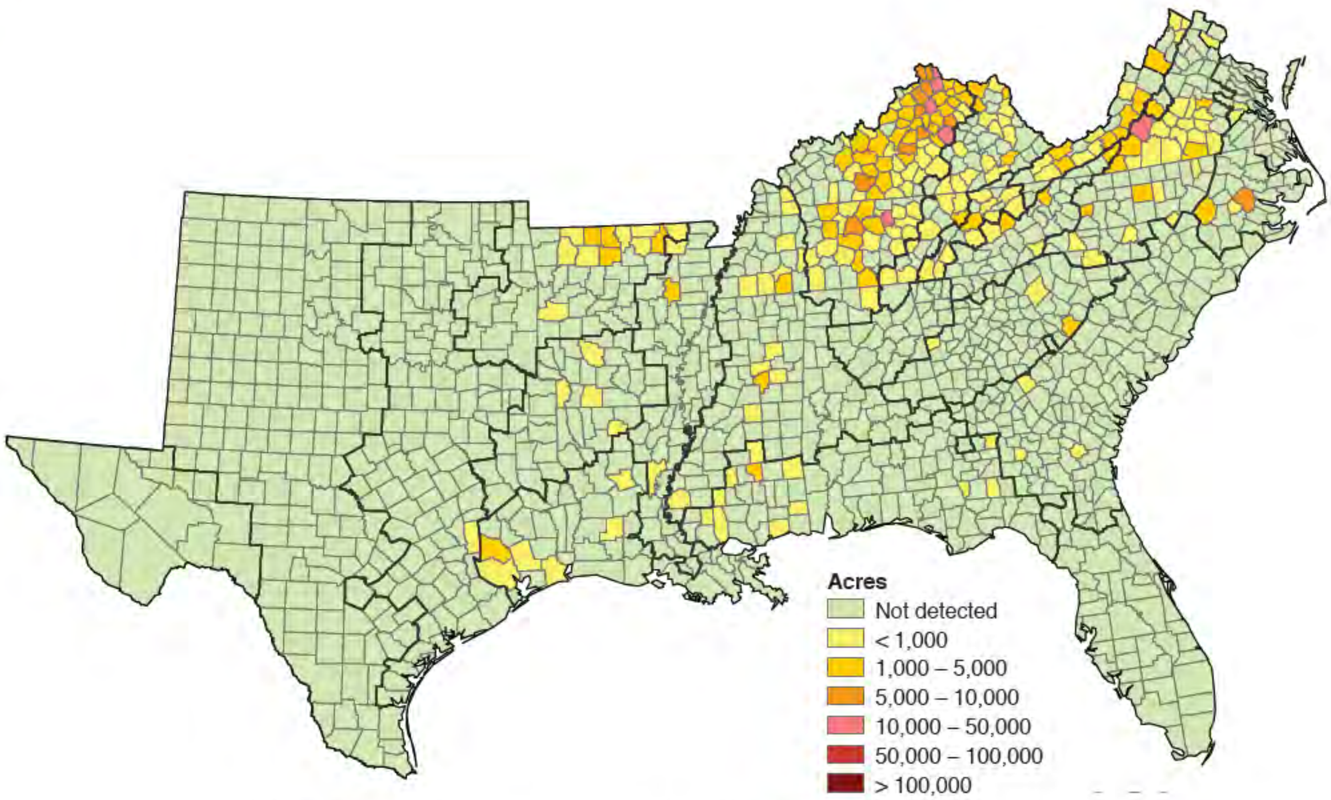

Figure 15.9—Bush honeysuckles: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

infestations in central Kentucky, Tennessee, and Virginia (fig. 15.9) as well as across the Midwest and Northeast. Amur honeysuckle (*L. maackii*), Morrow's honeysuckle (*L. morrowii*), Tatarian honeysuckle (*L. tatarica*), sweet breath of spring (*L. fragrantissima*), Standish honeysuckle (*L. standishii*), and Bell's honeysuckle [*Lonicera ×bella* (morrowii × tatarica)] are upright-to-arching, branched shrubs with a multitude of basal sprouts (Miller and others 2010a). The most widespread is Amur. All have dark green oval-to-oblong distinctly opposite leaves that appear early and remain into winter. Fragrant, showy, tubular and five-lipped, white-to-pink or yellow-paired flowers similar to Japanese honeysuckle appear from mid-March to June. Abundant paired berries that appear at 5 to 8 years in leaf axils (Deering and Vankat 1999, Dirr 1998) are red-to-orange during winter, are spread by birds and mammals (Vellend 2002, Williams and others 1992), and contain seeds that are long lived in the soil. Infestations intensify by prolific root sprouts. Nonnative bush honeysuckles resemble the American fly honeysuckle (*L. canadensis*), which is rare and occurs only around shrubby bogs at high elevations.

Although invasive bush honeysuckle infestations have been reported in southern Georgia and as far west as Houston, the highest levels are in the Cumberland Plateau and Mountains, the Interior Low Plateau, and Central Appalachian Piedmont sections (fig. 15.9). The least occupied are the Coastal Plains, with none reported in Florida. Subregional occupation varies by invasive bush honeysuckle species (USDA Natural Resource Conservation Service 2010). Current occupation of 345,622 acres is projected to more than double by 2060 (table 15.1).

Invasive elaeagnus—Autumn olive (*Elaeagnus umbellata*), silverthorn or thorny olive (*E. pungens*), and the infrequent (in the South but widely invasive in the West and Northeast) Russian olive (*E. angustifolia*) were initially planted as ornamentals (Dirr 1998, USDA Natural Resource Conservation Service 2010). Government and industry programs promoted and planted these species to form dense cover for soil stabilization, surface mine reclamation, and wildlife food plots (Allan and Steiner 1965). Elaeagnus infestations outcompete other species and reduce biodiversity, while the nitrogen-fixing bacteria on their roots alter nitrogen cycles to disrupt processes and alter the mix of soil organisms. Their spreading thorny branches will increasingly obstruct stand access and wildlife movement (Munger 2003).

The most widely invasive and high-threat species, autumn olive is a tardily deciduous bushy, leafy shrub to 20 feet in height (Miller and others 2010a). It has alternate leaves that are green above and silvery scaly beneath, and it produces many silvery-scaled red berries in autumn. Silverthorn is evergreen, shade tolerant, and densely bushy to 25 feet in height, with long limber projecting shoots that can eventually climb into tree crowns. Its leaves are simple, both silver and tawny, scaly, and its tiny cream-colored flower clusters appear in late autumn, producing oblong, red olive-like brown-scaled fruit in spring. Russian olive is deciduous with a single bole that grows to 35 feet tall, silvery-scaled leaves, and fruit that is produced in autumn. All have scattered thorn like short branches along their stems. The fruit are consumed by wildlife followed by widely dispersed seeds. Plants initially occur as scattered individuals, both in the open and under forest shade, and intensify by abundant arching basal sprouts (Munger 2003).

Occurrence is greatest in the Piedmont of Georgia and South Carolina, where government nurseries once supplied elaeagnus for wildlife plantings (fig. 15.10). Surface mine reclamation using autumn olive plantings has resulted in another epicenter in the northern Appalachian and Cumberland highlands. The more recent popularity of silverthorn as an ornamental is likely to result in region-wide escapes into urban forests and then into the broader landscapes. Invasive elaeagnus species are in their early "lag" phase of forest invasion when occurrences are scattered and populations are low, which means the spread of the current 96,421 acres will be at least 60 percent more acres in 50 years (table 15.1).

Sacred bamboo—Sacred bamboo or nandina (*Nandina domestica*) was an early imported ornamental from 1804 due to its evergreen foliage, spring flower clusters, and bunches of red berries that persist during winter. It was only in the 1960s (150 years after introduction) that escapes into forests of North Carolina were recognized (Radford and others 1964). It is still widely sold and cultured to yield new hybrids, some of which are seedless. It is now replacing the shrub layer in deciduous forests due its continuous evergreen growth habit (Langeland and others 2008).

Nandina is an erect shrub that can grow up to 8 feet in height, with multiple bushy jointed stems, somewhat resembling bamboo (Kaufman and Kaufman 2007). Glossy multiple divided leaves are green turning to red or pink in winter. Abundant berries in autumn and winter are a favorite food for birds, spreading seeds from back yards to forests. Nandina is widely escaped to varying degrees in all States (fig. 15.11). Continued production and sale in the plant trade have resulted in occupation on 24,000 acres of forest land, with as much as an 11-fold increase expected by 2060 (table 15.1).

Tropical soda apple—Tropical soda apple (*Solanum viarum*) was listed as a Federal Noxious Weed soon after its accidental introduction from South America into Florida in the late 1980s (Mullahey 1996). Spread was exceedingly rapid, predominantly through intra-State and interstate transportation of cattle with tropical soda apple fruit in their rumens. It infests pastures in at least eight other States. Wildlife now feed on the fruit in pastures and spread its seeds to many land-use areas, including forest margins and gaps and open forests (Akanda and others 1996). Once established, it forms exclusive thorny infestations.

Tropical soda apple is an upright, perennial subshrub or shrub, 3 to 6 feet in height, which remains green year-round in most southern locations. It has thorny oak-shaped and sized leaves, clusters of tiny white flowers, and golf-ball sized fruit that are mottled green-white turning to yellow in late summer to autumn. Even immature fruits can contain viable seeds, which adhere to machinery, wildlife, clothing, and boots. Fruits have a sweet smell that is attractive to livestock and wildlife, and each can contain 400 seeds. Shoots increase in numbers and size annually from the rootcrowns. Most infestations are in the Coastal Plains with migration occurring into the southern Piedmont (fig. 15.12). Research has shown that tropical soda apple will grow and reproduce as far north as Illinois (Patterson and others 1997), indicating that further spread in the South is probable. Forested acres occupied in the region are predicted to triple by 2060, from 9,570 to 31,320 (table 15.1). One biocontrol insect for tropical soda apple has been released with several others undergoing tests (Medal and others 2010).

Winged burning bush—Winged burning bush (*Euonymus alatus*) is an ornamental imported from China around 1860 due to its brilliant pink to red autumn foliage, thus its common name (Dirr 1998). Only recently has it been observed as infestations under forest canopies and along rights-of-way (Ebinger 1983). Winged burning bush is a deciduous, wing-stemmed, bushy shrub to 12 feet in height (Miller and others 2010a). Leaves are opposite, oval with elongated bases and tips, and thin, less than 2 inches long with both surfaces smooth and hairless. Plants are densely branched with a broad leafy canopy. Abundant tiny orange fruit appear in late summer as stemmed pairs in leaf axils and turn purple in autumn.

Winged burning bush has been used extensively as an ornamental in the Northeastern United States and upper reaches of Southern States, and has many cultivars (Dirr 1998). It escapes and spreads by bird-carried seeds and colonizes by root suckers. Along with occupying forest openings and rights-of-way, it forms dense infestations that replace understory shrub layers in deciduous forests because of its tolerance to shade (table 15.2). It resembles the threatened and endangered native burning bush (*E. atropurpureus*), which has erect hairs covering the lower leaf surfaces. Although infestations of winged burning bush are

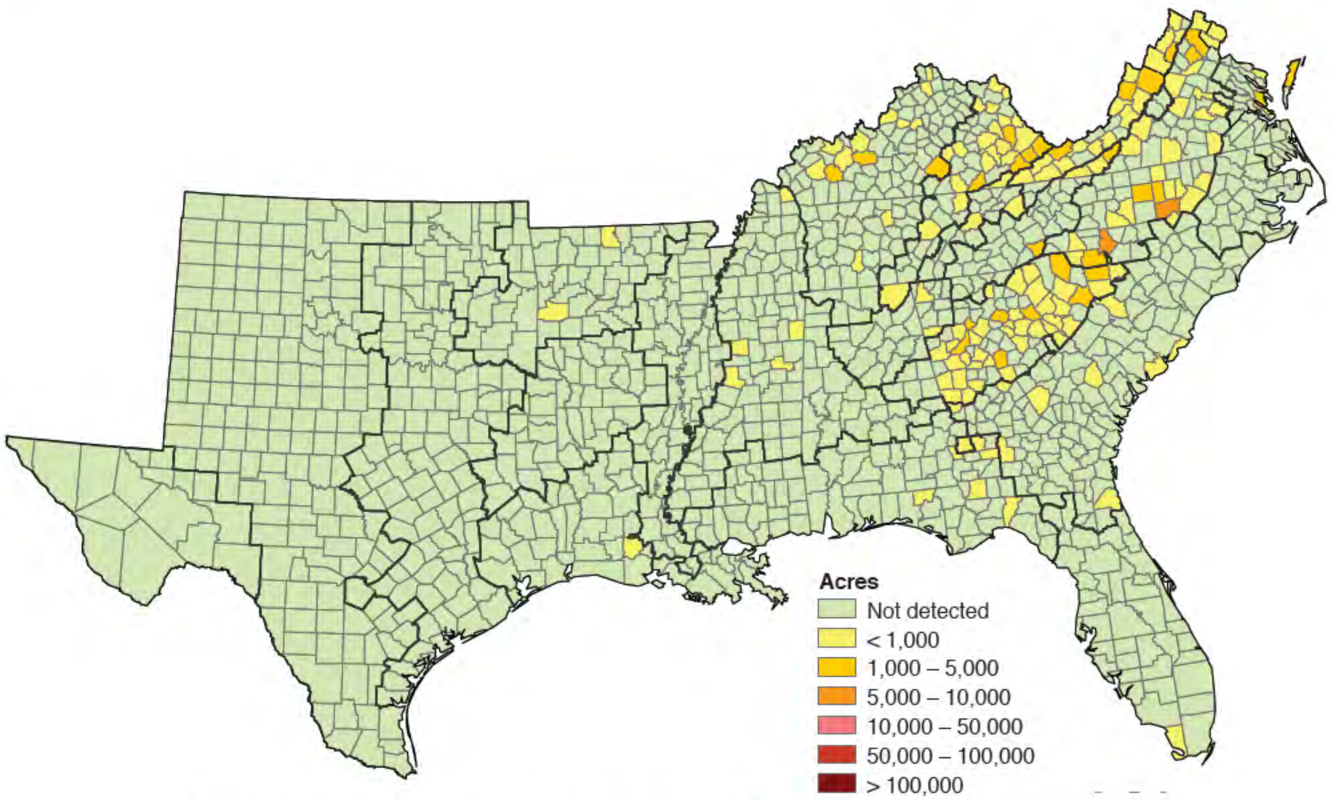

Figure 15.10—Invasive elaeagnus (autumn olive, silverthorn, and Russian olive): current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

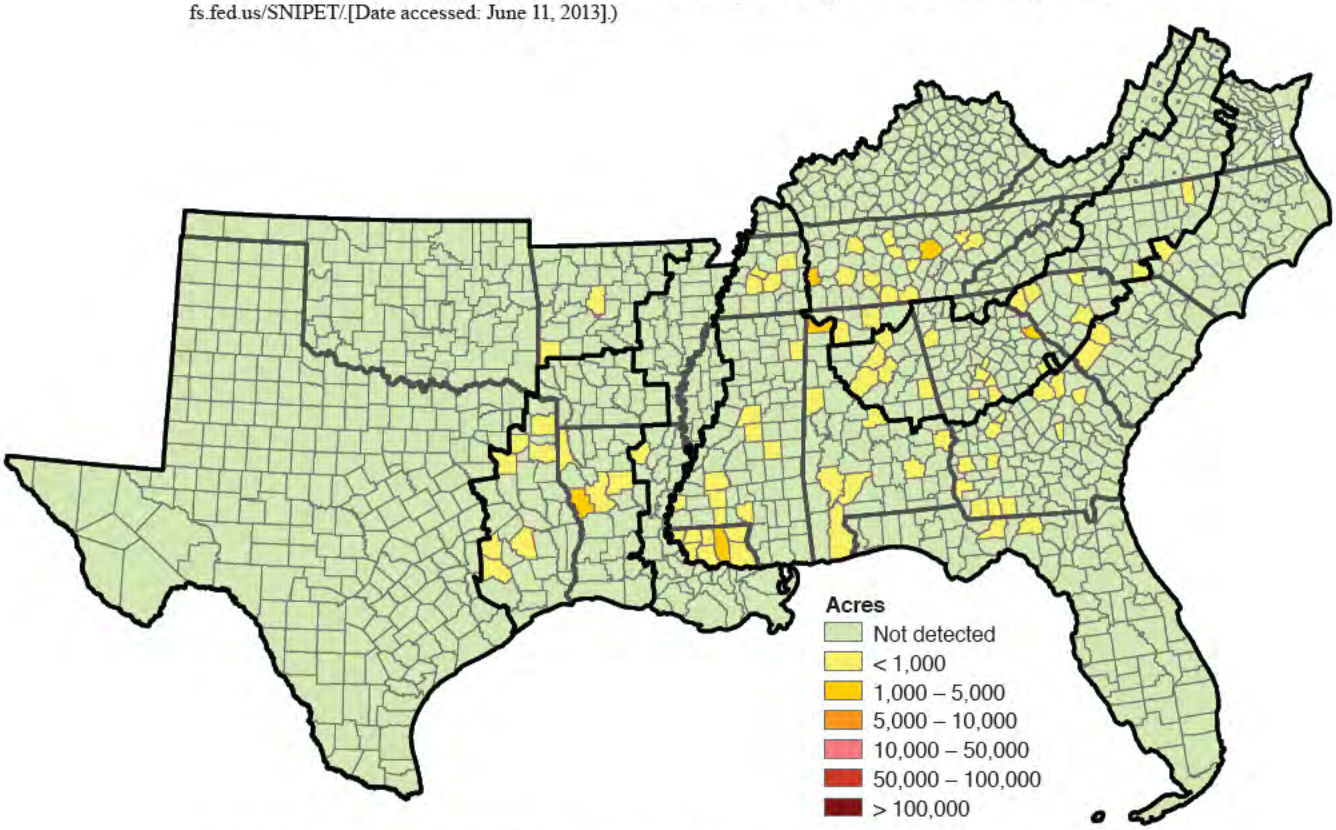

Figure 15.11—Sacred bamboo: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

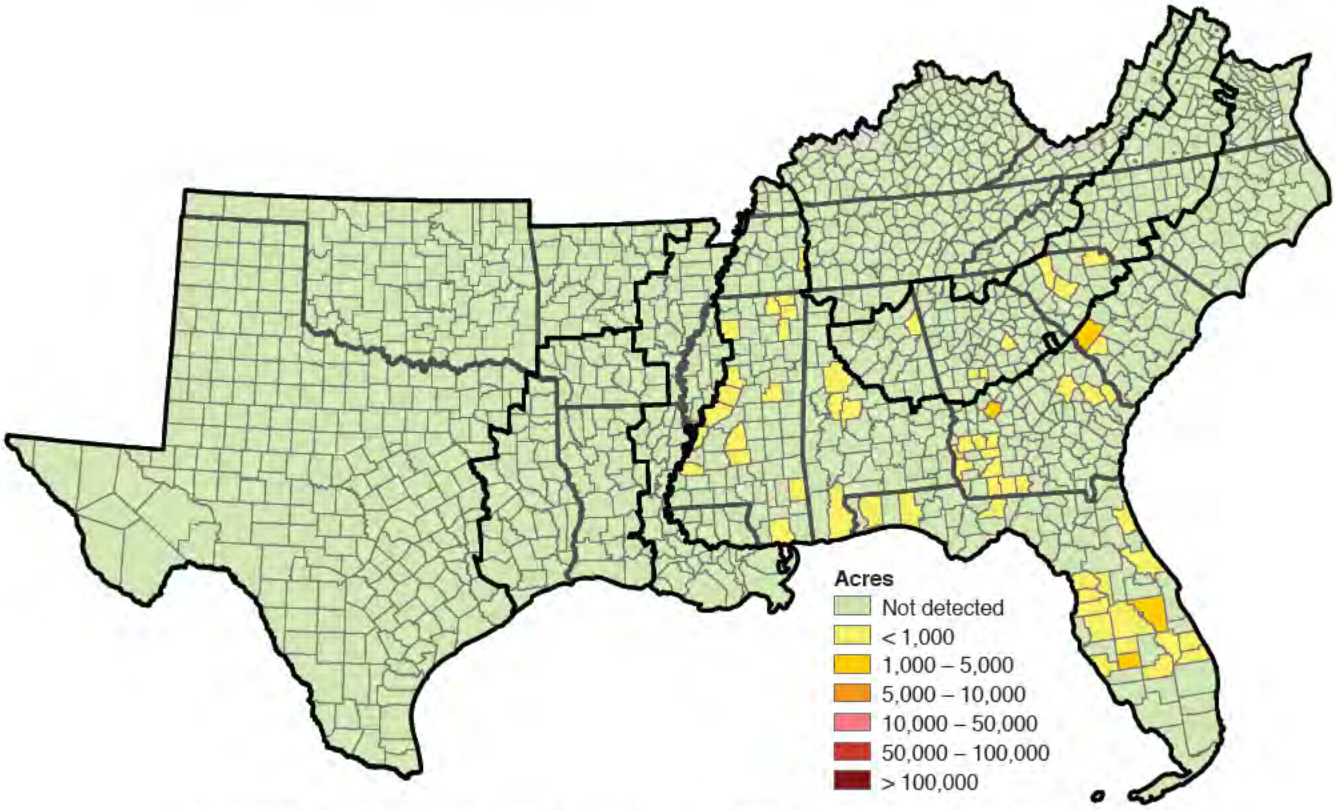

Figure 15.12—Tropical soda apple: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

concentrated in central Kentucky and along the Shenandoah Valley in Virginia, others are expected if ornamental planting continues to expand (fig. 15.13). Although forested acres currently occupied by winged burning bush are small (8,710 acres), they are likely to grow with expanding ornamental markets (table 15.1), up to 5.5-fold.

Nonnative Vines

Nonnative vines form dense infestations that can overtop even the tallest trees or can completely occupy a forest opening. Some invasive vines are shade tolerant and invade the ground layer and edges of forests, eventually climbing shrubs and trees (table 15.2). Herbicide applications and other treatments are complicated by the tendency of many vines to form mixed-species infestations with invasive trees and shrubs. Specific herbicides applied to vines can release the invasive trees and shrubs. Herbicide sprays should be applied as high as possible to foliage of climbing stems. If foliage reappears, cut stems as close to the ground as possible and treat the cut stems with appropriate herbicides (Miller and others 2010b). The upper vines must be cut high enough to prevent the vine from acting like a trellis for the new growth.

Japanese honeysuckle—The most occupying forest invasive in the region, Japanese honeysuckle (*L. japonica*) persists to block establishment of native plants in many forest types over a wide range of sites, often coexisting with both native and invasive plants (Honu and Gibson 2008, Loewenstein and Loewenstein 2005, Yurkonis and Meiners 2004). It was initially introduced into the United States from Asia in 1806 while the first collection in the South was in Kentucky in 1842 (Schierenbeck 2004). It quickly became a very popular plant for homestead beautification, soil stabilization, and wildlife food plots. Dense infestations occur along forest margins and rights-of-way, as well as under closed canopies, and as arbors high in treetops (Merriam 2003, table 15.2). It persists by woody rootstocks and spreads mainly by vines under forest litter rooting at nodes, and less often by animal-dispersed seeds (Evans 1984). It has infrequent seeding in forest stands due to lack of pollinators in some areas (Larson and others 2002). It has very low initial seed viability and low seed survival (less than 2 years) in the soil (Fowler and Larson 2004, Shelton and Cain 2002).

Japanese honeysuckle is a semi-evergreen to evergreen woody vine that climbs by twining and trails to 80 feet. It has opposite leaves less than 2.5 inches along hairy brown vines. Besides the frequently rooting vines, older plants have long underground woody rhizomes that frequently sprout, which often stymies eradication efforts. It is shade tolerant, a vigorous competitor to pine seedlings and has allelopathic

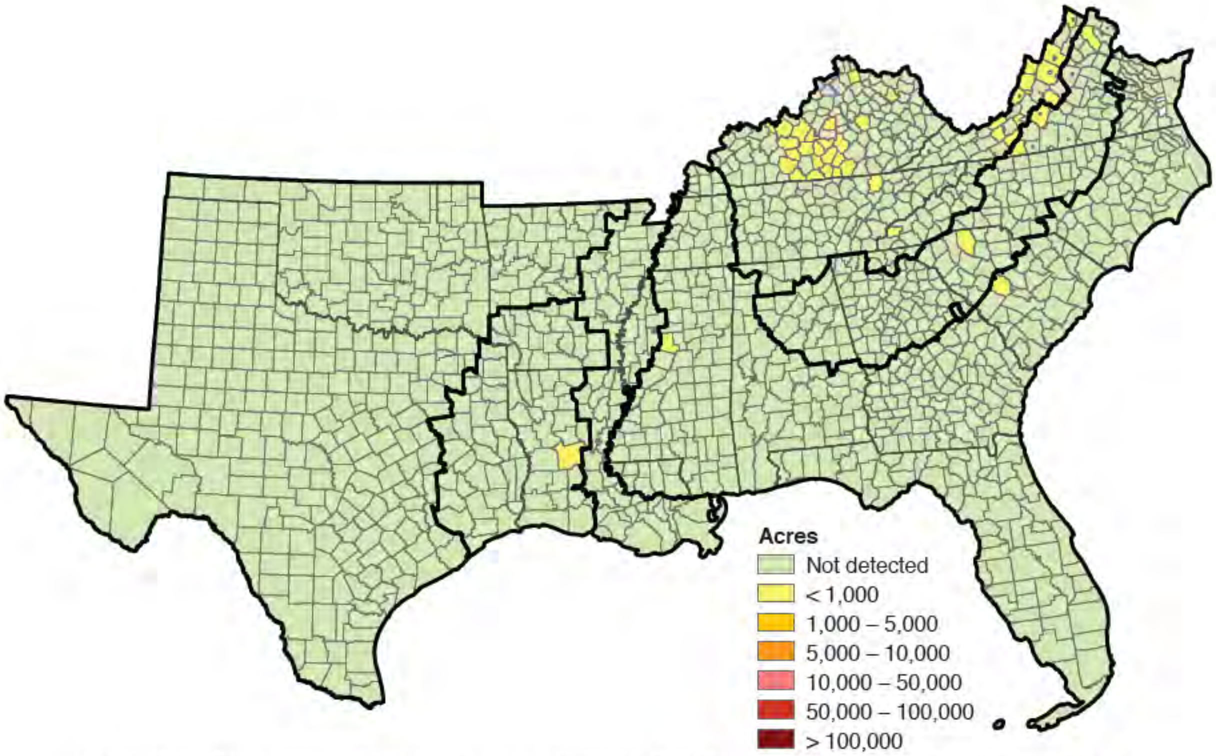

Figure 15.13—Winged burning bush: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

chemicals that inhibit other plants (Skulman and others 2004). It resembles viney native honeysuckles, which usually have reddish hairless stems and hairless leaves and do not have the ability to form extensive infestations.

Japanese honeysuckle is the region's most rampant invasive species, threatening forests in all States and terrains, and is still planted in wildlife openings and still invading surrounding lands. The highest levels of occupation are in east central Alabama and the lowest levels are in Florida (fig. 15.14). The projected spread of 65,000 acres per year would mean a 31 percent increase over the next 50 years and would sustain its ranking as the most occupying forest invasive plant in the South (table 15.1).

Japanese climbing fern—Japanese climbing fern (*Lygodium japonicum*) is rapidly becoming one of the most common invasive plants in Coastal Plain States along the Gulf of Mexico (fig. 15.15). It is a climbing and twining, perennial viney fern to 90 feet long and high, often forming mats of shrub- and tree-covering infestations (table 15.2). Its scattered and dense infestations erode plant diversity and this plant has no known wildlife value. It has lacy finely divided leaves along green-to-orange-to-black wiry vines. Vines arise as branches (long compound leaves) from below ground, widely creeping rhizomes that are slender, dark brown to black, and must be killed for eradication. Fronds that have been frost killed in winter turn tan-brown and persist, but they remain green in Florida and in sheltered places farther north. Dead vines from previous years serve as trellises for reestablishment. Both green and dead plants act as fire ladders to tree crowns during wildfires and prescribed burns. In addition to colonizing by rhizomes, Japanese climbing fern also spreads rapidly by wind-dispersed spores. Since its introduction as an ornamental around 1900 (Ferriter 2001) and eventual escape from plantings first reported in about 1918 in South Carolina (Anderson 1921), it has spread to 314,758 forested acres (table 15.1). It is predicted to increase by almost 54 percent over the next 50 years. Northward spread from the Gulf Coastal Plain is likely with warming trends. Estimates of spread rates with climate change scenarios are reported in a later section.

Kudzu—Kudzu (*Pueraria montana*), one of the most notorious of southern invasive plants, forms dense infestations that are principally limited to forest edges and young forests because it is shade intolerant (table 15.2). It commonly occurs with Chinese privet and often twines and climbs to 100 feet relying on existing Japanese honeysuckle and other vines to form infestations in forest canopies (Miller 2003). It cannot twine around trees or poles greater than 4 inches in diameter. Kudzu is a deciduous, woody leguminous vine that increases nitrogen in occupied soils (Forseth and Innis 2004).

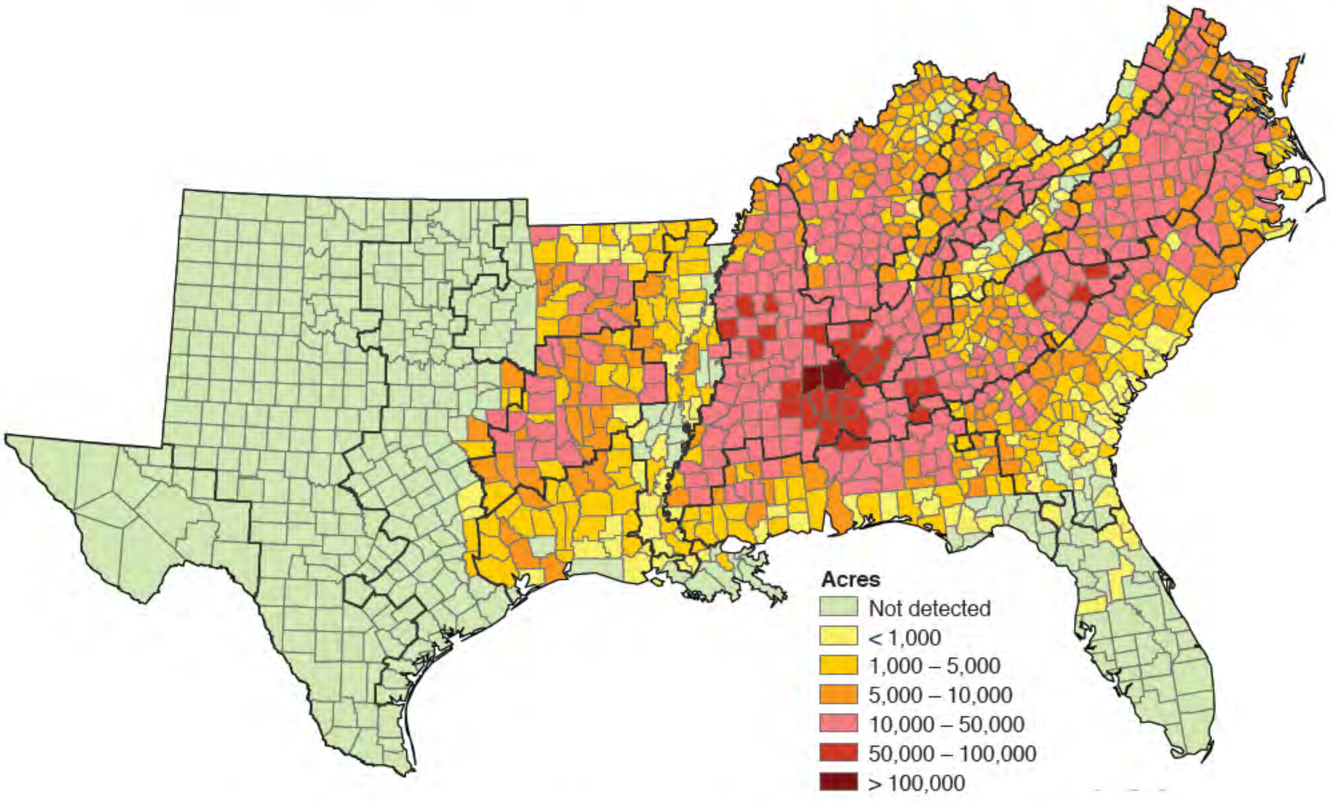

Figure 15.14—Japanese honeysuckle: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

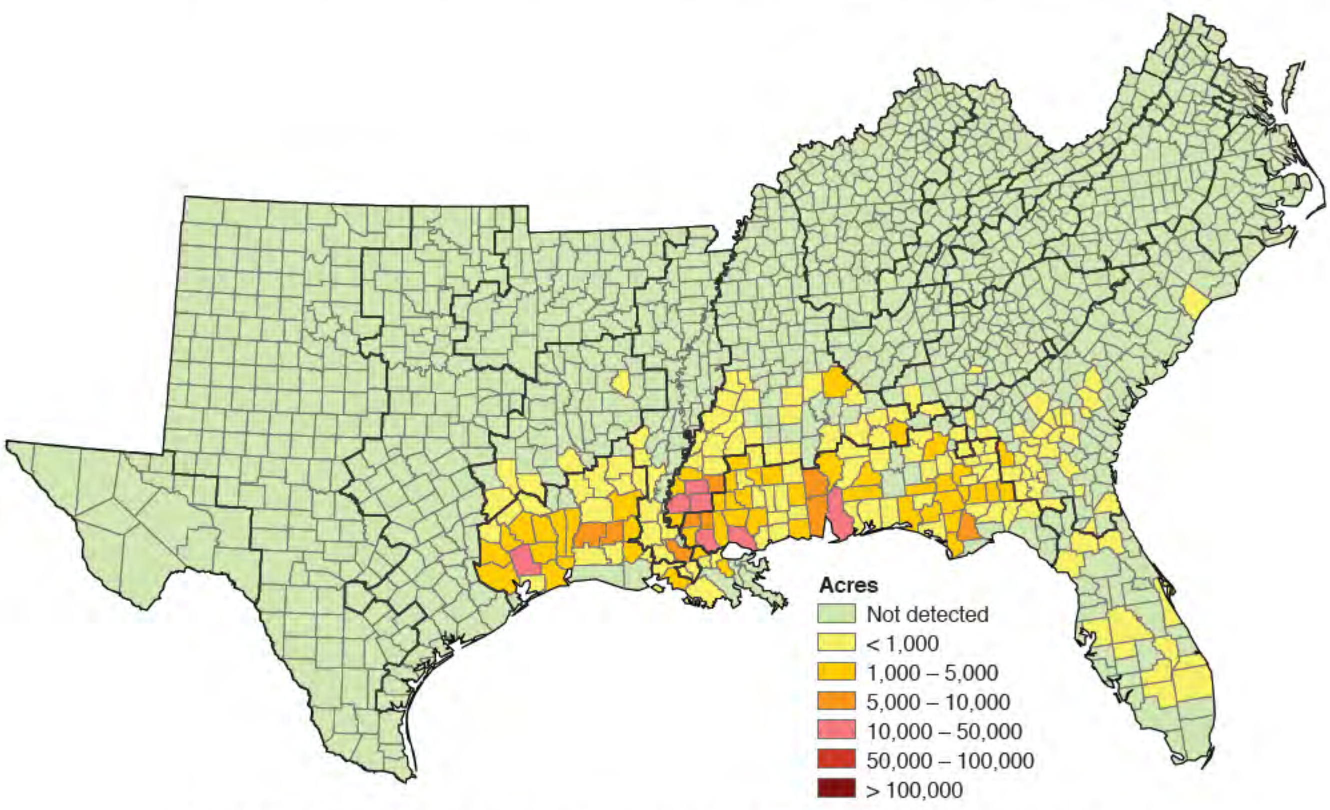

Figure 15.15—Japanese climbing fern: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

Leaves have three leaflets with variable lobes, and leaflets have a unique capability to rapidly re-orient to maximize photosynthesis during the day or to droop showing their white hairy underside to decrease plant water use during droughts (Forseth and Termura 1987). Slender tight clusters of white and violet pea-like flowers appear in midsummer and yield clusters of dangling flat, hairy pods in autumn containing 1 to 20 seeds. Pods fall unopened and the viability of seeds across the region is highly variable due to the degree of insect predation. Kudzu colonizes by vines rooting at nodes (stolons) and spreads by wind-, animal-, and water-dispersed seeds, which are also known to hitch-hike on equipment. Large semiwoody tuberous roots with no vine buds reach depths of 3 to 16 feet on older plants. The target of eradication efforts is to deaden or remove a knot- or ball-like root crown on top of the soil surface where vines and roots originate.

Kudzu was promoted by Federal programs in the early 20th century to be planted on an estimated 3 million acres in the South (Forseth and Innis 2004, Miller and Edwards 1983). Seeds were imported from Japan until 1940, and then from other countries for the next 40 years (Tabor 1941), which explains the high degree of genetic variability across the region (Jewett and others 2003, Pappert and others 2000). Kudzu infestations are most numerous in Mississippi and Alabama, States that championed research, promoted landowners to plant this species in 1920 to early 1950s and provided seedlings and incentive funds for planting (O'Brien and Skelton 1946, Sturkie and Grimes 1939, Winberry and Jones 1973, fig. 15.16). The current distribution appears to reveal those counties that were most "successful" with these programs. Kudzu infestations occur in all States in the region (Forseth and Innis 2004), while occupation of this shade intolerant plant is less frequent within forests (table 15.1). Total kudzu cover in the southern region was estimated in 1997 to be about 2 million acres (Corley and others 1997), while we find only 226,889 acres currently on forested plots (table 15.1). Kudzu has been shown to be very responsive to future heightened carbon dioxide levels relative to other woody plants (Sasek and Strain 1988), which means projected spread rates could increase.

Invasive wisterias—Invasive wisterias (*Wisteria* spp.) form some of the most dense and impenetrable invasive plant infestations in the region, often originating from farmstead plantings (Miller 2003) to threaten most layers in a forest community (table 15.2). Chinese wisteria (*W. sinensis*) introduced into United States in 1916 and Japanese wisteria (*W. floribunda*) in 1830 (Dirr 1998) are deciduous high climbing, twining, or trailing leguminous woody vines with

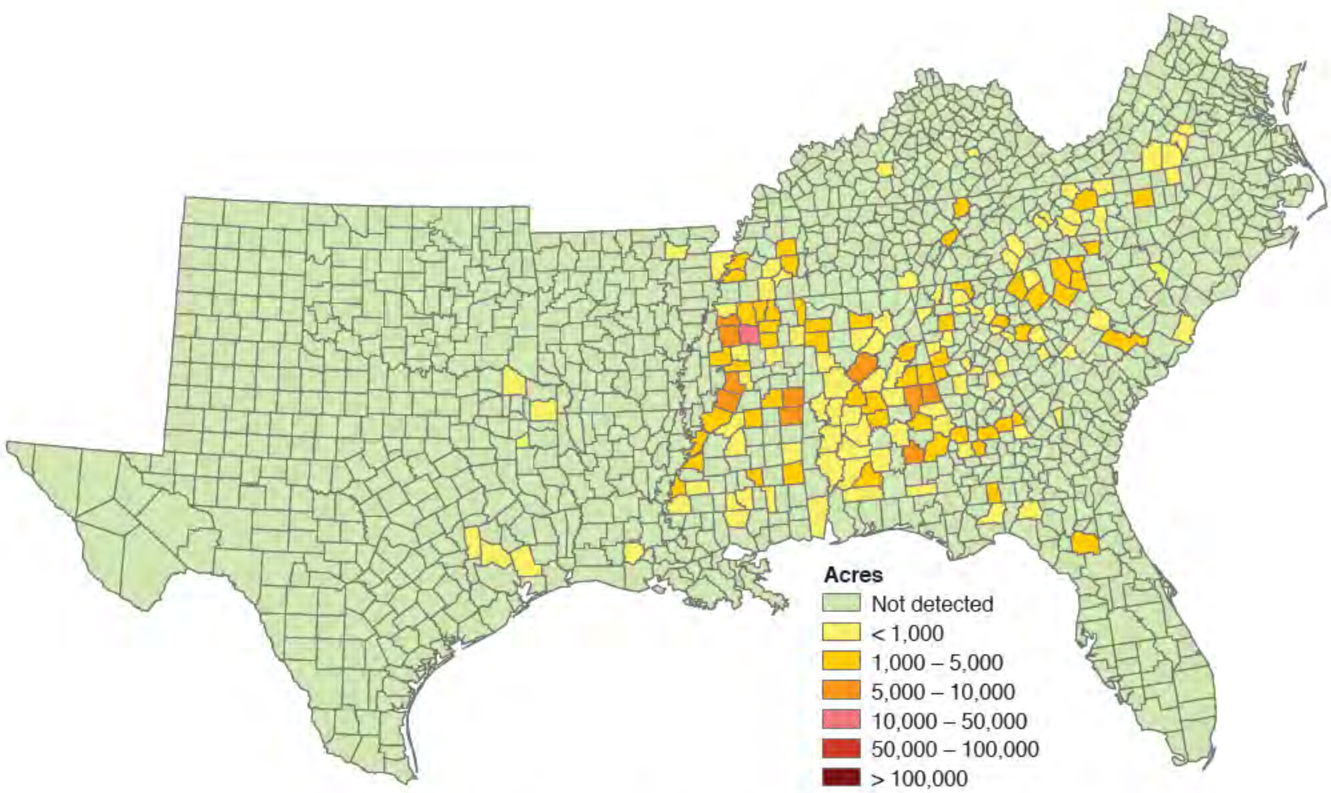

Figure 15.16—Kudzu: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

long pinnately compound leaves. Showy dangling clusters of lavender flowers appear in early spring before leaves that yield flattened hairy pods up to 6 inches long in autumn (Miller 2003). Both colonize by vines twining and covering shrubs and trees and by runners that root at nodes if they have been covered by leaf litter. They are only partially shade tolerant, with vines able to persist into deep shade only if parent plants are growing in open areas. Seeds are primarily water dispersed along riparian areas. Their large sized seeds resemble a dark brown lima bean and are highly poisonous, deterring animal dispersal (Turner and von Aderkas 2009). Genetic analysis shows that most specimens studied in the field are hybrids of the Chinese and Japanese species (Trusty and others 2007). Invasive wisterias are continually being hybridized by the plant industry with many varieties still sold and planted. They resemble the native or naturalized American wisteria (*W. frutescens*), which flowers in June to August after leaves develop and occurs throughout the region in wet forests and edges, sometimes forming large entanglements. Scattered dense infestations of invasive wisterias also occur throughout the region, but most are in the Coastal Plains and Piedmont (fig. 15.17). The current forest occupation of 57,129 acres is expected to increase to at least 77,795 acres in 50 years without concerted control measures (table 15.1).

Invasive ivies—English ivy (*Hedera helix*), Atlantic ivy or Irish ivy (*H. hibernica*), and colchis or Persian ivy (*H. colchica*) are evergreen vines that are difficult to constrain after establishment. They were introduced early in colonial times, while the escape of English ivy was not noted until the 1930s (Clarke and others 2006). They form dense ground cover and can climb to 90 feet by clinging aerial roots to encase trees (table 15.2). They have thick dark green leaves that are heart shaped with three to five pointed lobes when juvenile and that later become lanceolate and lobeless. Leaves are generally less than 3.3 inches wide for English ivy, up to 4 inches wide for Atlantic ivy, and 4 inches or more for colchis ivy. Mature plants at about age 10 have terminal flower clusters in summer that produce dark purple berries in winter that can be retained until spring. Their spread is by bird-dispersed seeds (Greenberg and Walter 2010), and they colonize through vines that root at nodes. All parts of the plant are toxic (even to humans), which discourages over consumption by birds. Contact with plant sap triggers dermatitis and sometimes severe blistering in sensitive individuals, which hinders hand removal (Turner and von Aderkas 2009).

Scattered infestations occur in the Coastal Plains and some in the Piedmont (fig. 15.17). Invasive ivies cover less than 30,000 acres but the infestations can be extremely

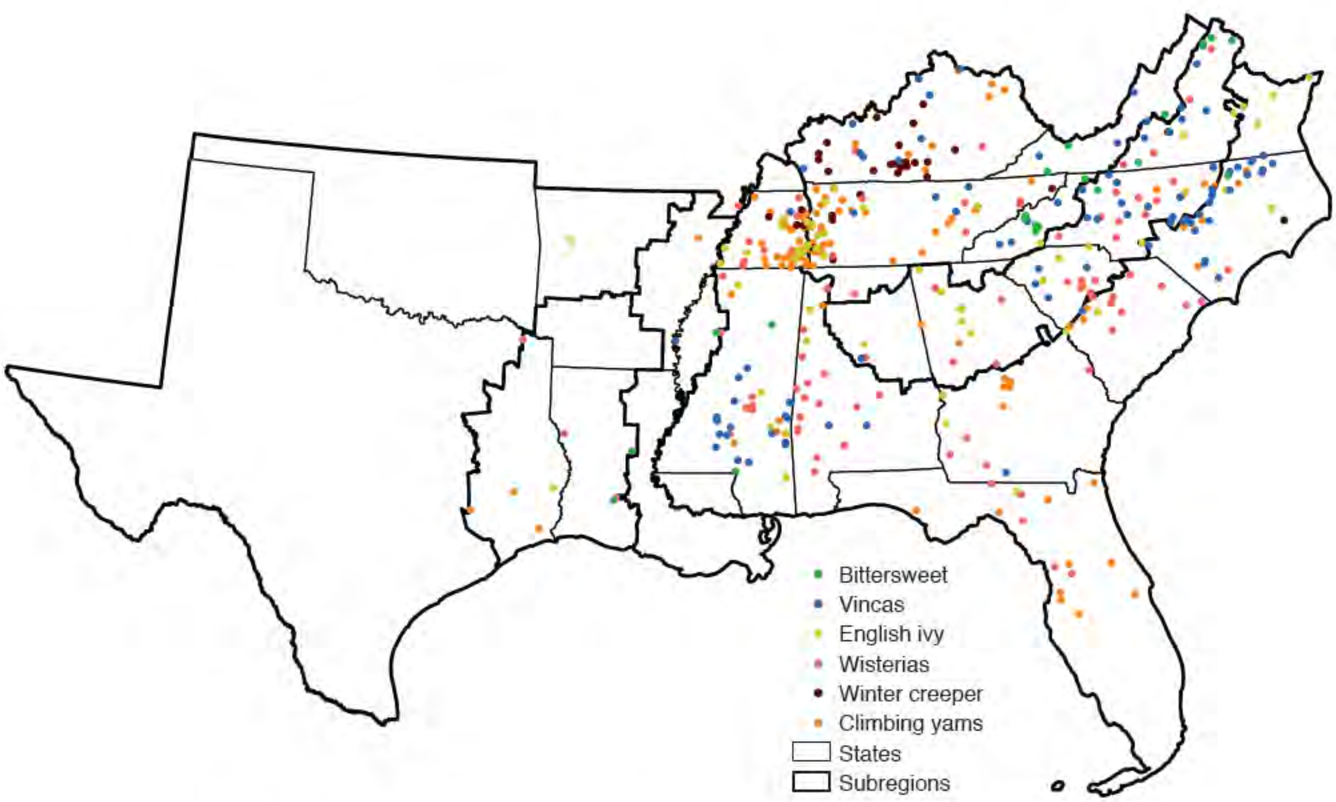

Figure 15.17—Oriental bittersweet, invasive wisterias, periwinkles, winter creeper, invasive ivies, and invasive climbing yams: current regional occurrence map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

dense, blocking introduction of native species (table 15.1 and 15.2). All are still widely produced, sold, and planted as ornamentals. Continued planting by landscapers and developers would accelerate spread at the same time that older plantings reach fruiting age.

Vincas, periwinkles—Periwinkles (*Vinca* spp.) were brought by European colonialists for their many medicinal purposes, but can also be poisonous if used inappropriately (Schittler 1973). Common periwinkle (*V. minor*), introduced in about 1711, and bigleaf periwinkle (*V. major*) in 1789 (Wells and Brown 2000) are evergreen, somewhat woody, trailing or scrambling vines to 3 feet long and upright to 1 foot, which form dense ground cover to exclude all native plants. They have thick opposite lance-to-heart-shaped leaves and five-petaled pinwheel-shaped violet single flowers. They can form mats and extensive infestations by vines rooting at nodes even under forest canopies, especially under deciduous hardwoods, usually near the site of original planting around farm houses. Viable seeds appear to be produced only rarely. Infestations originate from prior plantings and these species are still widely sold and planted as evergreen ground cover. Invasive vincas occur as scattered infestations that vary across States, probably because of historical sources and gardening practices. The highest concentrations are in Virginia, Kentucky, North Carolina, and Mississippi (fig. 15.17). Spread is expected to be slow, unless fertile hybrids appear (table 15.1).

Invasive climbing yams—One species of nonnative climbing yams—Chinese yam or cinnamon vine (*Dioscorea oppositifolia)*—is invading southern forests from the north and two others—air yam (*D. bulbifera*) and water yam (*D. alata*)—are moving northward from the Coastal Plain and Florida. All threaten forested parks and preserves by covering native plants (table 15.2). Water yam was introduced in the 17th century and may have arrived on slave ships from Africa while it became widely cultivated. It was noted as an escape in 1897 (Austin 1999). Air yam is believed to have been introduced before 1777 and was observed by the famous explorer botanist William Bartram in Mobile (Harper 1958). It escaped about 1905 (Morton 1976). Chinese yam was introduced in the 1800s (Flora of North America Association 2009) and believed escaped in the Carolinas after cultivation around 1900 (Rodgers and Shake 1965). Invasive climbing yams are herbaceous vines to 65 feet that cover shrubs and small trees in infestations (Langeland and others 2008, Mueller and others 2003). They have twining and sprawling stems with long-petioled smooth heart-shaped or shield-shaped leaves and dangling potato-like tubers (bulbils) that appear at leaf axils and drop to form new plants. Their aerial tubers spread down slope and by water, sprouting to form new plants, and they also have large underground tubers that hinder eradication. All three species are thought to rarely produce seeds. All vines die back during winter but can completely cover small trees the following year, with old vines providing trellises for regrowth.

Chinese yams are found scattered throughout the region with most common infestations occurring in western Tennessee and less common ones in Virginia; air and water yams occur along the Gulf of Mexico and throughout Florida (USDA Forest Service Natural Resources Conservation Service 2010) (fig. 15.17). All are difficult to control and contain because aerial tubers can persist in the soil. All were traditionally sold as unique ornamentals and readily escaped when fruits were discarded. Air yam and Chinese yams are still sold and their tubers and bulbils are prized as herbal diet supplements. Invasive vines with less than 21,000 acres of current forest cover, climbing yams are projected to increase by 45 percent in 50 years (table 15.1).

Winter creeper—Winter creeper or climbing euonymus (*E. fortunei*) has been planted as an ornamental since the 1907 introduction into the United States from China (Dirr 1998). It is an evergreen shrub to 3 feet in height or woody trailing vine to 40 to 70 feet that forms a dense ground cover, using aerial roots at nodes along stems to colonize and to cling to trees and rocks. Sensitive forest habitats, forested parks and preserves, and unmanaged forests are threatened by loss of diversity after invasion by winter creeper (table 15.2). It has thick leaves less than 2.5 inches long that are opposite, dark-green or green-white-variegated on green stems that become woody and brown with age. Clusters of small, inconspicuous flowers in summer yield pinkish-to-red fruit capsules that open in autumn to expose orange fleshy-covered seeds that are spread by birds, other animals, and water. Many cultivars are still widely produced, sold, and planted as ornamentals in a range of foliar colors, increasing the likely spread rate (table 15.1). Markets have traditionally been confined to the Northern States, although expansion into a more southern range should not be hindered under current climate conditions (Dirr 1998). The Cumberland Plateau in Kentucky and Tennessee has the most recorded occurrences of this species, and escapes from rural population centers continue to promote its spread across the region (fig. 15.17).

Old World climbing fern—Old World or small-leaf climbing fern (*L. microphyllum*), like Japanese climbing fern, is a climbing and twining, perennial viney fern to 90 feet in length, which only occurs in central Florida, escaping about 1960 (Langeland and Burks 1998). It covers shrubs and trees of all sizes and forms mats that are several feet deep (Volin and others 2004). Like Japanese climbing fern, it has lacy but not finely divided leaflets along green-to-orange-to-black wiry vines. Vines arise as long branches from underground wiry and black rhizomes that must be killed for eradication. Dead vines from previous years serve as trellises for reestablishment. This species persists and colonizes by rhizomes and spreads rapidly by wind-dispersed spores and spores carried on contaminated clothing or wildlife fur. Old World climbing fern has blanketed entire tree islands in the Everglades. Currently confined to central and south Florida, it is likely to steadily spread northward (Violin and others 2004), with coverage projected to almost double over the next 50 years (table 15.1). Several biological control insects are in various stages of testing.

Oriental bittersweet—Oriental bittersweet (*Celastrus orbiculatus*) is a popular ornamental vine in the Northeast and upper South, introduced in 1860 (Rehder 1940). The first noted escape in North Carolina was 1895 (Merriam 2003). It is a deciduous, twining, and climbing woody vine to 60 feet high with drooping branches in tree crowns. It forms thicket and arbor infestations (table 15.2) on disturbed sites mainly in the southern Appalachians (McNab and Loftis 2002). It has alternate elliptic-to-rounded leaves 1.2 to 5 inches long. Female plants have axillary dangling clusters of inconspicuous yellowish flowers that yield spherical fruit capsules that are green maturing to yellow. The capsules split in autumn to reveal abundant scarlet fleshy fruits, each with five seeds (Miller and others 2010a), that remain through winter at most leaf axils. It colonizes by prolific vines that root at nodes and seedlings from prolific seeds that have been spread throughout the winter, mainly by birds and possibly by other animals (Greenberg and Walter 2010). Wreaths made of vines covered in the showy fruit have been a traditional Appalachian folk craft item but, when discarded, they are often a source of new infestations.

Seeds are highly viable, germinating immediately even under dense shade and growing rapidly when exposed to light (Greenberg and others 2002) but only remaining viable in the soil for a single year (Ellsworth and others 2004). Oriental bittersweet resembles American bittersweet (*C. scandens*), which has terminal white flower clusters that produce orange fruit capsules and leaves that are usually twice as large but not among the flowers and fruit. Hybridization is occurring between the two species (Pooler and others 2002, White and Bowden 1947). At present, escape of oriental bittersweet can only be found around small towns and cities in North Carolina and Virginia with outliers in Mississippi (fig. 15.17). The widest occupation by this species is in Northern States. Spread projections for the South are based upon the current occupation and an estimate of date of escape. This estimate could be deceptively low because it is clear that oriental bittersweet is still in its early "lag" phase of forest invasion when occurrences are scattered and populations are low (table 15.1).

Invasive Grasses and Bamboos

Nonnative grasses and bamboos continue to spread along highway rights-of-way and gain access to adjoining lands. Because herbicide treatments of southern highways do not extend to the outer margins, they become an invasive plant "free-zone" and a conduit for rapid spread. Most invasive grasses are highly flammable, increasing fire intensity and subjecting firefighters to higher risk; and then spreading rapidly after a wildfire or prescribed burn. Invasive grasses have compromised wildlife management efforts because they have low general nutritive value and leave little room for native plants (Barnes 2007). Repeated applications of herbicides are required for control of invasive grass infestations often followed by establishment of native plants to suppress the grasses that survive.

Nepalese browntop—Nepalese browntop or Japanese stiltgrass (*Microstegium vimineum*) is the most widely distributed invasive grass in eastern forests. The earliest herbarium specimen collected for this species in the United States was found in 1919 by G.G. Ainslee along a creek bank at Knoxville, TN (Fairbrothers and Gray 1972). This is a sprawling, dense mat-forming annual grass even under forest canopies, 0.5 to 3 feet long with stems growing to 1 to 3 feet in height. It bends over and roots at nodes to form extensive entangled infestations that remain during winter dormancy. It has alternate, lanceolate leaf blades to 4 inches long with off-center veins and thin seed heads in summer and autumn. Hidden, self-pollinated seeds within leaf sheaves are produced in early summer. Each plant produces 100 to 1,000 seeds that can remain viable in the soil for up to 3 years (Barden 1987). It is flood tolerant and flourishes on the alluvial floodplains and streamsides where its seeds have been dispersed, mostly colonizing flood-scoured banks (Touchette and Romanello 2010). It is also common in forest edges, roadsides, and trailsides, as well as damp fields, swamps, lawns, and ditches. It spreads along trails and recreational areas by seeds hitchhiking on hikers' and visitors' shoes and clothes. It occurs up to 4,000 feet elevation and is very shade tolerant to invade partly shaded and fully shaded habitats (Flory and others 2007).

Nepalese browntop has been emigrating from the Northeastern States and therefore occurs mostly in the Appalachian-Cumberland and Piedmont subregions (fig. 15.18). Infestations also are concentrated in the deep silt bluffs west of the Mississippi River Alluvial Flood Plain where westward spread currently stops. Scattered infestations are popping up all across the region in every State. Linear spread projections are 10,000 plus acres per year (table 15.1). Estimates of spread rates with climate change scenarios are reported in a later section.

Tall fescue—Tall fescue (*Schedonorus phoenix*) is one of the region's most important forage crops for cattle and sheep with the discovery of the Kentucky 31 variety in 1931, even though it is a severe invasive in all other land uses. Tall fescue (formerly *S. arundinaceus*, *Lolium arundinaceum*,

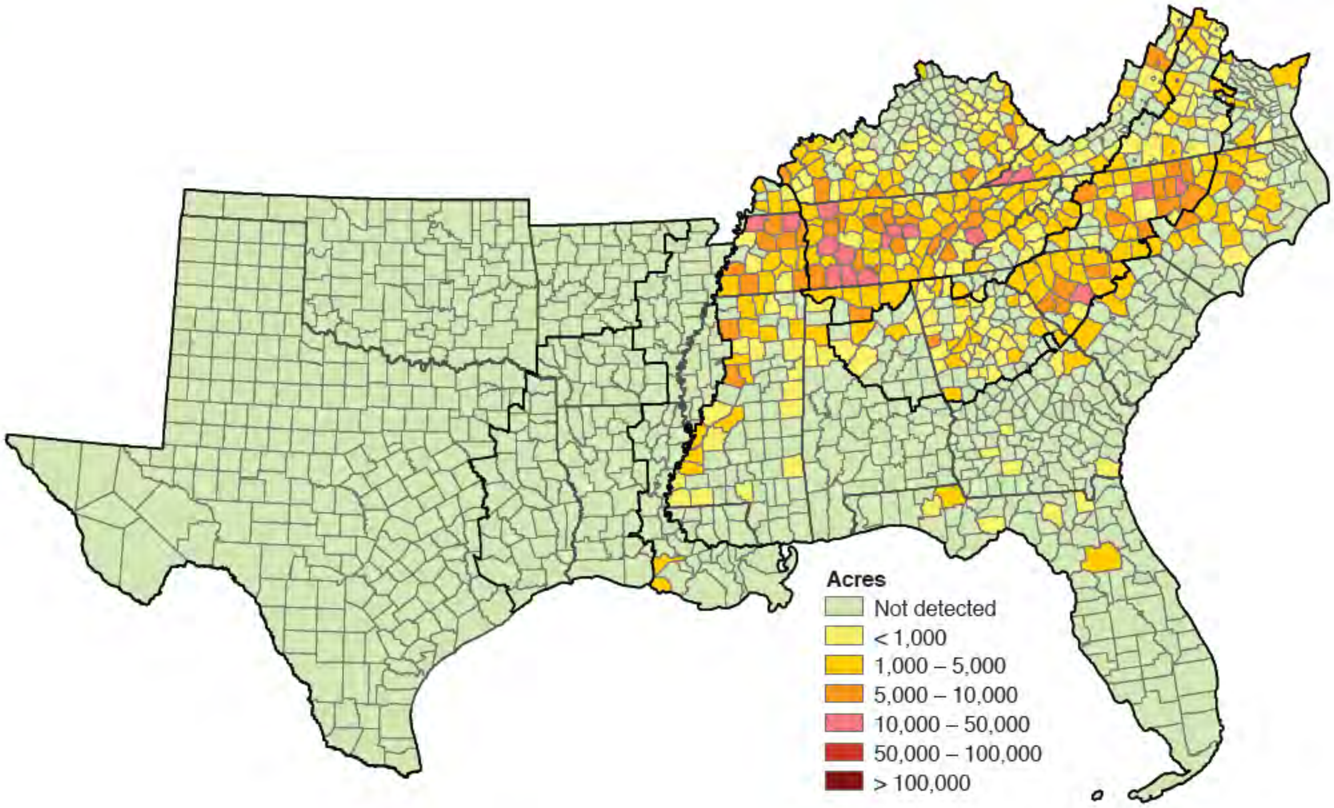

Figure 15.18—Nepalese browntop: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

Festuca arundinacea, and *F. elatior*) is an erect, tufted cool-season perennial grass, 2 to 4 feet in height that occurs throughout the United States. It has whitish-eared areas where leaf blades connect to the stem, and each stem has one or two swollen whitish nodes. Dark-green seed stalks and leaves appear in late winter, usually flowering in spring (infrequently in late summer). This grass is dormant by midsummer. Most tall fescue is infected with a fungus that can reduce weight gains and lower reproductive rates in livestock (Ball and others 1993), while also adversely affecting the nutrition of songbirds and the Canada goose (*Branta canadensis*) (Conover and Messmer 1996). Tall fescue monocultures are generally poor habitat for wildlife, especially ground nesting birds (Barnes and others 1995) and vigorously compete with loblolly pine seedlings (Smith 1989). It is still sold and widely planted for soil stabilization, pastures, and reclamation, with many cultivars available. Tall fescue spreads by expanding root crowns, plantings, and somewhat less by natural seeding.

A cool season grass, tall fescue infestations are most severe in the forests of Kentucky, Virginia, and central Tennessee (fig. 15.19). Satellite populations are present throughout much of the South, with most congregated in the Coastal Plain of Mississippi and the Piedmont of South Carolina. Tall fescue is forecasted to remain the fourth most occupying invasive plant of forests in 2060 (table 15.1).

Cogongrass—Cogongrass (*Imperata cylindrical*) is one of the most aggressive, colony-forming invasive grasses in the region, a century after accidental introduction in southern Alabama (Dozier and others 1998). Dense swords or circular and linear infestations of cogongrass now occur along highway and utility rights-of-way and in preserves, pastures, prairies, hayfields, orchards, lawns, underused lands, and all forest types in eight Southern States along the Gulf of Mexico (Center for Invasive Species and Ecosystem Health 2010). The 66,000 acres currently recorded in forests (table 15.1) is a small component of a broader invasion (fig. 15.20). Cogongrass is a Federal and State listed Noxious Weed, and is considered to be one of the "World's worst 10 weeds" since it is invasive in most tropical and semitropical countries (Holm and others 1977, MacDonald 2004). There were at least three introductions of cogongrass into the United States. The first was an accidental introduction to Alabama from Japan in 1912, as packing material in a shipment of orange trees; and an intentional importation occurred in 1921 from the Philippines to Mississippi and Florida for forage testing (Dickens and Buchanan 1975; Tabor 1949, 1952). In about 1935, cogongrass was taken without authorization from

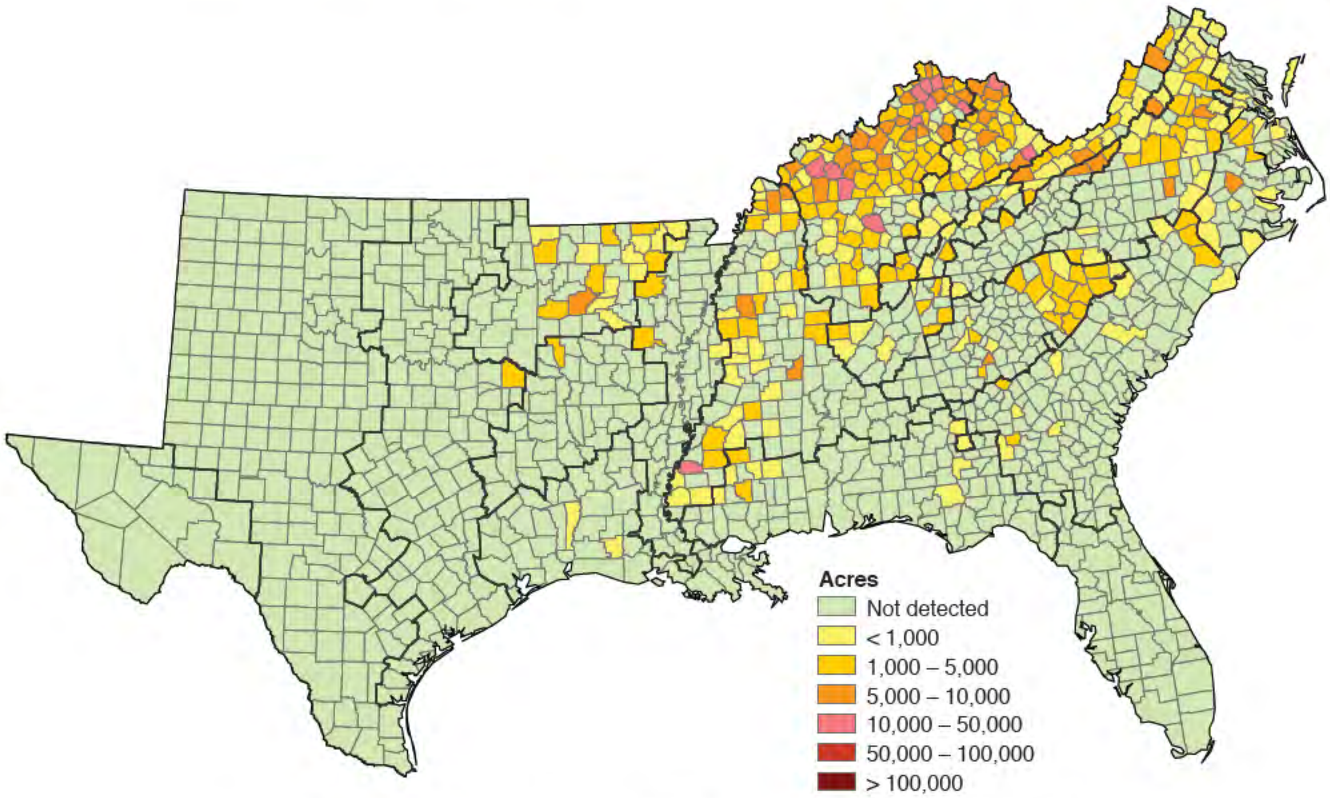

Figure 15.19—Tall fescue: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

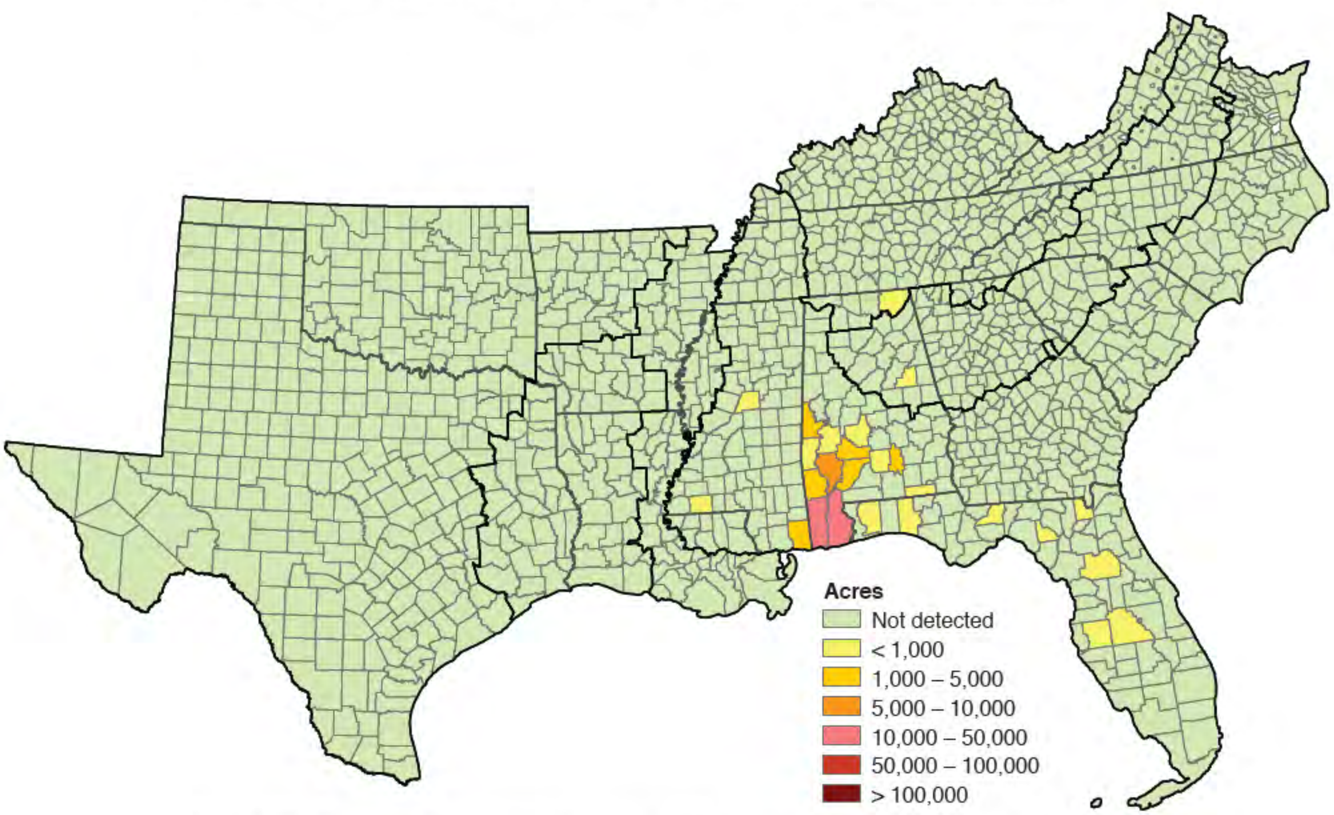

Figure 15.20—Cogongrass: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

the Florida Experiment Station at Gainesville and planted in northwest Florida for pastures and surface reclamation (Tabor 1949). In the 1990s red varieties were developed as ornamentals with cold tolerance for northern gardens and sold as "Japanese Blood Grass," "Rubra," and "Red Baron" (Greenlee 1992). Although no viable seeds have been reported for these red varieties, their viable pollen can impart cold tolerance to nearby invasive populations and reversion to aggressive green plants have been observed as far north as Idaho. In response, several Southern States prohibit the sale of these red varieties (Miller and others 2010b).

Cogongrass is a dense erect perennial grass 1 to 6 feet high with tufts of long leaves from short stems, yellow-green leaf blades (each with an off-center whitish mid-vein and finely saw-toothed margins), and silver-plumed flowers and seeds in spring (sporadically year-round after disturbance) (MacDonald 2004). Cogongrass leaf and inflorescence dimensions vary widely (Bryson and others 2010). Abundant plumed seeds are dispersed by wind and on contaminated clothing, equipment, and products like pinestraw mulch and fill materials. Seed viability is up to a year (Brook 1989). Cogongrass was found to occur on a full range of soils in Mississippi, which indicates that most southern soils can support this invasive plant unless they are permanently flooded (Bryson and others 2010, King and Grace 2000). Dense stands of dried plants remain standing during winter to prevent natural succession and present a severe fire hazard. Cogongrass can remain green year-round in central and southern Florida where infestations have been estimated at over a million acres (MacDonald 2004). Infestations form dense mats of underground stems with buds every one-half inch, making eradication difficult, because abundant shoot and rhizome buds usually sprout after treatment or lay dormant to sprout within months (Williard and others 1996). New invasions occur as circular patches; they are thought to become more difficult to control as they mature (Miller 2003). Federal and State funded control programs have been under way in all infested States for several years. These programs were upgraded in 2010 with Recovery Act funding and are aimed at stopping the spread by eradication of outliers and treating the advancing fronts and selected epicenter infestations in South Carolina, Georgia, Alabama, Mississippi, Tennessee, and Texas. Through these cooperative efforts all known infestations in Tennessee, Texas, and South Carolina are thought to have been eradicated in 2011.

The epicenter of cogongrass infestations remains near the point of initial introductions in coastal Alabama and nearby Mississippi with another in central Florida (fig. 15.20). These multiple introductions have gradually hybridized in South Alabama where fertile seeds are most common (Capo-chichi and others 2008). Because it thrives in the wide range of climates and habitats, northward spread is likely unless dramatic eradication efforts are undertaken (MacDonald 2004). The 60,000 acres infesting forest lands (table 15.1) is just a small percent of the total southern occupation on pastures, hay fields, natural preserves, and urban and rural home landscapes.

Golden and other invasive bamboos—Nonnative bamboos (*Phyllostachys* spp. and *Bambusa* spp.) form exclusive dense stands scattered throughout the region from past plantings. Golden bamboo, the mostly widely occurring species in the South, was first planted in Alabama in 1882 (Lady Bird Johnson Wildflower Center 2007). Invasive bamboos are perennial infestation-forming canes 16 to 40 feet in height. They have jointed cane stems and bushy tops of grass-like leaves in fan clusters on jutting branches, often golden-green. Plants rise from large branched rhizomes (underground stems) that must be killed for eradication. Infestations rapidly expand after disturbance through rhizome extensions. Seeds rarely, if ever are produced—potentially once every 50 to 100 years. Bamboos are still sold and planted as ornamentals and golden bamboo stems have value in Asia for construction, paper, fishing equipment, ski poles, javelins, irrigation pipes, musical instruments, furniture, and handles for umbrellas and fans (Barkworth and others 2007). Rivercane or switchcane (*Arundinaria gigantea* and other *Arundinaria* spp.) are the only native bamboo-like canes in the South, and are distinguished by a lower height—usually only 6 to 8 feet—persistent sheaths on the stem, and absence of long opposite horizontal branches. Invasive bamboos are actively being promoted as a potential biomass crop, but supporting research has yet to appear in scientific literature.

Invasive bamboos occur throughout the region in scattered dense infestations (fig. 15.21) on the edges of forests, fields, and rights-of-way—the result of past plantings over a 130-year period for various structural uses, fishing poles, and more recently as managed roosting sites for migrant black bird species that have been shown to be vectors for the human respiratory disease, histoplasmosis (Glahn and others 1994). The potential exists for a broad general flowering and seeding, which characterizes bamboo forests in their native ranges.

Chinese silvergrass—A locally invasive plant, Chinese silvergrass (*Miscanthus sinensis*) is a tall, densely tufted, perennial grass, 5 to 10 feet in height that grows from a perennial root crown. It has long, slender, and upright-to-arching slender leaves with whitish upper mid-veins and many loosely plumed panicles turning silvery-to-pink in autumn. Dried stalks, some with seed heads, remain standing with during winter, but seed viability is variable depending on cultivar and location. This species requires pollination by another cultivar to produce viable seeds and fertile offspring. This results in extensive infestations that

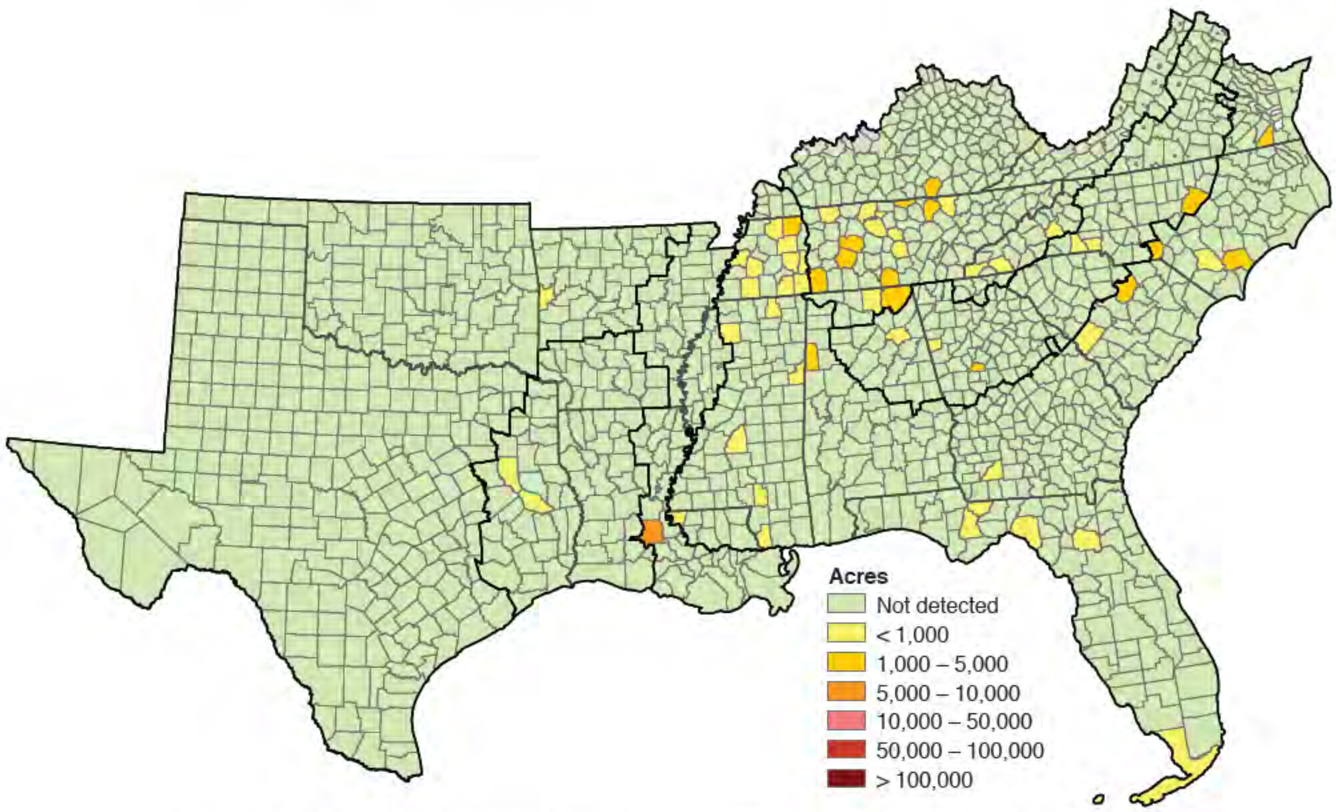

Figure 15.21—Invasive bamboos: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

escape along roadsides, forest margins, rights-of-way, and adjacent disturbed sites, especially after burning. Although introduced in 1904, escaped plants were not noted until 1957, in waste areas and tidewater in the Virginia and Maryland Piedmont. (Gilman 1957). Proposed widespread plantings of hybrids and giant silvergrass (*M. xgiganteus*) for biomass and biofuels could result in aggravated problems. Infestations, although they occur as dense monocultures, have only been found in scattered locations (fig. 15.22), with an epicenter in eastern Kentucky.

Nonnative Forbs

Forbs are broadleaf herbaceous plants that usually reproduce by seed and can be perennial with root crowns that persist over winter. Invasive forbs form dense monocultures that hinder or stop forest regeneration and plant diversity (table 15.2). Control treatments are usually by foliar spraying of herbicides. Persistent seeds in the soil and underground stems and rhizomes make control a lengthy and exacting process that involves eradication and rehabilitation.

Garlic mustard—Garlic mustard (*Alliaria petiolata*) is an upright cool-season biennial forb that is shade tolerant and increasingly occurs in small-to-extensive colonies under forest canopies and along roadsides in the Central Appalachians and the Northeastern United States (Meekins and McCarthy 2001, Rogers and others 2008, Shuster and others 2005). Even without bare soil (Slaughter and others 2007), it can become established and form dense infestations of basal rosettes and broadly arrowhead-shaped leaves with wavy margins in the first year (remaining green during winter). The second year produces 2- to 4-foot stalks with terminal clusters of self-fertilizing small white flowers that yield stalks of many upward jutting thin pods 1 to 5 inches long (Drayton and Primack 1999). The plant dies after June, and its pods ballistically broadcast their seeds up to 10 feet, with seedlings germinating in spring. The average spread from one plant has been measured at 18 feet per year (Nuzzo 1999), but farther distribution also occurs by water and when seeds cling to humans and animals. Seeds can lie dormant for 2 to 6 years (Drayton and Primack 1999), which prolongs the period of control.

Stand density varies yearly depending on germination requirements of seeds in the soil seed bank, with a single crop germinating over a 2- to 4-year period. Persistent infestations exclude most herbaceous cohorts probably by the release of inhibitory chemicals in tops and roots (Roberts and Anderson 2001, Vaughn and Berhow 1999). Foliage has been shown to also produce chemical barriers to feeding by a select group of larval insects (Renwick and others 2001).

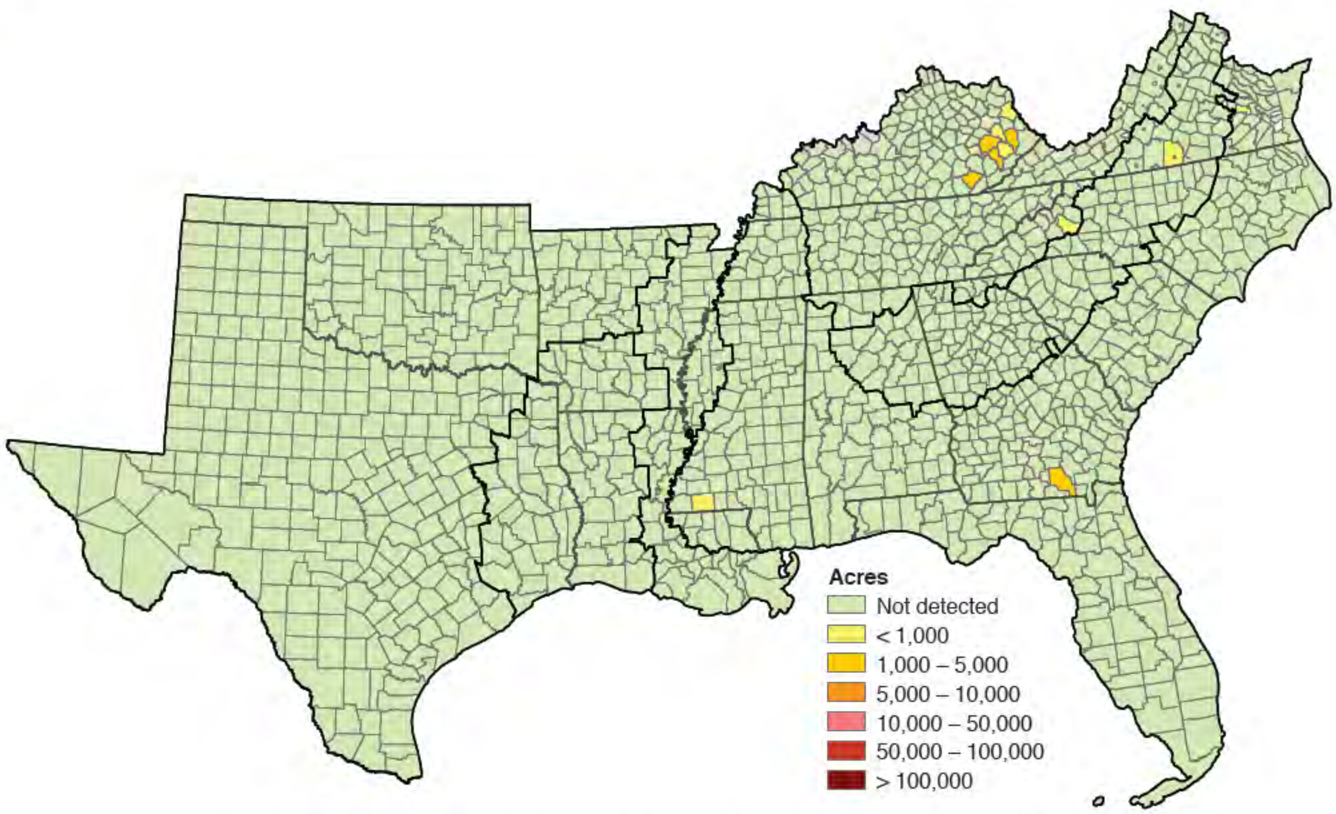

Figure 15.22—Chinese silvergrass: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

Current data show high infestations in scattered counties of the Appalachian-Cumberland highlands with outliers in northern Coastal Plain areas west of the Mississippi River (fig. 15.23). The current 6,000 acres is projected to increase by 45 percent in 50 years (table 15.1).

Other Invasive Plants in the South

These 35 groups, although the most prevalent now, are only part of the more than 300 terrestrial invasive plants in the South in various phases of spread (Miller and others 2010a). Many of the other invasive plants, although not as formidable, threaten special habitats and will combine to form exclusive invasive communities, like those that comprise our common lawns and roadsides.

Projected Increases in Infestations

Invasive plants cover more than 19 million acres of forests in all Southern States and are spreading at an average rate of 147,000 acres per year (table 15.1). Over half of all infested forested lands have Japanese honeysuckle (10.3 million acres), a common companion of many other invasive species. Privet species are the second most pervasive invasive plants, followed by Nepalese browntop and tall fescue grasses. The invasive lespedezas, tallowtree, and invasive roses, each occupies over 700,000 acres. Several other invasive species currently capture over 100,000 acres: tree-of-heaven, chinaberrytree, bush honeysuckles, Japanese climbing fern, and kudzu (table 15.1). By growth form, vines have the greatest coverage at 11 million acres (led by Japanese honeysuckle), followed by shrubs at 4.9 million acres, grasses at 1.8 million acres, and trees at 1.2 million acres (table 15.1). The only invasive forb covered here, garlic mustard, covers 6,000 acres.

A simple linear projection of occupancy by invasive plants in 2060 forecasts an approximate 40 percent increase with coverage of 26.6 million acres. Japanese honeysuckle is expected to cover over 13.5 million acres. Because of the tendency for multiple occupancy by invasives, Japanese honeysuckle is forecasted to entangle 4 million acres of privets with 353,000 acres of kudzu. Based on the regressions, the invasive with the largest projected spread is tropical soda apple at 227 percent, followed by winged burning bush at 167 percent, and Old World climbing fern, sacred bamboo, and Chinese silvergrass, which will double in coverage. Several others are predicted to increase by

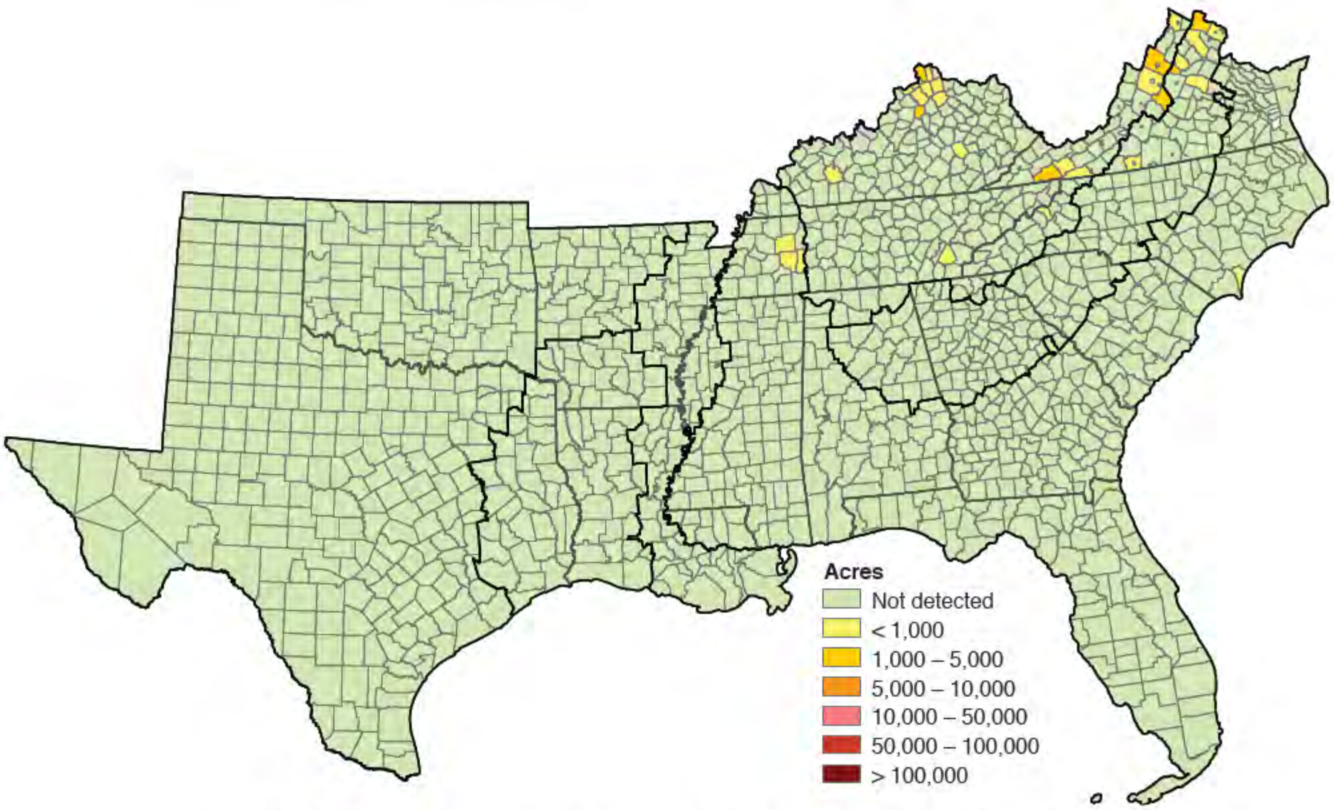

Figure 15.23—Garlic mustard: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

about 60 percent: melaleuca, bush honeysuckle, invasive elaeagnus, sacred bamboo, winged burning bush, tall fescue, cogongrass, and Chinese silvergrass.

Geographic Distribution of Infestations

Figure 15.24 shows the percent of counties that are occupied by one to four invasive plants. Counties with the highest occupations occur in the long inhabited and highly disturbed mining regions of north central Alabama in the Southern Piedmont, extending north into central Tennessee's Interior Low Plateau, and northeast along the Southern Ridge and Valley of the Appalachian-Cumberland highlands. Invasive species were planted in the past and continue to be used for reclamation because of their tolerance to difficult site conditions. From the 1920s through the 1960s, Federal programs encouraged the planting of invasive species on erodible and eroding soils on the over-farmed lands in the Black Belt Prairie across central Alabama and northwestern Mississippi, the Southern Appalachian Piedmont in northern Georgia, and the Middle Gulf Coastal Plain in Mississippi, Alabama, and north Georgia. The abundance of invasive plants in South Carolina stems from a long-standing tradition of producing, promoting, and planting invasives for soil stabilization and wildlife habitat improvement. Other scattered highly infested counties occur as testament to the long-term "success" of government cost-share and incentives programs aimed at promoting nonnative invasive plants for a multitude of purposes.

Model Predictions of Current and Future Potential Habitat

The predictive models for five invasive plants of high threat indicate their current potential range and intensity could be greater than their current occupation. This means that none of these species have spread to all suitable habitats and are limited by vectors (figs. 15.26, 15.28, 15.30, 15.32, and 15.34). The extent of their spread will be influenced by a number of factors (table 15.3).

Tallowtree—A subtropical-to-temperate species, tallowtree is likely to be limited in its northern range by minimum temperatures (Dirr 1998). The modeled distribution of tallowtree had high AUCs and low omission rates, suggesting a strong model. The model for the potential distribution if current trends continue (figs. 15.1 and 15.25) indicates that further spread is possible along the Atlantic Coast into North

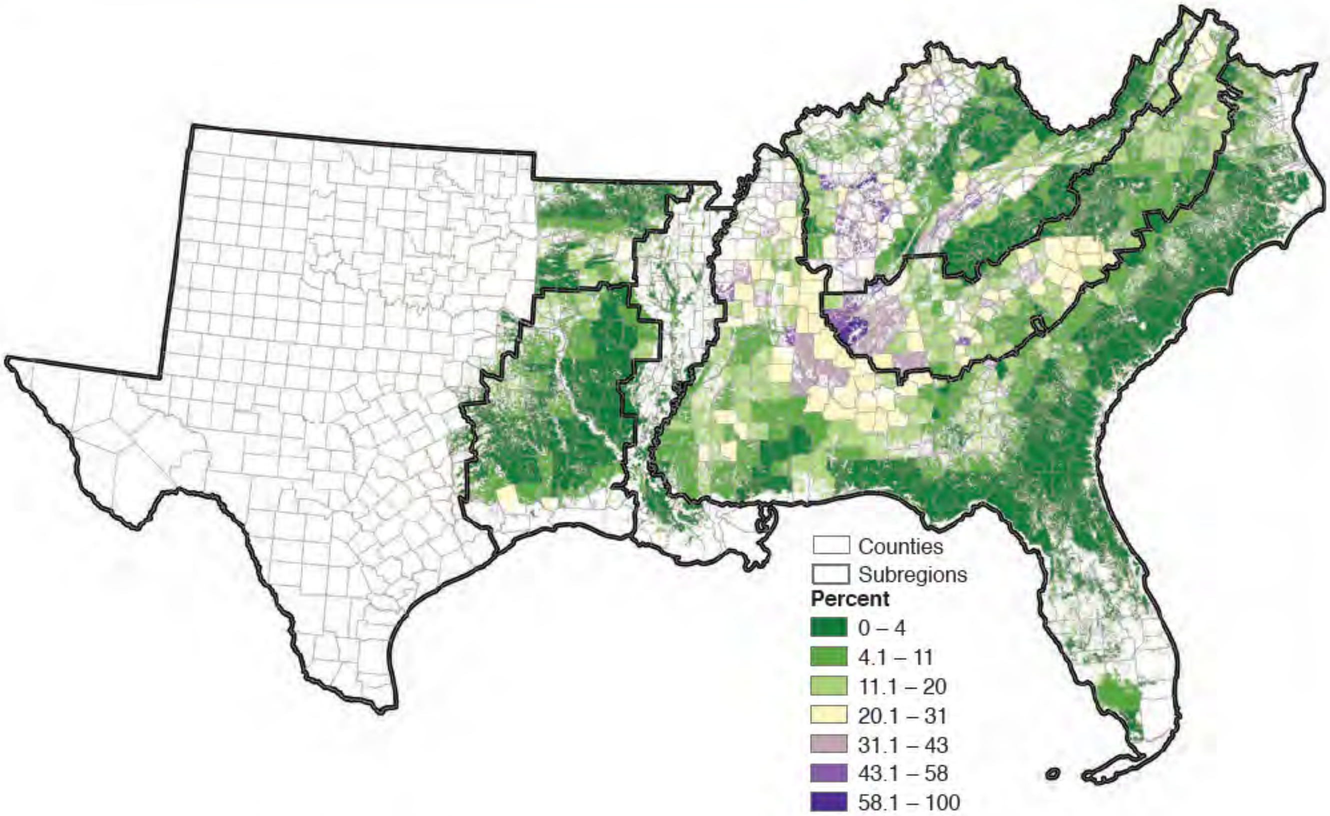

Figure 15.24—Percent of survey plots within a county occupied by one to four invasive plants, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/. [Date accessed: June 11, 2013].)

Table 15.3—The contribution weight and direction for significant variables by species used in modeling the potential for invasion (+ positive relationship, - negative relationship, ∩ binomial, N polynomial)

Variable (unit)	Variable range of data	Tallowtree	Silktree	Roses	Japanese Climbing Fern	Nepalese Browntop
Mean minimum temperature in Jan. (°F)	6 – 65	∩	-	-	∩	∩
Mean annual rainfall (inches)	9 – 104	+	∩		∩	N
Elevation (feet)	0 – 6900	-	∩	-	-	-
Distance to interstates (mile)	0 – 17.8		-			
Distance to roads (mile)	0 – 5.75		-			
People per square mile	0 – 2676		∩			
Proportion of forest in county (percent)	0 – 100		+			∩
Proportion of pasture in county (percent)	0 – 100			+		

Contribution to the model

- Dominant (50 to 100 percent)
- High (20 to 50 percent)
- Moderate (10 to 20 percent)
- Low (5 to 10 percent)

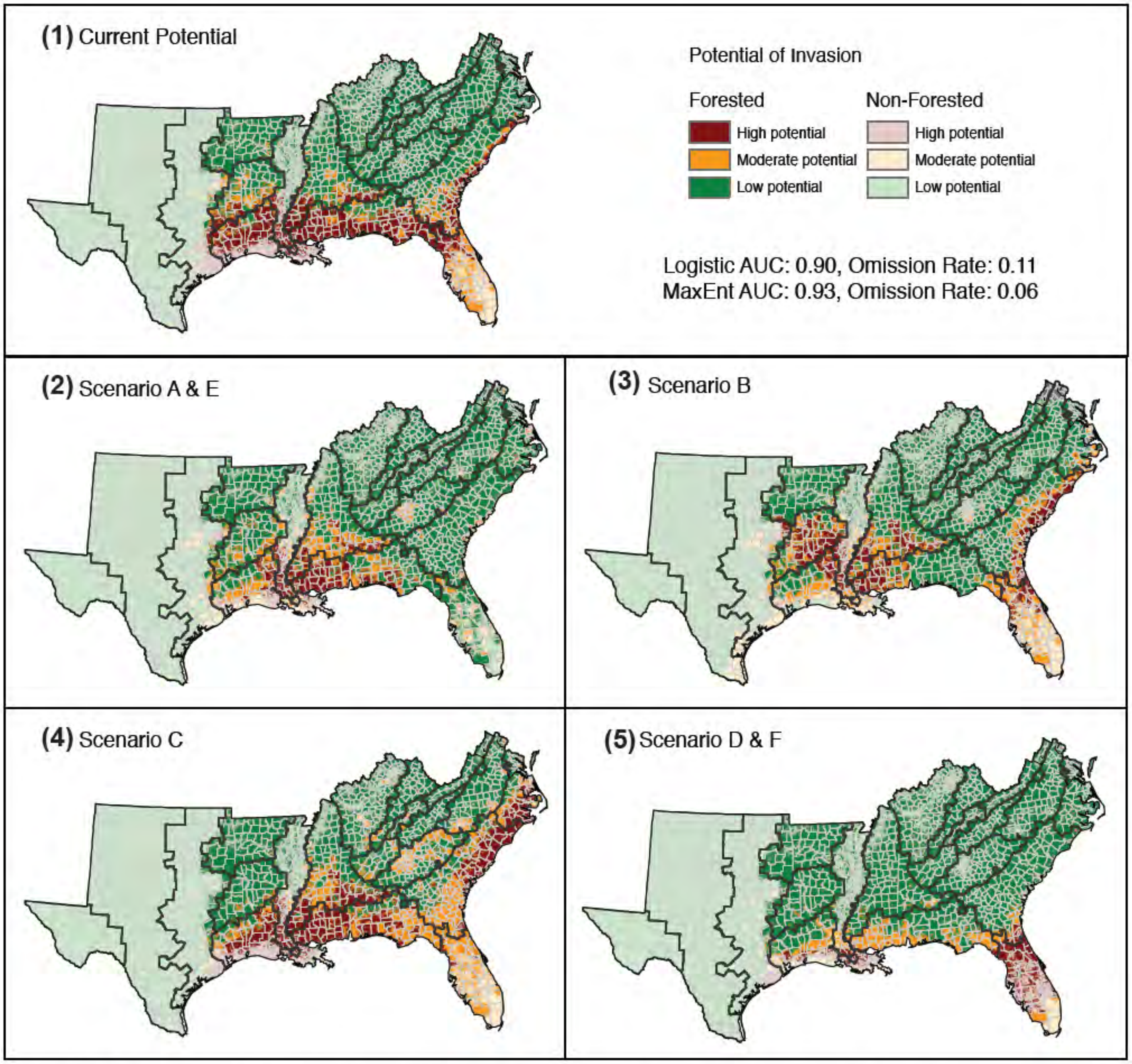

Figure 15.25—Tallowtree: potential for occupation into 2060 under (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) minimal warming with increased rainfall, Cornerstone B; (4) moderate warming and minimal drying conditions, Cornerstone C; and (5) cooling and drying conditions, Cornerstones D and F.

Carolina, across northern Florida and southern Georgia, and in the Black Belt Prairies across central Alabama and northwestern Mississippi—with specimen trees already reported for southern North Carolina and southern Arkansas (North Carolina State University 2010). Tallowtree's western limits in Texas appear to have been reached, and northward migration from the Gulf of Mexico is unlikely under current conditions. However, the density of cover across the South has a high potential to increase from the current three percent of forests occupied to 20 percent (fig. 15.26), with a 43 percent increase within the Mississippi Alluvial Valley, and a 33 percent increase in the Coastal Plain, particularly north Florida. The model identified three main variables that influence the occurrence of tallowtree (table 15.3). Mean minimum temperature in January was the strongest, followed by elevation and annual rainfall greater than 40 inches. Minimum temperature represents 42 percent of the model for tallowtree, with ranges below 30 °F and above 50 °F diminishing the likelihood of occurrence, while higher elevations decrease the probability of tallowtree. Gan and others (2009) also found elevation and minimum temperature to be prime variables and reported no occurrences on plots with temperatures below 10 °F and none above 500 feet elevation. And a common garden experiment (Pattison and Mack 2009) showed that tallowtree seeds can germinate and grow in temperatures as low as 25 °F. These results suggest that our model may be a little conservative.

With moderate-to-maximal warming of the South (fig. 15.26) described in chapters 2 and 3, the potential for tallowtree is expected to be greater than its current occupation (Cornerstones A, B, C, and E). With the exception of those that predict decreasing minimum temperature (Cornerstones D and F), all futures would permit a slightly more northerly distribution (fig. 15.25)—an outcome supported both by Gan and others (2009) and by Pattison and Mack (2008). Under the Cornerstones that predict reduced rainfall along the Gulf of Mexico (A, E, and B), tallowtree would have a more limited distribution but would still be more than twice its current potential (table 15.3). With the land-cover variables used in this model, tallowtree is absent only at the extremes: in areas of very low urbanization and pasture, and at the upper extreme, in areas with more than 65 percent urbanization or 85 percent pasture.

Under the significantly warmer and drier climate of Cornerstones A and E, tallowtree could move up the Mississippi Alluvial Valley but would remain in Mississippi and Alabama, with decreased rainfall reducing the potential for occupation eastward into Florida, and along the Atlantic Coast. The moderate warming and similar rainfall to current

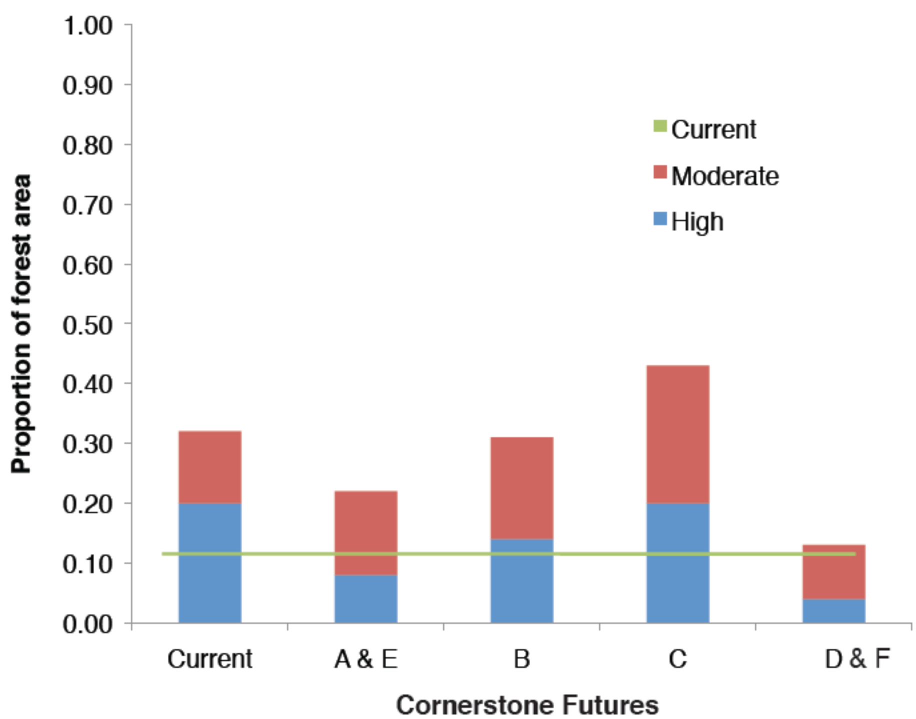

Figure 15.26—Tallowtree: the actual current proportion of survey plots (line), (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) moderate warming and minimal drying conditions, Cornerstone C; (4) minimal warming with increased rainfall, Cornerstone B; and (5) cooling and drying conditions, Cornerstones D and F at high (agreement of both models) and moderate (predicted by one model) probability.

in the mid-Mississippi valley, Florida and along the Atlantic Coast under Cornerstone B would allow tallowtree to exist in these locations. A predicted drier zone in Coastal Alabama and along northern Florida would nullify invasion potential in these areas. The areas of increase potential are related to rainfall. Cornerstone C would have the largest potential distribution of tallowtree with high or moderate potential of occurrence on 43 percent of forestland (fig. 15.26), a range that could expand westward from the Atlantic Coast and northward from the Gulf of Mexico, and an increase in inland pockets with medium potential. Cornerstones D and F, with decreasing minimum temperatures and a slightly drier Gulf Coastal Plain would have the lowest potential distribution (13 percent, combined higher and moderate potential), but still higher than the current occupation. Similar local conditions as now would confine tallowtree to Florida and the coastal areas of Alabama, Mississippi, and Louisiana.

Silktree—Our model for silktree was one of the weakest, but was still statistically significant with AUC of 0.75 and 0.80 and omission rates of 0.15 and 0.26. Seven variables had moderate contribution (table 15.3), ranging from 6 to 25 percent. A number of these variables, such as proximity to roads, were not addressed when the Cornerstones were developed, reducing the confidence in predictions. The two strongest variables were temperature (24 percent) and distance to interstates (25 percent). Silktree has some tolerance to cold weather but cannot withstand winters below -5 ºF (Dirr 1998). Herbarium specimens have been collected from throughout the region except south Florida, which supports the current potential range (fig. 15.27). Its current preference to roadways is widely evident, both visually when driving and by its web-like pattern of potential occurrence on the maps (fig. 15.27). The next most dominant variables are rainfall at 14 percent and elevation at 13 percent contribution (fig. 15.28). These variables have a binomial relationship, with silktree preferring intermediate levels for both. Under all Cornerstones, silktree showed much greater potential (16 to 28 percent at high potential) than its current occupation of 2 percent (fig. 15.28). Compared to the status quo prediction, potential would diminish under Cornerstones A, E, and B, primarily of increasing temperatures and decreasing rainfall, The current potential distribution range would push, but not extend, the range northward. Under the minimal decreases in rainfall of Cornerstones C, D, and F the potential of silktree increases the most compared to the current potential, although by only a few percentage points. It is clear that silktree thrives with human habitation and the roadway systems that will likely increase.

Invasive roses—Invasive roses currently predominate in the upper portion of the South, with a few areas scattered through the Coastal Plain and in the Black Belt Prairie across central Alabama and northwestern Mississippi (fig. 15.7). Of the five species modeled, roses had the highest occurrence on forested FIA plots (5 percent). They include a number of species with the principal one being multiflora rose (Miller and others 2010a), which is also one of the most pervasive invasive plants in the Midwest and Northeast United States and Ontario. The model drops out Macartney and Cherokee roses, which are concentrated in Louisiana and the Black Belt Prairie across central Alabama and northwestern Mississippi (figs. 15.7 and 15.29). The statistics on the models show they are reasonable with AUCs of 0.86 and omission rates of around 0.15. The model is highly influenced by minimum temperature, which is different for multiflora and the more southern adapted Macartney and Cherokee roses which were selected, bred, and widely planted for this reason. The status quo model predicts that 40 percent of the forests in the South have a high to moderate potential of habitats suitable for invasive roses (fig. 15.30). In the Appalachian-Cumberland highlands, this potential increases to 90 percent of forests. The model is dominated by a strong negative relationship (63 percent) to minimum temperature and a weaker negative relationship (12 percent) to elevation (table 15.3). Field observations show heavy infestations in high-elevation plots along the Blue Ridge Parkway in North Carolina, raising questions about the true elevational relationships. The only other variable with a reasonable contribution to the model is the positive relationship to the amount of pasture in a county (table 15.3). This is also supported by findings of Glasgow and Matlack (2006) that a higher percentage of pasture lands increases the expectation for invasive roses. Federal and State programs from 1930 to 1950 promoted the planting of multiflora rose as a "living fence" around pastures, where it eventually spread into pastures (Bergmann and Swearingen 2009). It is possible that such planting at high elevations predated the construction of the Blue Ridge Parkway on lands reclaimed from subsistence farming (and presumably grazing), explaining the difference between model output and field results.

Under the cooling of minimum winter temperatures of Cornerstones D and F, the potential for occupation gets as high as 87 percent (fig. 15.30). The potential distribution of invasive roses is smaller than the current potential under all other Cornerstones. With the warmer Cornerstone C, the potential (4 percent) all but disappears, falling below the current occupation level (fig. 15.30).

Japanese climbing fern—Japanese climbing fern currently occurs on 4 percent of FIA plots in northern Florida and southern Louisiana, Mississippi, Georgia, and Alabama (figs. 15.15 and 15.32). The prediction of current potential shows moderate expansion into Florida with a few isolated areas further up the Atlantic Coast (fig. 15.31), a sizable increase of 18 percent at the high potential and 10 percent at the moderate potential (fig. 15.32). This model was one of the strongest (AUCs of over 90 and omission rates near

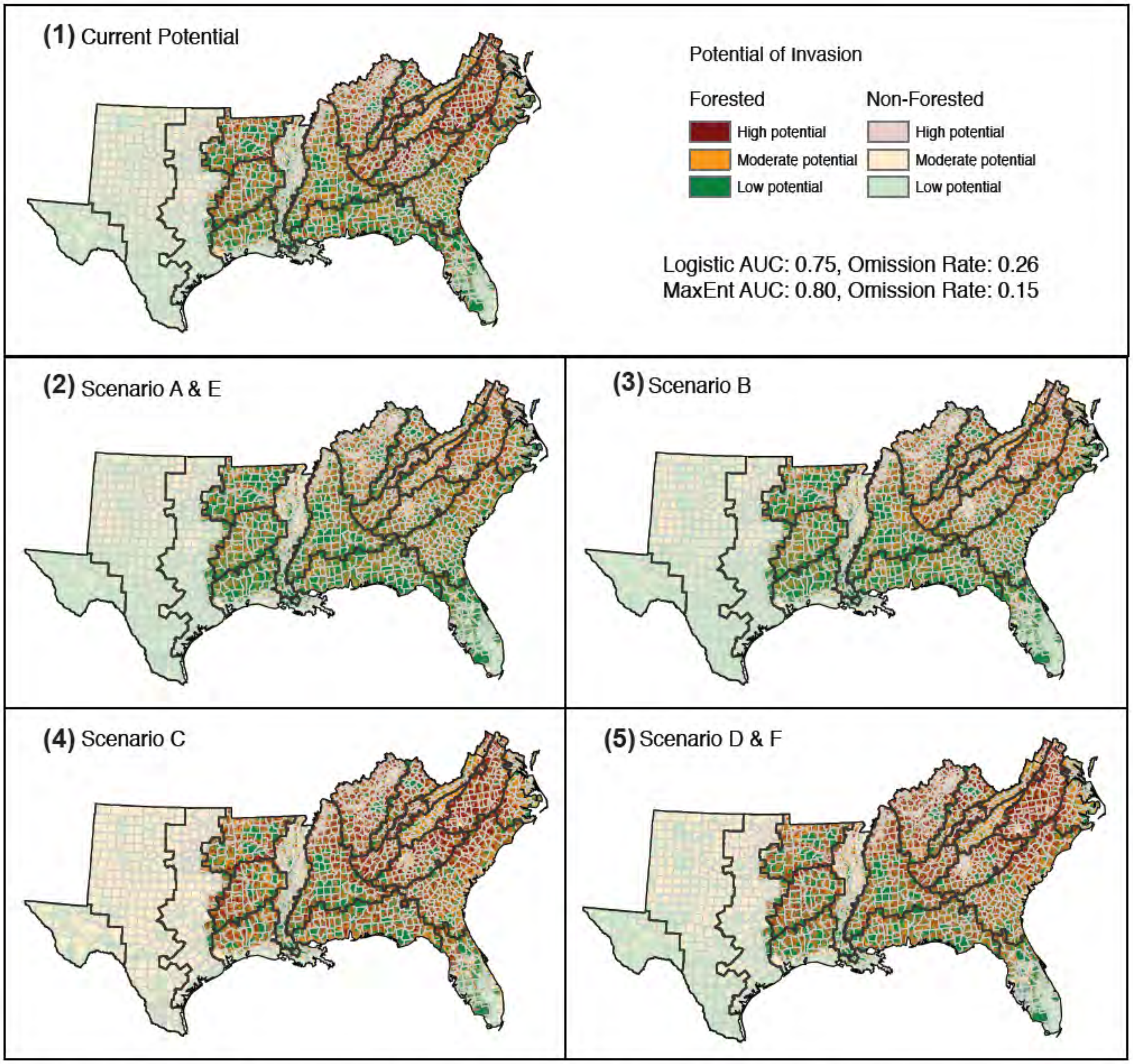

Figure 15.27—Silktree: potential for occupation into 2060 under (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) minimal warming with increased rainfall, Cornerstone B; (4) moderate warming and minimal drying conditions, Cornerstone C; and (5) minimal warming and drying conditions, Cornerstones D and F.

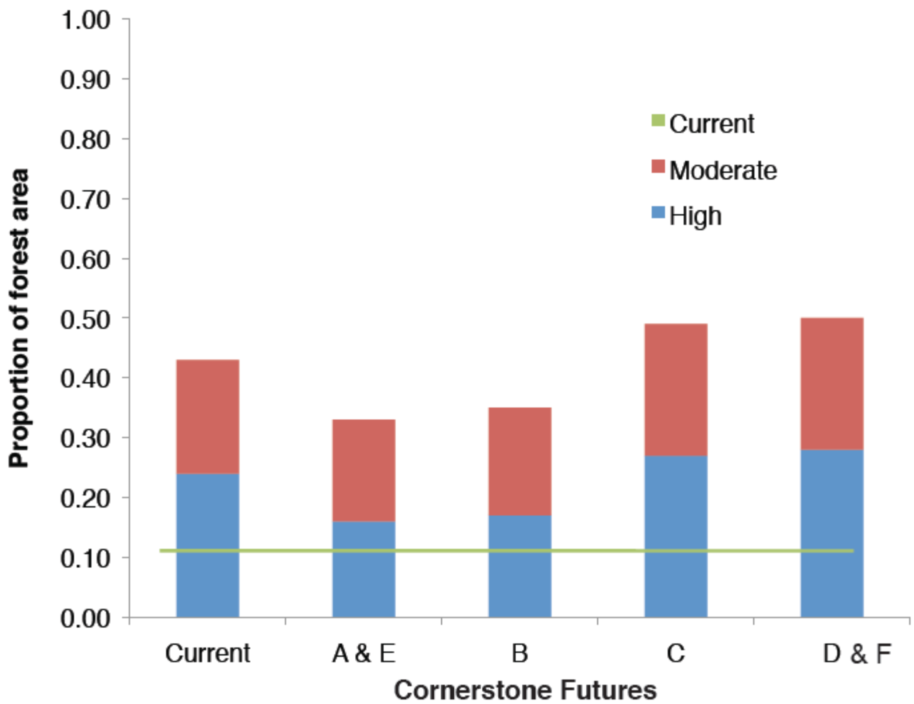

Figure 15.28—Silktree: the actual current proportion of survey plots (line), (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) moderate warming and minimal drying conditions, Cornerstone C; (4) minimal warming with increased rainfall, Cornerstone B; and (5) cooling and drying conditions, Cornerstones D and F at high (agreement of both models) and moderate (predicted by one model) probability.

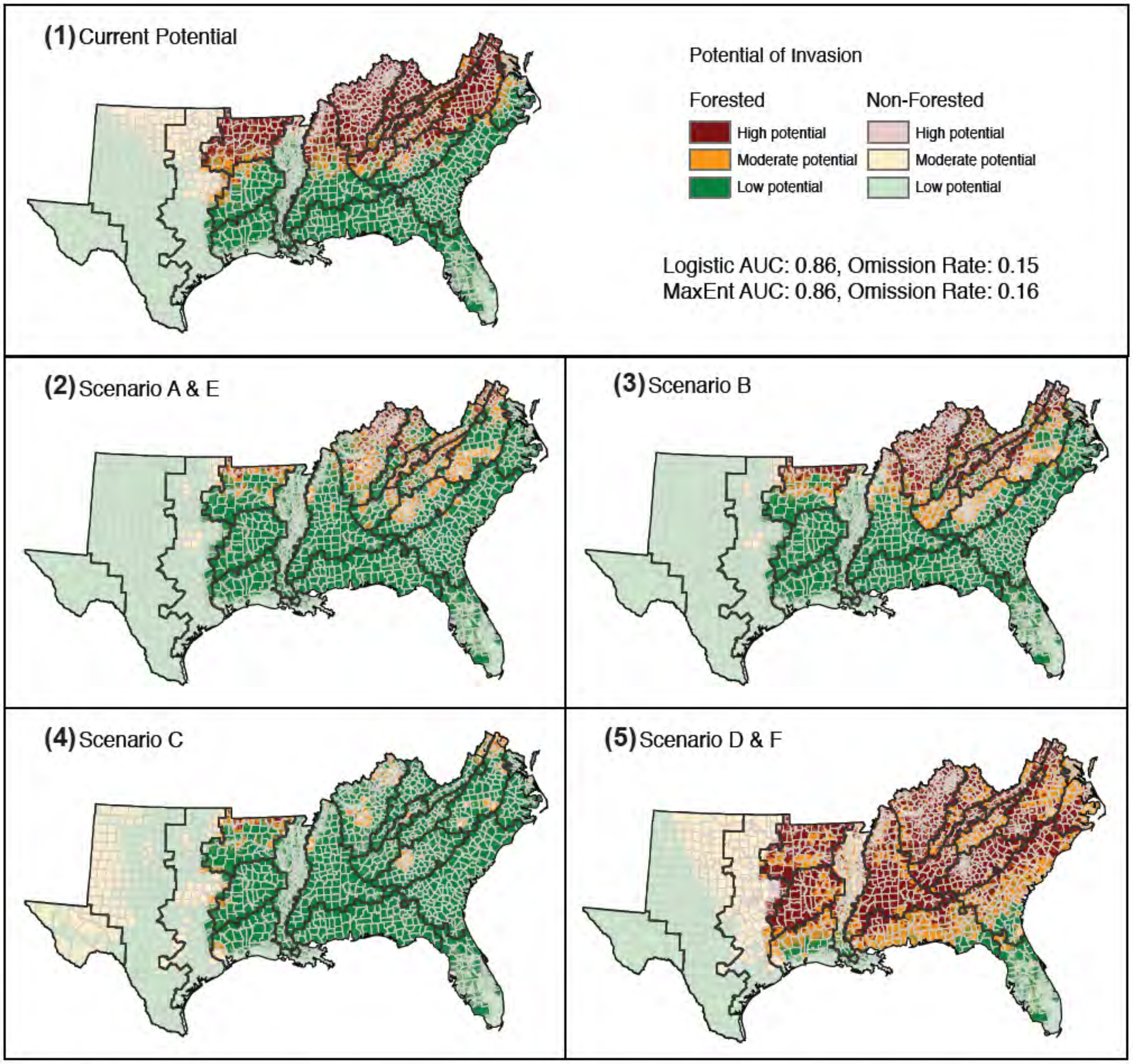

Figure 15.29—Invasive roses: potential for occupation into 2060 under (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) minimal warming with increased rainfall, Cornerstone B; (4) moderate warming and minimal drying conditions, Cornerstone C; and (5) minimal warming and drying conditions, Cornerstones D and F.

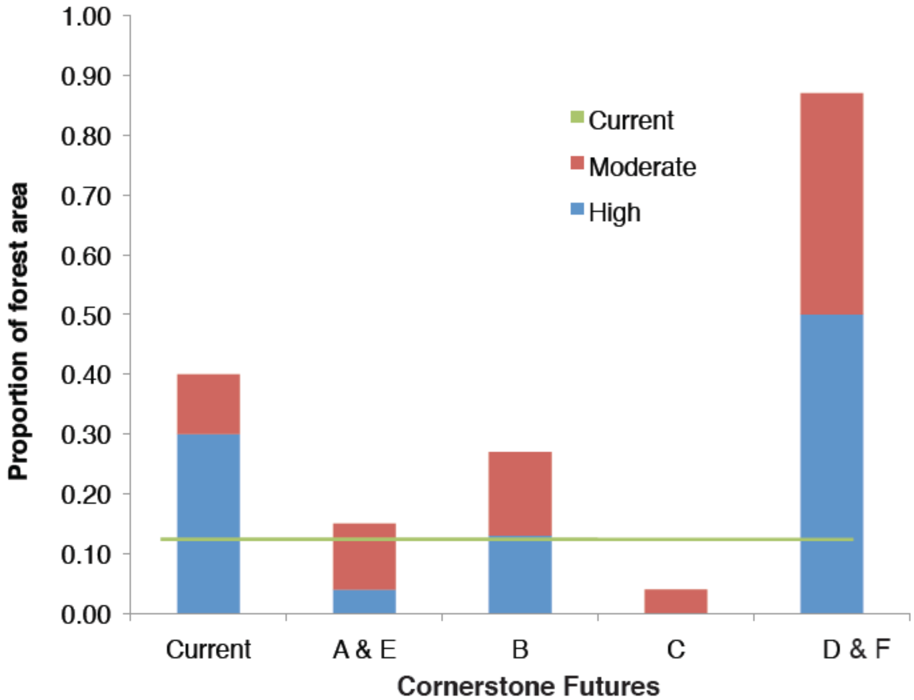

Figure 15.30—Invasive roses: the actual current proportion of survey plots (line), (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) moderate warming and minimal drying conditions, Cornerstone C; (4) minimal warming with increased rainfall, Cornerstone B; and (5) cooling and drying conditions, Cornerstones D and F at high (agreement of both models) and moderate (predicted by one model) probability.

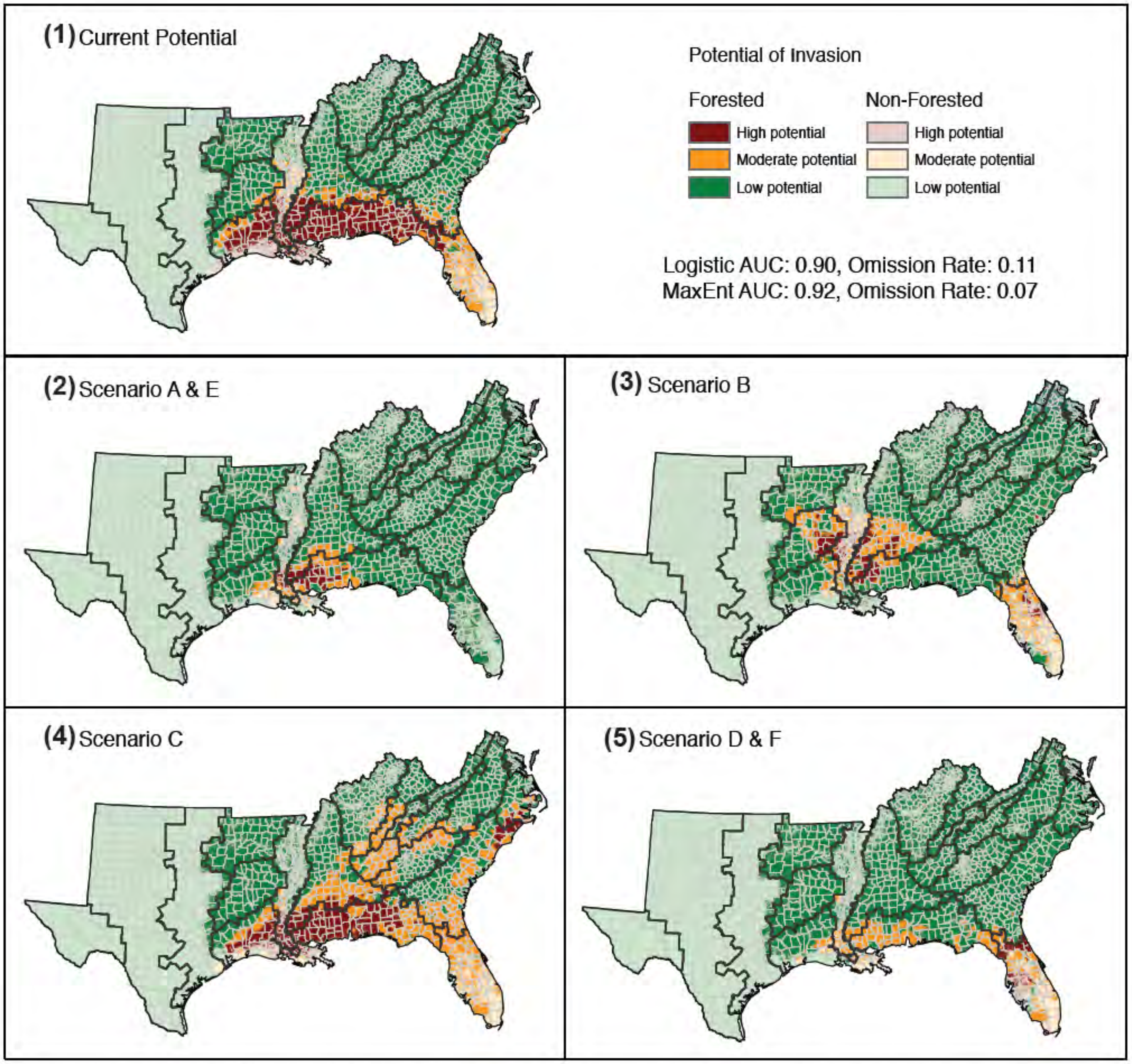

Figure 15.31—Japanese climbing fern: potential for occupation into 2060 under (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) minimal warming with increased rainfall, Cornerstone B; (4) moderate warming and minimal drying conditions, Cornerstone C; and (5) minimal warming and drying conditions, Cornerstones D and F.

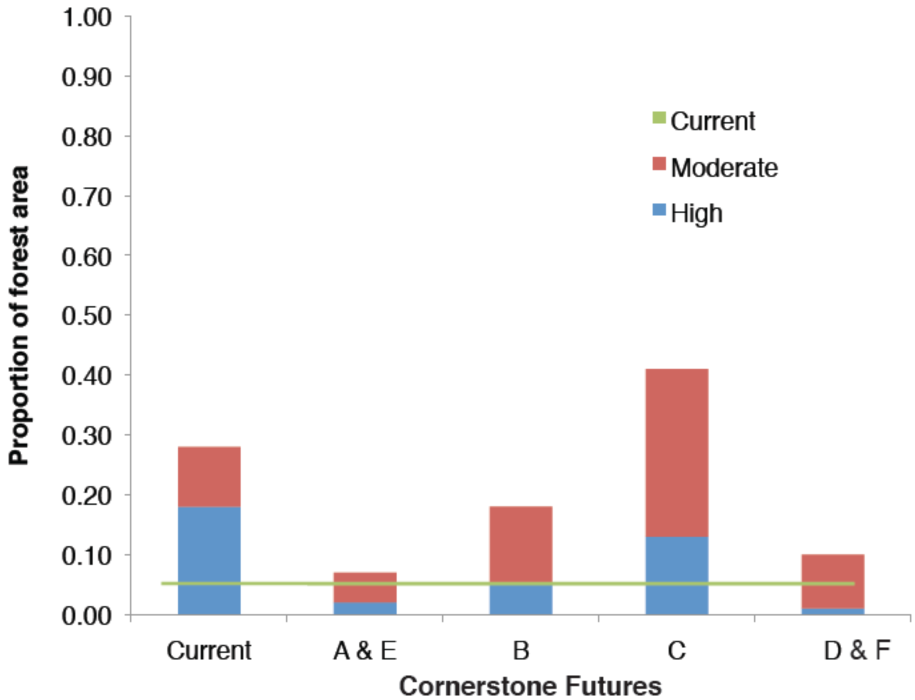

Figure 15.32—Japanese climbing fern: the actual current proportion of survey plots (line), (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) moderate warming and minimal drying conditions, Cornerstone C; (4) minimal warming with increased rainfall, Cornerstone B; and (5) cooling and drying conditions, Cornerstones D and F at high (agreement of both models) and moderate (predicted by one model) probability.

0.10), with rainfall, temperature, and elevation dominating (table 15.3). Potential for Japanese climbing fern becomes higher as temperature and rainfall increase, although this effect diminishes at the extremes of both. The negative relationship to elevation may be an artifact of the dataset limitations, as populations currently only occur at low elevations. The potential distributions under the varying climate forecasts seem primarily driven by rainfall, with reduced rainfall within the current potential distribution and in Cornerstones A, E, and B limiting distribution (fig. 15.31). Under Cornerstone A, B, and E the areas of high potential are lower than the status quo prediction (fig. 15.32). Under Cornerstone C the area of moderate potential extends to as far as Tennessee—the result of sustained rainfall patterns from the central Gulf to Appalachia coupled with a minimal increase in temperature. Under Cornerstones D and F cooler temperatures in winter are expected to reduce the potential significantly, pushing the distribution mainly into Florida.

Nepalese browntop—The potential habitat range for Nepalese browntop under current conditions is projected to occupy up to 41 percent more forest land than its current distribution of 3 percent (fig. 15.33 and 15.34). The models had reasonable statistics with AUCs around 0.85 and omission rates of 0.24 and 0.14. The dominant variables in the model are minimum temperature, rainfall, elevation, and proportion of forest (table 15.3). Temperature is the biggest contributor at 62 percent, with a bimodal relationship of minimum temperature preferences ranging from 21 ºF to 32 ºF. The other dominant variables suggest the highest potential occurs at lower elevations with intermediate forest cover and moderate rainfall (table 15.3). Under Cornerstones A, E, and C, Nepalese browntop all but disappears in the South (fig. 15.33), driven predominantly by the higher temperatures pushing its range northward. Cornerstone B, with minimal warming, has some reduction but is most similar to the current potential. Under Cornerstones D and F, with reduced winter temperatures and slightly less rainfall, the potential for southern expansion is greatly increased (91 percent).

South-wide projections—Overall, the current proportion of forest invaded (2 to 5 percent) is substantially lower than the current potential (28 to 44 percent) for all five species, and predictions of potential suitable habitats for most Cornerstones are also lower than the status quo predictions. Nevertheless, in only 2 of the 20 high-moderate projections (figs. 15.26, 15.28, 15.30, 15.32, and 15.34) are the Cornerstones lower than the current portion of forest invaded (Cornerstone C for invasive roses and Nepalese browntop). Both of these species have current distributions in the upper reaches of the South, and warming temperatures that extend to the northern part of the South (less so with Cornerstone A or B) will push their ranges further north.

With these models at the regional level, the dominant variables were temperature, rainfall, and elevation. Overall, these models suggest that the probable distribution of suitable habitats for these invasive species increases under most climate forecasts.

Treatments for Integrated Management of Invasive Plants

A successful program for invasive plant management usually involves a combination of treatment methods integrated into an approach that considers the invader and the site. Many methods are available to manage invasive plants leading to site rehabilitation, and more are under development. Current treatment options for specific areas involve herbicides, prescribed fire, prescribed grazing, mechanical, and manual removal (Miller and others 2010b). Fire, grazing, and mechanical cutting treatments usually control only the above-ground plant parts, resulting in reduced height, but not resulting in permanent suppression.

Herbicidal Control Methods

Most nonnative invasive plants in the South are perennials with extensive roots, tubers, or rhizomes. This means that effective herbicide applications offer the best means of containment or eradication, because herbicides can kill roots without baring soil, protecting the site from reinvasion and erosion and leaving the soil seed bank in place for native plant reestablishment. Research has found that herbicides tested and registered with the U.S. Environmental Protection Agency are safe for humans and animals when stored, transported, and applied according to label directions. For successful herbicide treatments:

- Use the herbicide most effective for the targeted species and appropriate for safety to non-target species and situation.
- Follow, in detail, the application methods prescribed on the label. Adhere to all label prohibitions, precautions, and safety requirements during herbicide transport, storage, mixing, and application.
- Choose the optimum time for applications. For foliar-applied herbicides to non-evergreen woody plants, the best time is usually midsummer to early autumn and not later than a month before expected frost. Evergreens and semi-evergreens with leaves can be treated effectively until they lose their leaves (Frey and others 2007). The optimum time of application for each specific herbicide on each specific invasive has not been fully researched; future findings should greatly improve prescription efficacy.
- After application, watch for herbicidal activity—detectable as yellowing of foliage or as leaves with dead spots or margins—which may take a month or longer.

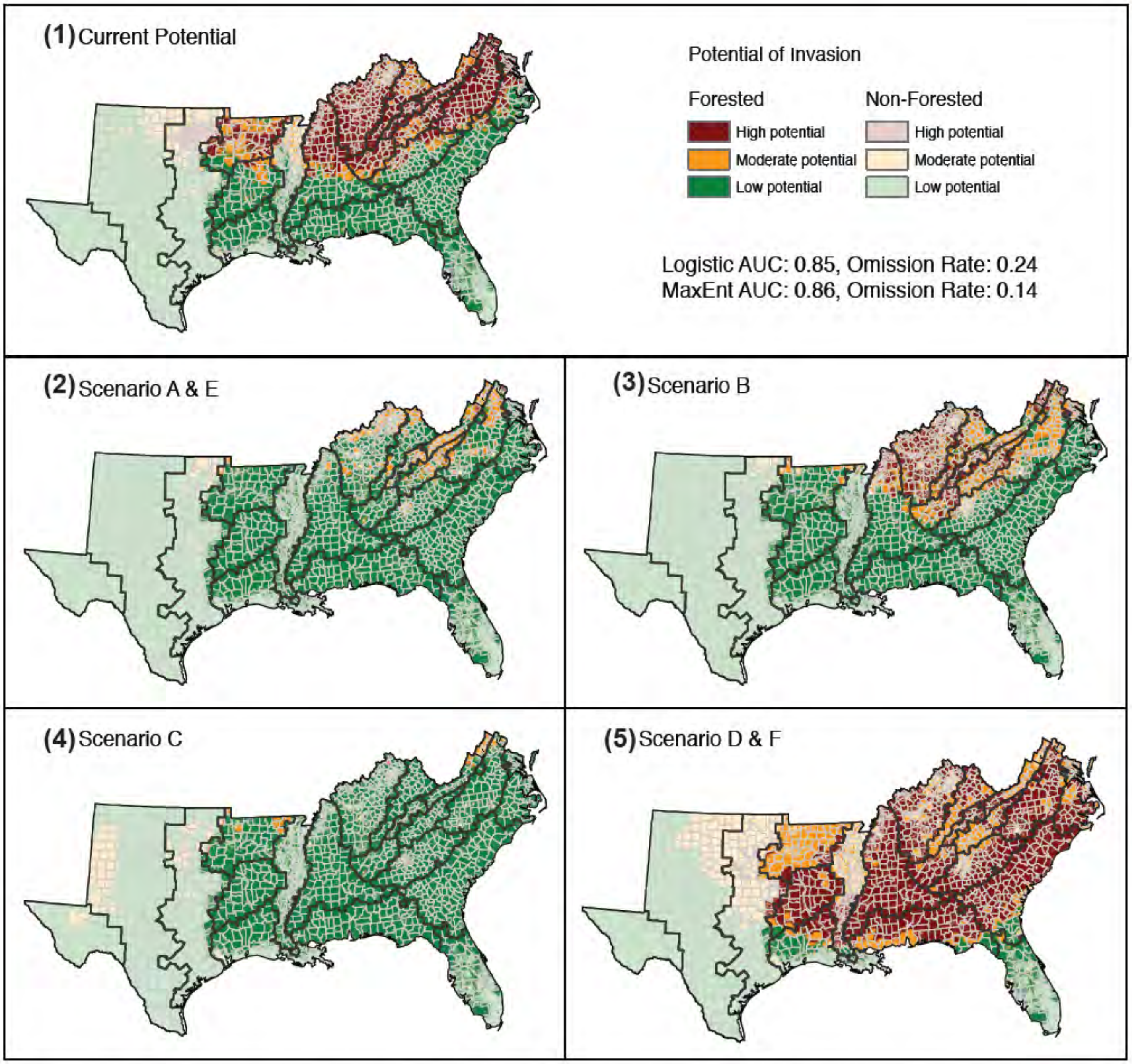

Figure 15.33—Nepalese browntop: potential for occupation into 2060 under (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) minimal warming with increased rainfall, Cornerstone B; (4) moderate warming and minimal drying conditions, Cornerstone C; and (5) minimal warming and drying conditions, Cornerstones D and F.

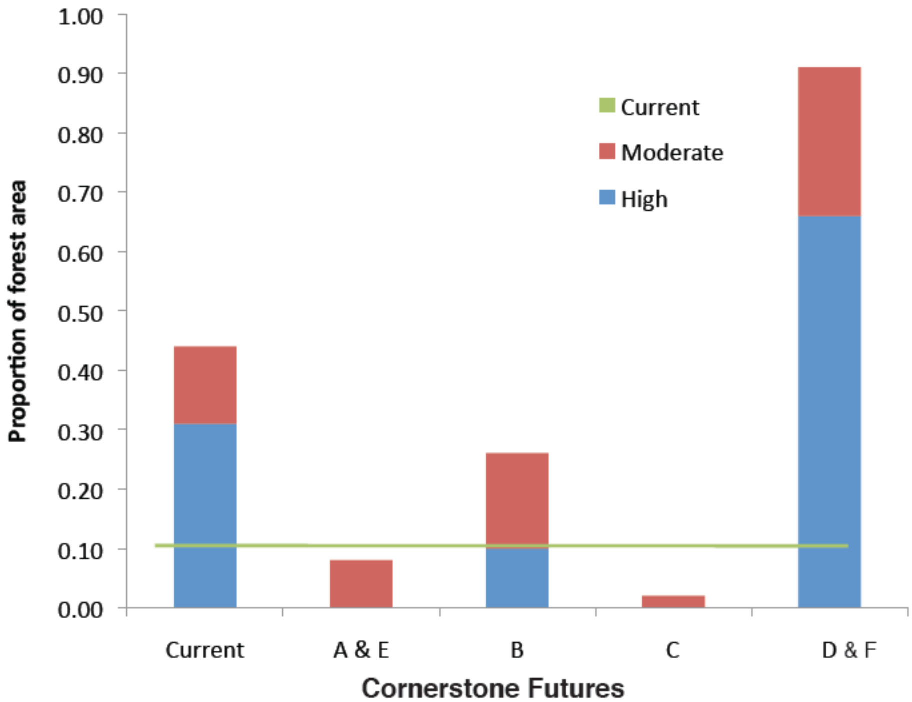

Figure 15.34—Nepalese browntop: the actual current proportion of survey plots (line), (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) moderate warming and minimal drying conditions, Cornerstone C; (4) minimal warming with increased rainfall, Cornerstone B; and (5) cooling and drying conditions, Cornerstones D and F at high (agreement of both models) and moderate (predicted by one model) probability.

Allow herbicides to work for several months to a year before resorting to other treatment options. Consult the herbicide label for timing of expected response of treated vegetation, but if green foliage reappears, retreatment should follow.

Specific herbicide prescriptions for invasive plants of southern forests are provided in manuals (Langeland and others 2009, Miller and others 2010b, Tennessee Exotic Pest Plant Council 1996) and on Web sites (www.invasive/org/ species/weeds.cfm, http://www.nps.gov/plants/alien/factmain.htm, http://www.srs.fs.fed.us/pubs/gtr/gtr_srs131.pdf). The use of nonselective herbicides can damage non-target native plants, hindering recovery efforts (Carlson and Grochov 2004); this realization is leading to refined prescriptions that support restoration (Flory 2010).

Selective herbicide applications—Although treating extensive inaccessible infestations may require broadcast treatments of herbicide sprays or pellets by helicopter or tractor-mounted application systems, the most effective approach is usually selective applications to target nonnative plants while avoiding or minimizing application to desirable plants (Miller and others 2010b). Selective methods include directed foliar sprays and wipes, basal sprays and wipes, stem injection, cut stem applications, and soil spots. Directed treatments of nonnative vines and forbs usually involve foliar sprays using backpack sprayers.

Broadcast herbicide applications—Many infestations of nonnative plants are too extensive or dense to permit selective herbicide applications, and instead require broadcasting of sprays and pellets. Herbicides with appropriate selectivity can be used to minimize damage when native species have herbicide tolerance to the active ingredient. In pockets of non-target native plants, broadcast applications can be discontinued in favor of the selective methods described above. In special plant habitats, small desirable plants can be protected by plastic covers during broadcast treatment. Broadcast sprays of foliar active herbicides (no soil activity) can be applied on evergreen or early greening invasives when native plants are dormant (Johnson and others 2009). Many equipment types are available for mounting broadcast application systems, depending on the situation: utility skid and trailer-mounted sprayers, all-terrain-vehicle and recreation-vehicle mounted sprayers, tractor-mounted sprayers, roadside sprayers, and helicopter sprayers.

Other Treatments

Manual treatments—Manual methods include hand pulling and using a wide array of tools for cutting, chopping, wrenching, and girdling. Manual methods are most effective on woody invasive plants when they are small. Eradication is only possible when the root crown or roots that can sprout are completely extracted and seedlings are pulled or eliminated following germination. Because it is difficult and even impossible to extract all of the shallow roots, stolons, and rhizomes of many invasives, re-sprouting usually occurs. Unless an herbicide is applied to cut surfaces, merely pulling small plants and cutting top growth will result only in short-term control before stump or root sprouting occurs. Manual treatments are labor-intensive and can only be used on small-sized plants, resulting in limited but effective use on special habitats (such as recreational trails or nature preserves).

Mechanical treatments—In many situations, hand labor is unavailable or cost prohibitive and more horsepower is needed. Specific machines developed for forestry and land clearing operations are available to clear large or dense infestations (Klepac and others 2007). Skid-steer loaders, mulchers, mowers, and tractors and bulldozers having special attachments can be used to reduce invasive woody plants (Miller and others 2010b). Tree shears, root-rakes, and harrows have been used to cut and dislodge woody and rhizomatous plants, but can leave soil bare for probable reinvasion and possible erosion. These methods can complement and increase the efficiency of herbicide treatments, but merely cutting above ground parts can aggravate plants—such as cogongrass (Willard and others 1996) and Chinese lespedeza (Brandon and others 2004)—that have surviving rootcrowns or rhizomes. Although highly disturbing, mechanical treatments have been used to clear dense infestations of multi-species of invasive woody plants and prepare the way for other more selective followups.

Cultural treatments—Several cultural practices, including prescribed burning and water level manipulation, can reduce or control nonnative invasive plant populations. However, if not applied with care, these practices may have undesirable impacts to soils, animal habitat, and native species, so care in planning and enactment must be exercised. Burning to weaken woody invasives is most effective in the late spring after plants begin using their root reserves for early growth. Burning in late winter or spring leaf-out can minimize the period of bare soil, while summer burns are the hottest and can maximize consumption of standing plants. Burning can predispose a forest stand or opening to invasion, even though prescribed burning increasingly is favored for native plant and longleaf pine ecosystem restoration as well as fuel reduction. A close evaluation of the benefits and risks is demanded before applying prescribed burning to avoid unexpected consequences (Brooks and Lusk 2008, Glasgow and Matlack 2006). A propane spot burner can be used to kill individual or small groups of herbaceous or woody invasives. Commercial kits are available for attaching propane cylinders to a backpack frame and fitting the cylinder with a flame nozzle. Other units are available for mounting propane cylinders on tractors. When plant and wet fuel conditions permit, the flame is directed at herbaceous and woody invasives.

In areas where water level can be manipulated, flooding or drawdowns can reduce invasive plant populations in aquatic and wetland habitats but these are species- and site-specific and usually not effective as stand-alone treatments (Allen and others 2007). They require an understanding of the biology of both invasive and native plants in the treatment area.

Mulching and solarization—Mulching involves covering the soil surface with materials that block light, thereby preventing weed germination and growth. Although application of mulches and landscape fabrics is common for reseeding and soil stabilization in restoration operations, mulching for control of tough invasive plants will not be effective unless adequate amounts of materials are applied. Mulching is most effective on small seeded species and marginally effective on established re-sprouting perennials such as kudzu. Many types of mulches are available, including natural ones such as straw, bark, sawdust, crop residues, and grass clippings; and artificial ones such as paper, cardboard, and plastic. Although mulch applications are not commonly used to control invasives on a large scale, they are still useful. Tallowtree and Chinese privet suppression have been achieved by chipping standing trees and dense shrubs into a deep mulch layers (Donahue and others 2006, Klepac and others 2007). In soil solarization, polyethylene sheeting covers low-growing, cultivated, mowed, or chopped invasive infestations and traps solar energy to kill and suppress invasive plants by heating the soil and air underneath the sheeting. Two or more years of summer cover are needed to suppress most invasive plants by 90 percent. Other, more desirable, plants are also killed by this method—it is not selective.

Biological Controls

Biological control methods range from prescribed grazing to the introduction of insects, pathogens, and other agents that feed solely on target species. Classical bio-control involves finding agents from the home range (or similar habitat) of the invasive plant, followed by intensive research on feeding habits and reproduction and a planned introduction into infested areas. The goal is to identify predators that are host-specific to the target invasives, will avoid attacking native plants, and will increase and spread in the new range to permanently suppress the invasive species. The process is usually expensive, often involving lengthy searches for the right agent, extensive feeding tests in special quarantine facilities, coordinated releases that are strictly controlled and documented under Federal oversight, and long-term monitoring. Following release, non-target damage is very rare but has occurred (Moran and others 2005). In general, scientific evaluations of past releases have shown that the benefits from bio-control over a region outweigh the threats (Messing and Wright 2006).

Prescribed or targeted grazing is an approach that relies on cattle, sheep, goats, or horses to reduce infestations. Grazing is a potential control treatment only if the invasive is palatable and not poisonous to the animal. Grazing can either promote or reduce plant abundance at a particular site. By itself, grazing will rarely, if ever, completely eradicate invasive plants. However, when combined with other control techniques, such as herbicides or bio-control, grazing can reduce severe infestations and eliminate small ones. Grazing by cattle and horses is limited to herbaceous invasive plants. Sheep and goats both feed on woody plants as well, but goats can also eat bark and thorny vegetation and are able to reach higher areas of shrubs, saplings, and small trees. The animal species is important, as is the breed, with the most effective being larger and able to handle difficult situations, such as hair goats and range cattle. Best results come from leaving an appropriate number of animals on a site long enough to reduce the infestation, and then reintroducing them at intervals when invasive regrowth appears (Luginbuhl and others 1999).

Rehabilitation, Restoration, and Reclamation

The promotion and establishment of desirable vegetation during the latter phases of control and eradication treatments is one of the most important phases of an integrated invasive plant management program (Hartman and McCarthy 2004). The severity of infestation, site degradation, and desired future outcome determine whether a rehabilitation, restoration, or more stringent reclamation effort is appropriate. Rehabilitation is effective when soil, stream, and wetland damage is minimal and native plants are present or will enter from surrounding areas. Genetically improved loblolly pine seedlings or other fast-growing native tree species can be planted to suppress regrowth of invasive plants. Restoration is a much more involved process that combines soil and streambank stabilization methods with planting and seeding of desirable species to create a planned landscape. Reclamation is appropriate for surface-mined lands, large road construction projects, and other severely altered sites to reshape landform, replace surface soils, and establish fast-growing plants—often in conjunction with mulches and fertilizers. Invasive plants have been most often planted on reclamation sites and now warrant control efforts. Native or noninvasive, nonnative plants are substitutes now available and recommended for reclamation operations.

The goal of all three approaches is to establish and/or release fast-growing native plants that can outcompete and outlast any surviving nonnative plants while stabilizing and protecting soil and water (Hartman and McCarthy 2004, Kaeser and Kirkman 2010). At times, nonnative plants must be used to suppress invasives—then eradicated—to facilitate native plant establishment; an example is planting bahiagrass after herbicide treatments to suppress cogongrass regrowth (Ewel and Putz 2004). The ultimate goal is to replace invasive plants with native alternatives (Burrell and others 2006).

If the soil seed bank remains intact, native plant communities will naturally become established and regenerate during eradication of nonnative plants (Barnes 2007). Light-seeded native species are usually present in the seed bank, and heavier seeded plants will gradually be deposited on a site by birds and other animals. Continued surveillance and follow up treatments are often required to control nonnative plant infestations. Select herbicides and other treatments such as mowing and prescribed burning can play a role in continued suppression (Barnes 2007).

DISCUSSION AND CONCLUSIONS

Examination of survey data, literature, and modeling shows that invasive plants are not an issue that is going away. Using dates of introduction and current levels of occupation we predict that in the next 50 years the acres of invasives will increase from the current 19 million acres to 27 million acres. This conservative estimate does not take fully into account the growing amounts of land disturbance, fragmentation, parcelization, and urbanization that foster invasive plant spread, or effects of potential climate changes. Of the five species evaluated with modeling, none were close to their full potential of occupation. This is supported by other research (Bryson and Carter 2004, Gan and others 2009, Simberloff 1996). Also, we have only considered those species already present in the South that have already been identified as high threats.

Common Traits of Invasive Plants

Nonnative plants when they escape cultivation usually remain at low levels as scattered occurrences of small infestation size with low populations and numbers of individuals, known as the “lag phase.” Further generations are better adapted to their new environment through cross pollination and selection pressures and then reproduce and spread more successfully at increasing speed (fig. 15.35). Invasive traits can be enhanced

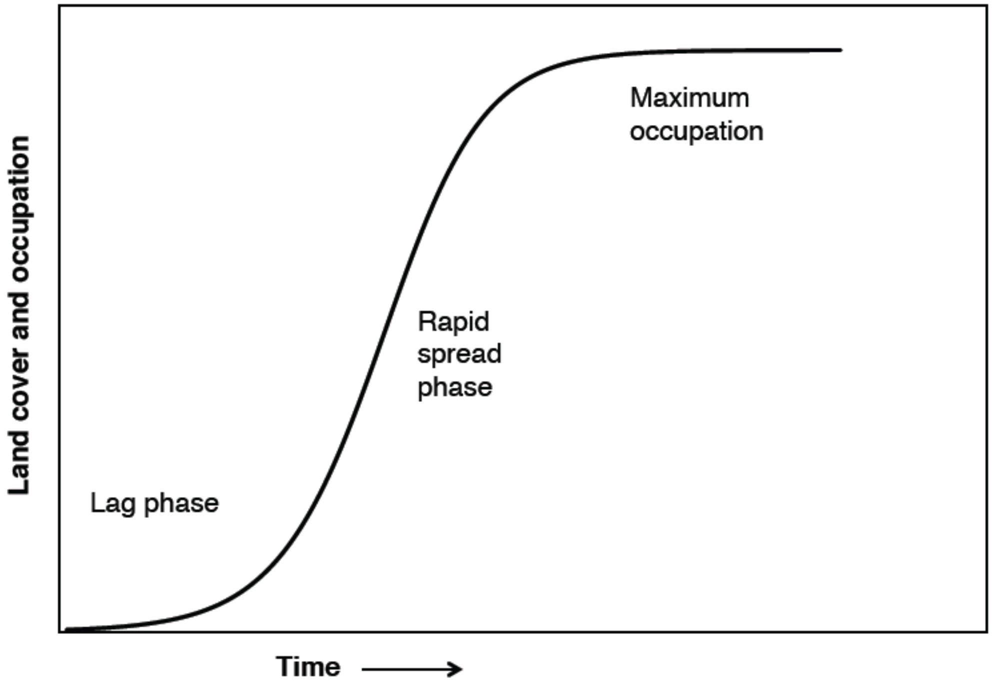

Figure 15.35—A logistic schematic showing the typical progression of nonnative invasive species as they escape and spread from their original planting sites.

through hybridization with native or nonnative plants of the same genus. There are nonnative plants at every stage of invasion in the Southeast while across the region none are thought to be at the “maximum occupation” phase. Many escaped nonnative plants are currently considered “naturalized” plants and occur in the early lag phase. They will likely become invasive due to hybridization, adaptation, and increased disturbed habitat.

Nonnative plants become invasive for many reasons. Early introduction in the 1700s and 1800s resulted in a long period of use, spread, hybridization, and adaptation (table 15.1). They were used for forage, as ornamentals and herbal plants by hundreds of thousands of small farms and remained after the great exodus to cities in the late 1800 and early 1900s.

Nonnative plants can outpace native cohorts because of their rapid early growth rates, abundance of often-evergreen leaf area, longer growing seasons, and tolerance to shade, drought, a wide range of soil conditions, and flooding. Dominance increases after disturbance and storms (Butterfield and others 2004, Jones and McLeod 1990).

Roots or rhizomes of many nonnative plants persist and resprout after herbicide applications, cutting, or burning. They grow outward above or below the soil to yield clonal infestations with one or few genotypes (Capo-chichi and others 2008). Many species adapt and spread in a new site through a “sit-and-wait” strategy that takes advantage of disturbance to spread after prior establishment (Greenberg and others 2002). Others occur as infestations with multiple invasive plants, especially in Piedmont forests (fig. 15.36).

Nonnative plants have few native predators and are resilient to predation by insects, pathogens, and mammals (Rogers and Siemann 2003, Siemann and Rogers 2003, Zou and others 2008). Many can suppress other plants’ seed germination and growth by releasing allelopathic chemicals through their foliage and roots. Examples are tree-of-heaven (Gomez-Aparicio and Canham 2008), Brazilian peppertree (Morgan and Overholt 2005), and garlic mustard (Vaughn and Berhow 1999).

Many nonnative plants produce abundant fruit and seeds at a young age (Bruce and others 1995). Seeds are readily spread by wind, water, birds, and mammals (Renne and others 2000) and can remain viable in the soil for more than a year and even up to decades (Flory and Clay 2009).

Most nonnative plants can establish and spread in sites of periodic disturbance, such as urbanized forests (Burton and Samuelson 2008, Loewenstein and Loewenstein 2005), fragmented forests with expanding lengths of forest edge (Honu and Gibson 2008) and rights-of-way (Hansen and Clevenger 2005, Merriam 2003), along stream and river

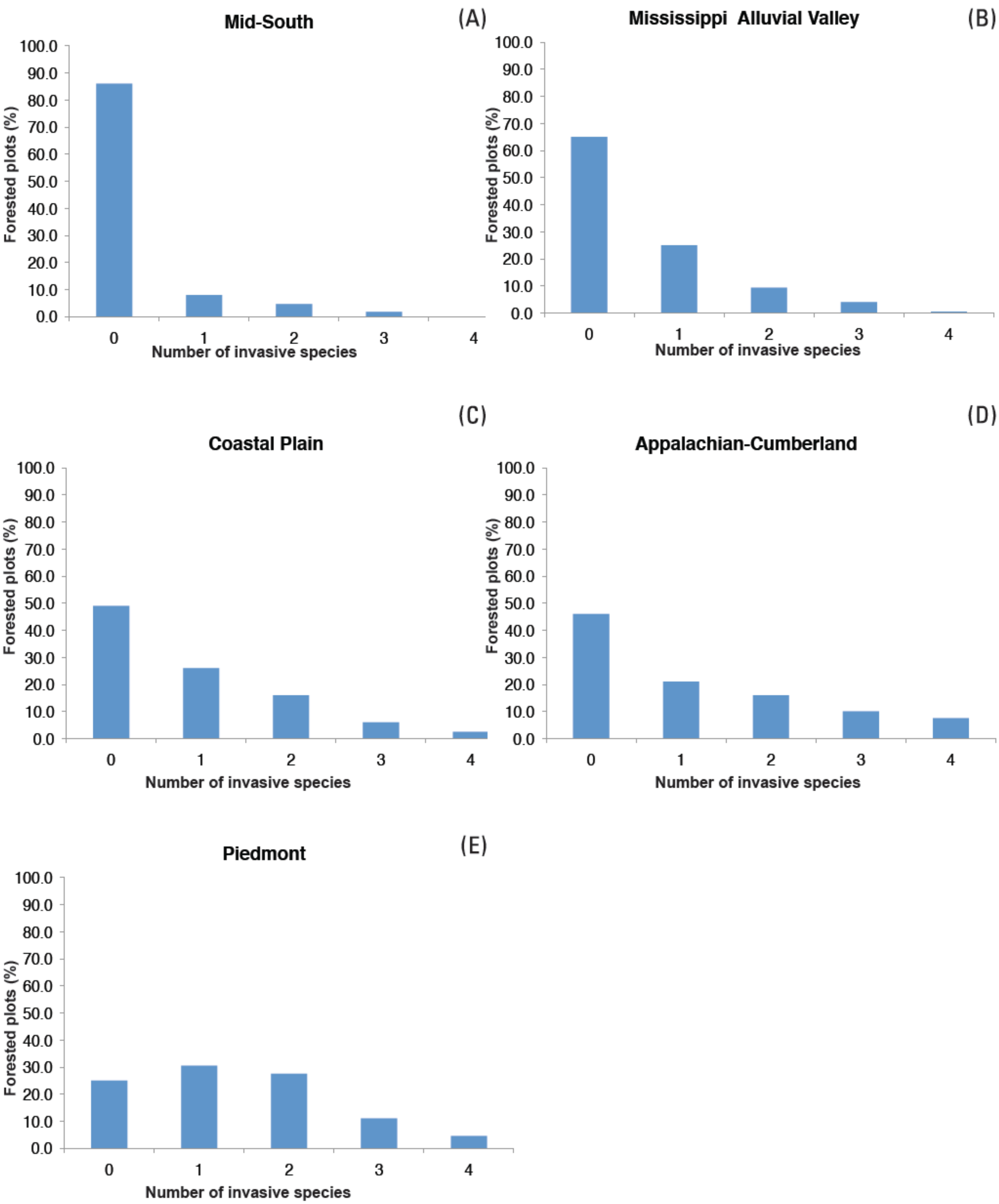

Figure 15.36—Percentage of survey plots in which one to four nonnative invasive plant species were reported in the Mid-South, Mississippi Alluvial Valley, Coastal Plain, Appalachian-Cumberland highlands, and Piedmont.

banks (Gan and others 2009), and in abandoned crop and pasture lands (Stapanian and others 1998).

Having more of these traits increases the likelihood that a nonnative plant species will succeed in establishing itself, spreading, and resisting control and eradication.

Damages Caused by Invasive Plants

The damages and impacts of nonnative invasive plants are numerable and have not been completely determined. The costs of damage and control of invasive species has been estimated in the billions of dollars (Pimentel and others 2000, U.S. Congress OTA 1993) while no economics exist to evaluate the more widespread ecological and sociological effects of invasive plants (Holmes and others 2009, Perrings and others 2002).

- Dense infestations of most invasive plants limit or stop productive land management and especially regeneration of forests, such as cogongrass's severe competition with planted pines (Jose and others 2002), Japanese honeysuckle's allelopathic impacts to young pine regeneration (Shulman and others 2004), Nepalese browntop's physical completion with natural hardwood regeneration (Oswalt and others 2007), and Chinese privet's suppression of tree regeneration in mixed hardwood forests (Merriam and Feil 2002). Infestations replace native plant strata in forest communities (table 15.2).
- Invasions may initially increase species richness and diversity upon first entry (Gan and others 2009). However, with intensified infestations, they displace and permanently decrease biodiversity, even among insects (Ulyshen and others 2010), they are especially harmful to rare plants and animal habitat, and they hybridize with native plants to dilute genetic traits (Heywood 1989, Pooler and others 2002, Stohlgren and others 1999, Wilcove 1998). A few harbor plant diseases (Swearingen 2000) and several are toxic to people, wildlife, and livestock (Everest and others 1996, Turner and von Aderkas 2009, Williams 1980). Flowering Brazilian peppertree and English ivy can cause respiratory difficulties and contact dermatitis in sensitive individuals (Morton 1978).
- Some invasive plants produce overabundant pollen that causes widespread allergenic reactions in humans.
- Invasive plant occupation alters vital ecological processes such as soil formation and wetland function (Ehrenfeld 2003). For example, tallowtree changes soil and litter chemical properties (Cameron and Spencer 1989), cogongrass lowers soil pH and potassium (Collins and Jose 2009), and melaleuca greatly alters soil microbial processes and litter in ways to maintain site dominance (Martin and others 2009). Soils invaded by kudzu have exceptionally high levels of nitrogen through nitrogen fixation by root bacteria; they release excess nitrogen as minerals in soil water and as gases that contribute to ground level ozone (Hickman and others 2010). In an opposite manner, soils invaded by Nepalese browntop have slower nitrogen internal cycling (DeMeester and Richter 2010).
- Invasive-plant alterations to wildlife habitat favor more common species over those that are at-risk, complicating restoration efforts (Asland and Rejmanek 2010, Cipollini and others 2009, Schmidt and Whelan 1999).
- Most invasive plants grow formidable barriers of vegetation that limit land access for recreation such as hiking, fishing, hunting, and bird watching. They can cause psychological anxiety though a sense of the inability to control one's surroundings (Blaustein 2001).
- Some invasive plants present extreme fire hazards to forests, preserves, and homes, such as cogongrass and giant reed (*Arundo donax*).

The damages and costs are both ecological and societal, with many complex linkages that stymie economic analysis. Mack and others (2000) concluded that the threat of large nonnative infestations is largely the unintended consequences of uninformed decisionmaking, and Perrings and others (2002) added that the threat is compounded by societal resistance to change.

Potential Uses of Invasive Plants

Because of their increasing replacement of usable forest species, we are faced with the challenge to discover uses for the widespread or abundant invasive plants, determine how to efficiently harvest and process wild populations, or learn how to cultivate them in plantations or farms to lower harvesting and transportation costs.

Many invasive plants are being proposed, considered, bred, propagated, and experimentally planted in plantations for biomass and potential biofuel production due to their rapid juvenile growth and pest resistance: tallowtree (Scheld and Cowels 1981), Chinese and giant silvergrass (*M. floridus*) (Jessup 2009), melaleuca (Wang and others 1982), giant reed (Lewandowski and others 2003), golden bamboo (Scurlock and others 2000), princesstree, and kudzu (Sage and others 2009). The Invasive Species Advisory Council (2009) considers this a high-risk use with escapes to surrounding natural and productive landscape eventually inevitable. The same concerns exist for the existing commercial plantations of princesstree in the southern region, recognizing that mature straight trees, rarely produced in the region, only have a high value in Japan at this time (Tang and others 1980). On another front, research has found that tallowtree can be used for all three composite panel types meeting various American National Standards Institute grades (Shupe and others 2006) and has value as a source of drying oil (Howes 1949). The current coverage of all these invasive species, with the possible exception of tallowtree, would have to be increased in plantations to make economically viable operations, bringing a high probability of additional escapes.

Extracts from kudzu, Brazilian peppertree, and Chinese yam have traditional medicinal uses, while the leaves of garlic mustard and kudzu and the root starch from kudzu are valued Asian cooking ingredients (Shurtleff and Aoyagi 1985). Dietary root extracts from kudzu have been found to regulate blood pressure, high cholesterol, and blood glucose in lab rats predisposed to these conditions (Peng and others 2009). Autumn olive fruits have 3 to 15 times more of the lycopene anti-oxidant than tomatoes (Fordham and others 2001). Thus, utilization of invasive plants is in its infancy with probable increases likely.

General Concepts for Managing Nonnative Invasive Plants

How we manage invasive plants will ultimately determine the severity of damages and costs. The most effective and efficient strategy is early detection and effective early treatment of initial invaders. Three overarching concepts provide powerful ways to get organized and counter invasive plant takeovers: collaboration, adaptation, and restoration (Buck and others 2001, Schelhas and others 2001, Miller and Schelhas 2008). Collaboration with adjacent and area landowners is essential because invasive plant infestations most often occur across ownership and political boundaries. Communication networks can link local, county, State, and regional programs (Meyerson and Reaser 2003). Adaptation, or adaptive resource management, is a community shared cyclical process of learning by doing (Foxcroft 2004) that consists of goal setting, learning from the experience and research findings of others, monitoring actions and outcomes, and then rapidly incorporating new knowledge into refined goals and actions. This process is useful for decisionmaking in the face of uncertainty, because it reduces uncertainty over time by monitoring results of actions and making careful adjustments. Its effectiveness can be enhanced by monitoring print and Web resources for new and forthcoming information (Jordan and others 2003). Restoration of infested lands to healthy and productive ecosystems is the guiding objective, involving the establishment and monitoring of desirable and useful plants that protect soil, produce needed resources and habitats, and safeguard to prevent a resurgence of invasive plants. Restoration approaches for most invasive plants are just being developed and will require adaptive management cycles in order to perfect them (Hartman and McCarthy 2004, Sauer 1998).

Organizing Across Borders

The common elements of successful regional, State, and local invasive plant management programs include developing:

- Scientifically based and coordinated invasive plant lists that recognize that priorities will differ by subregion as well as frequency and severity of infestations
- Multi-level, cooperative knowledge networks that link stakeholders, land managers, scientists, and policymakers, provide real-time information and connectivity (Jordan and others 2003), and encourage timely actions and communication by all participants regardless of their roles
- Collaborative prevention strategies and programs, including legislative, policies, and public outreach components (Britton and others 2005), "good neighbor" programs among rights-of-way managers and adjacent landowners (Randall 2007), sanitization protocols (Fleming 2005), and safeguards against the spread of contaminated products (Evans and others 2006)
- Early detection and rapid response networks to identify and map high-risk sites and new introductions, verify the invasive species, and facilitate communication, eradication, and restoration (Westbrooks 2004)
- A Web-accessible interactive survey, inventory, and mapping system to corporately track existing and spreading invasions (Bargeron and Moorhead 2007)
- Coordinated control, containment, and eradication programs that establish cycles of integrated treatments, share successes and mistakes (Miller and Schelhas 2008), raise public awareness, close known pathways, and facilitate regional biological control programs (Messing and Wright 2006)
- Restoration treatments that suppress new invasions, maintain ecosystem functions and services, incorporate adaptive information cycles, and provide for continued surveillance and monitoring with timely re-intervention if necessary (Miller and others 2010b)
- A continuous cycle of research, research syntheses, practical application of findings, and a feedback mechanism for communicating additional research needs (Miller and Schelhas 2008)

The spread of invasive plants from State to State means that State-level plans need to include common elements that assure regional protection, including working elements and programs for adaptive collaborative restoration. The most effective strategies for constraining invasions and restoring ecological services are unified and readily shared through collaborative networks that define zones of occupation severity and show areas where different strategies should be employed (fig. 15.37).

Managing outlier areas—Outlier (or satellite) infestations exist beyond highly infested areas due to long distance movement of plants or plant reproductive parts. Outlier infestations must be detected and eradicated early if containment is to be successful. Early detection rests with public awareness as well as organized search and surveillance efforts and strong reporting networks.

Movement of contaminated equipment and materials must be effectively prevented to stop new outlier infestations from being established.

Managing the advancing front—All infestations along the advancing front must be found, mapped, and documented through intensive search and surveillance programs. The search and surveillance programs must include all ownerships. To stop seed dispersal from worsening the situation, treatments must be timely and persistent. For all work near or inside infested areas, extra care must be taken to ensure sanitation of equipment and personnel to prevent spread. Special habitats of rare plants and animals within the advancing front zone should be carefully treated to save them from ultimate loss. The front must be held and then pushed back.

Managing severely infested areas—Surveys employing sampling techniques are required to quantify the acres of infestation. Concerted programs in cooperation with landowners including funding assistance are needed to fully implement, support, and maintain management programs in severely infested zones. Equipment and personnel sanitation as well as quarantines of product movement out of severely infested areas must be strictly regulated to prevent both short- and long-distance movement of plants and reproductive parts. Any forest and nursery product movement must be monitored for contamination. Special habitats of rare plants and animals must be safeguarded from destruction and restored using special techniques. People's homes must be safeguarded against wildfire by highly flammable invasive plants.

Small Scale Stewardship

Invasive plant strategies and programs ultimately depend upon the eradication and restoration of one infestation at a time at the local level and preventing new entries. Following these principles will greatly increase the chances of success.

Prevent entry and spread—Do not plant invasives such as those covered in this book, others listed in the appendix in Miller and others 2010b, entitled "Nonnative Invasive Plant Species Not to be Used or Recommended for Wildlife Food Plots and Bird Viewing Plots," and those on your State's noxious and invasive plant lists. For wildlife food plots, soil stabilization, and ornamentals, plant only native plants of local origin when possible or choose noninvasive alternatives. Employ sanitation practices to avoid introducing or spreading invasive plants.

Make a plan—Base your planned treatments on stated objectives and the best information, then schedule and acquire resources that support your plan. Devise a timeline for implementation of your plan's action items, and add some "wiggle room" for contingencies. Devise both a short- or long-term plan to include both specific infestation treatment regimes and ideas for how these fit into a general land management plan. Your maps of infestation locations and priority ratings of invasive species will assist the planning process.

An eradication and rehabilitation program for specific invasive plant infestations usually requires several years of treatments and many more years of surveillance to check for rhizome and root sprouts, seed germinates, or new invaders. Newer infestations and smaller plants require much less time than extensive and dense infestations.

Prioritize treatments by targeting the worst of the plants first. Remember that the worst plant may not be the one with the highest level of infestation but the one that has the greatest potential for spreading. Balance eradication of first entries of high-priority invasive plants with persistent treatment of extensive infestations (see www.invasive.org/south/ for a regional list of High Priority Invasive Species of Southern Forests and Grasslands). Monitor the effectiveness of treatments, retreating as needed.

During the treatment and retreatment phase, take steps to safeguard, promote, or establish desirable vegetation. To effectively combat plant invasions and restore lands, you will need to carefully plan for each step in the program by incorporating primary and contingency schedules of enactment. You should project a minimum of 4 years and up to 10 years for older infestations when less than maximum effective treatments are used. You can use short-term plans to target specific areas, but you will need a long-term management plan for an increasingly invaded landscape. You must consider surrounding lands, particularly the degree of current infestation in those lands as well as the invasive plant management programs the owners and managers of those lands have in place. Also consider emerging State funding assistance programs.

Make a map and monitor results of locations—Detect invasive plants early through active surveillance of your lands. Map and mark locations of the invasive plants you find. Identify invasive plant location sites at risk, and denote treatments and their outcomes. You must positively identify those invasive plants that are present and those poised to enter from adjacent lands, determine their locations and abundance, and record this information on a sketch map or Geographic Information System (GIS) map. Gain their Global Positioning System (GPS) locations when possible. Make the locations easy to find again by marking them with flagging. Monitor the locations through repeated visits and record progress or the lack of it. Agencies should map as many acres as possible with the dollars available before investing in unorganized treatments of extensive invasions, while new entries of severe invasives should be tackled early.

The five-option Search, Survey, Inventory, Monitor, and Surveillance method, can help map, monitor, and track treatments with their results at several scales: (1) Look at the most likely points of entry, like along roads and especially near bridges, and record any occurrence of invasive plants you find in such areas. Then widen your search as time and resources permit. (2) Systematically locate plots or conduct band sampling across the landscape to determine the extent of occupation and acres covered. By mapping the survey plot findings, areas of highest infestation density and multiple invasive species can be identified. (3) Prepare an inventory by recording the location and area of every infestation and the treatments that you apply. This is the best approach for individual land ownerships. Inventories can map individual patches and plants or circle them as a group when they occur in close proximity to one another. The GPS locations can be taken and mapped, or a sketch map made to plan the program of treatment and restoration. (4) Monitor the site by revisiting inventoried points at scheduled times or resurveying tracks with scattered infestation to record and track treatment effectiveness and any further invasions. (5) Practice surveillance, a constant task for all those who work on and/or otherwise use your land. Everyone should be alert for new infestations and know how to report these when and where sighted.

A Time to Reflect, Rethink, Redouble Efforts

In an article about introduction of new species into the United States, Simberloff (2001) admonishes, "What is needed is a change in philosophy, away from innocent until proven guilty. The very nature of introduced species makes current risk assessments unreliable documents, that introductions are generally irrevocable once they are established, and that the harm some species can cause is not only staggering in economic terms but incalculable in ecological ones."

Now More Than Ever: Sanitation Is the Key

- Educate yourself, employees, and other users of your land about the invasive plants that pose major threats and how to prevent their entry. Learn how to identify both invasive and native plants in your area. The more native plants that you can identify, the easier you will spot the "plants out of place."
- Require or instruct those who work, hunt, and recreate on your lands, to minimize invasive plant spread by: (1) inspecting the site and infestation before operations especially noting the presence or absence of invasive plant fruit, seed heads, or spore clusters under climbing fern (*Lygodium* spp.) leaves; (2) when possible, avoiding driving vehicles, mowers, all-terrain vehicles (ATVs), or spray equipment through infestations bearing seed or fruit, especially of late-flowering cogongrass and musk thistle (*Carduus nutans*); (3) removing all seeds and debris from clothes, boots, socks, boot laces, soles, and personal protective equipment, avoiding cuffed pants, carrying contractor-size refuse bags to stand in while brushing and removing seeds or place contaminated gear within the bag for careful cleaning at a designated location; (4) when working in infestations, thoroughly cleaning motorized equipment (especially the undercarriage and tire surfaces, radiator front, and engine compartments), removing excess grease and oil, and modifying vehicles and equipment to prevent buildup of debris or selecting vehicles that have the least potential for contamination.
- When moving cut fruiting or seeding invasive plants offsite such as to a burn pile, always cover loads or bag before transport.
- Monitor burn pile areas for new seedlings as the fire may not consume or kill all seeds. Also, monitor any designated decontamination sites for seedlings.
- Avoid entering or working in spore-forming species such as invasive climbing fern infestations when spore clusters are present (October to November in temperate climates); if entry is unavoidable, complete sanitation of all equipment, clothing, and workers is necessary to prevent potential spread.
- Use only non-contaminated fill materials, mulches, and seeds. Inspect material sources at the site of origin for indications of contamination by invasive plants growing on or near the area. Regularly inspect areas where offsite fill materials have been used and areas used by visitors and lessees.
- Be careful not to disturb areas where there is a high probability of invasion. Most land disturbing activities raise the potential for establishment of aggressive plant invaders, especially when the invaders occur nearby.
- Practice search and surveillance at these likely points of entry: lands adjacent to yours that you do not own (such as highways, county roads, and utility rights-of-way and their edges and fencerows) especially after new construction or maintenance activities; internal roads, trails, and fire lines; lands next to streams, rivers, and lake shores, especially after recent flooding or high-flow periods; recently prepared and seeded wildlife food plots; harvested, thinned, burned, or storm-damaged areas during the years following disturbance.

Successful management of nonnative invasive plants requires recognition that the number of species, their area of occupation, and their spread are drastically increasing—and that new knowledge, approaches, and cooperation are needed. Management of undesirable plants has been a growing science and practice in intensive agriculture and horticulture, at the same time that invasive plant populations toughened by hybridization and new introductions, are spreading across land uses. Forestry, right-of-way, park, and preserve managers can borrow and modify control techniques from agriculture and from one another. Accurate identification skills of both invasive and native plants are required for precise management, as are new tools, machines, products, and techniques.

Management of invasive plants would be more effective if augmented by integrated planning, better and timelier preparation, and heightened resolve and persistence. Ownership, area, and site management plans (long range and for specific activities such as timber harvesting, stand thinning, prescribed burning, and road and firebreak maintenance) would benefit from goals and actions addressing prevention, eradication, and control of invasive infestations, especially those that minimize entry and spread of invasive plants and anticipate the possibility of new infestations. It is important to remember, however, that such plans are incomplete if they do not lead to site rehabilitation or restoration.

Preparation always has been critical to forest, roadway, and natural area managers and landowners. As invasive plant populations increase in size and density, new concepts, tools, and materials will be needed. Preparation includes having the very latest information as well as using reliable sources of uncontaminated fill dirt and rock, seed, and mulch for soil stabilization. Preparing for rehabilitation and restoration may involve extra expenditures for newly available native seeds, planting tools and equipment, landscape fabrics and fiber mats for stabilization, or consultations with professionals.

Without persistence, all efforts to control and rehabilitate infested lands will be lost. Nurturing a healthy native or noninvasive community of plants usually requires a regime that includes timed treatments and retreatment, tenacious follow through, and years of site monitoring for reappearance or new introductions.

KNOWLEDGE AND INFORMATION GAPS

There is a critical need for research and policy action to address many aspects of invasive plants in the southern forests and elsewhere (Sieg and others 2010, Simberloff and others 2005). Specific gaps include the absence of data on the degree that invasive plants impact tree and stand growth and structure for any forest type. There are essentially no data in the southern region on relationships among invasive plants, hydrology, and changes in water quality and quantity. There is a critical need for new approaches that will help managers avoid marked and permanent alterations of forest, agricultural, and conservation lands and waters as invasive plants spread from urban, suburban, and exurban lands and connecting rights-of-way (Liebhold and others 1995, NRC 2002, Simberloff 1996, Von der Lippe and Kowarik 2006).

Invasive plants thus represent a complex and perplexing societal dilemma, with need for a more comprehensive awareness, management strategies, coordinated programs, and effective laws if we are to avoid bequeathing future generations degraded ecosystems and ecosystem services. A concerted, holistic effort that integrates science with management in new ways will be required for predicting, managing, and mitigating the spread of invasive species (McPherson 2004), as will the involvement of the wider society in new approaches (Miller and Schelhas 2008).

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