Assessment of Non-Native Invasive Plant Species on the United States Department of Energy Oak Ridge National Environmental Research Park

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ABSTRACT

Invasive non-native species are important because of the potential negative ecological and economic effects that they have. Because of the number and variety of invasive species, it is important to prioritize them in terms of their presence in and their potential impacts on natural ecosystems. At least 167 non-native, invasive plant species occur on the United States Department of Energy Oak Ridge National Environmental Research Park, Oak Ridge, Tennessee. Our objective was to assess the distribution, abundance, impact, and potential for control of 18 of the most abundant invasive species on the Research Park. In 2000, we conducted field surveys of 16 Research Park management areas to acquire qualitative and quantitative data on the distribution and abundance of these taxa. Survey results were used to rank the relative importance of these species using a quantitative ranking system developed by the United States Geological Survey. *Microstegium vimineum*, Japanese honeysuckle (*Lonicera japonica*), and Chinese privet (*Ligustrum sinense*) were ranked first, second, and third-most problematic, respectively. Other non-native, invasive species, in decreasing rank order, included kudzu (*Pueraria lobata*), multiflora rose (*Rosa multiflora*), and Chinese lespedeza (*Lespedeza cuneata*). Results can be used to prioritize management and research activities related to these invasive taxa on the Research Park.

INTRODUCTION

Invasive species are broadly defined as those species that are not native to an area and that may potentially displace or otherwise adversely affect native plant and animal species (Mack et al. 2000, Reichard and White 2001). They have important ecological and economic consequences because they can alter ecosystem function and negatively impact agriculture and human health and transportation (Drake, Mooney, and di Castri 1989; Manchester and Bullock 2000; Ellstrand and Schierenbeck 2000; Tsutsui et al. 2000; Mack and Lonsdale 2001; Reichard and White 2001; and Rossman 2001). Because of the above factors, much effort has been spent to predict future invasions based on general attributes and to eradicate or control existing invasive species (Mack et al. 2000, Kolar and Lodge 2001).

Plants that are novel to a particular site or region may successfully establish and maintain relatively dense populations for several reasons. There may be a lack of natural growth inhibitors, such as predators, parasites, and diseases at the site of introduction (Mack et al. 2000, Tsutsui et al. 2000). In addition, invasive species are often prolific seed producers, with seeds that may disperse widely and that may remain viable in the soil for long periods of time (Rejmanek and Richardson 1996). Alternatively, invasive species may reproduce asexually

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through extensive root growth, suckering, and resprouting (Thompson et al. 1995, White 1997) and may be capable of more vigorous growth than conspecifics in the species' home range (Willis and Blossey 1999) as well as native congeners in the introduced range (Williamson and Fitter 1996). For example, Larson (2000) found that the highly modified circumnutation in the prostrate shoots of the non-native vine, Japanese honeysuckle (*Lonicera japonica* Thunb.) [species names are in accordance with Radford, Ahles, and Bell (1968)], allow it to root more successfully and thus increase its lateral spread more effectively than the native vine, trumpet-honeysuckle (*Lonicera sempervirens* L.). Invasive species are often capable of producing larger and higher quality fruit than native congeners, thus making it a better food source for animals and birds that may aid in its dispersal (e.g., Sallabanks 1993). In contrast, Thébaud and Simberloff (2001) found that introduced species were not necessarily larger (i.e., taller) in the introduced range than in their native range.

Invasive species tend to be most problematic in disturbed areas (Vitousek 1990, Binggeli 1996). For example, kudzu [*Pueraria* (Lour.) Merr. var. *lobata* (Willd.) Maesen and S.M. Almeida] is a notorious invader of roadsides and power transmission line rights-of-way in the southeastern United States, but it is seldom found in adjacent, less-disturbed habitats (Plant Conservation Alliance 1997). Recently disturbed areas are also likely to have lower species diversity than undisturbed habitats depending on the scale, intensity, and time since the disturbance event occurred. Non-native organisms may more readily invade areas of low species diversity, or lower stability (MacArthur 1955, 1972; Elton 1958; Drake, Flum, and Whitteman 1993; Lodge 1993; Law and Morton 1996; and Naeem et al. 2000). Recently, it has been suggested that invasibility is more closely related to resource availability (Levine and D'Antonio 1999, Stohlgren et al. 1999) or canopy structure (Mack et al. 2000) than species richness. Consistent with Stohlgren's hypothesis, some invasive species are capable of becoming established in relatively undisturbed sites. For example, microstegium [*Microstegium vimineum* (Trin.) A. Camus], a C4 shade-tolerant annual, appears to invade forests that have been undisturbed for decades (Barden 1987, Redman 1995). This may be due to high soil fertility and/or water availability in these areas. Climate stresses, such as changes in means or extremes of temperature, may also affect a species' ability to invade by either increasing their numbers, or shifting their distribution northward (Dukes and Mooney 1999, Rogers and McCarty 2000).

Invasive species are often the targets of management activities designed to eradicate them, or control their spread, in order to minimize their impact on existing ecological systems. However, limited funds, time, and personnel often hamper management activities (Kuppinger 2000). Even if adequate resources were available, managers may lack information about the natural history of the many different species in question, and knowledge about the potential impacts that each species may have. Further, depending on the region and the management area in question, there may be numerous invasive species all deserving of management attention. Inventory and monitoring efforts should be initiated so that managers can formulate a control plan and prioritize their activities to focus on those species that may pose the greatest threat to existing management goals.

Surveys of the flora at the Department of Energy Oak Ridge National Environmental Research Park (hereafter Research Park) in Tennessee, have documented 167 non-native, invasive species to date. These species were classified as "aggressive," "questionably aggressive," "passive," and "questionably passive" based on their abundance, distribution, and a qualitative assessment (informally based on field experience of ORR Research Park botanical staff) of their tendency to exclude native plant species (Oak Ridge Reservation Exotic Pest Plants 2001). However, the relative importance of taxa within each classification has not been determined.

Forty-two of the 167 invasive species are classified as "aggressive" (Oak Ridge Reservation Exotic Pest Plants 2001). The goal of our research was to determine the relative importance of 18 of the most abundant or widespread of these "aggressive" invasive species on the Research Park, in terms of their potential impact on natural systems, their tendency to become management problems, and their potential for control (Table 1).

Our objectives were to rank these 18 species (1) for the entire Research Park and (2) for

Table 1. Non-native, invasive species on the Oak Ridge National Environmental Research Park ranked by this study

MONOCOTS
DIOSCOREACEAE
1. *Dioscorea batatas* Decne
LILIACEAE
2. *Allium vineale* L.
POACEAE
3. *Microstegium vimineum* (Trin.) A. Camus
4. *Sorghum halepense* (L.) Pers.
DICOTS
APONCYNACEAE
5. *Vinca minor* L.
ASTERACEAE
6. *Cirsium vulgare* (Savi) Tenore
BRASSICACEAE
7. *Rorippa nasturtium-aquaticum* (L.) Hayek
CAPRIFOLIACEAE
8. *Lonicera japonica* Thunb.
CELESTRACEAE
9. *Celastrus orbiculatus* Thunb.
ELAEAGNACEAE
10. *Elaeagnus umbellata* Thunb.
FABACEAE
11. *Coronilla varia* L.
12. *Lespedeza cuneata* (Dum. Cours.) G. Don
13. *Pueraria lobata* (Willd.) Ohwi
LAMIACEAE
14. *Mentha spicata* L.
OLEACEAE
15. *Ligustrum sinense* Lour.
ROSACEAE
16. *Rosa multiflora* Thunb.
SCROPHULARIACEAE
17. *Paulownia tomentosa* (Thunb.) Steudel
SIMAROUBACEAE
18. *Ailanthus altissima* (Miller) Swingle

each of 16 important management areas on the Research Park using the "Alien Plant Ranking System (APRS)" developed by the US Geological Survey (APRS Implementation Team 2000). Data for ranking were collected using field surveys and a review of the literature.

STUDY AREA

The Oak Ridge National Environmental Research Park, located in Anderson and Roane Counties, Tennessee (Figure 1), encompasses about 8,094 ha of the 13,863 ha Oak Ridge Reservation. The Research Park is situated within the Ridge and Valley Province west of the Appalachian Mountains (Oak Ridge National Laboratory 2000). This region is characterized by roughly parallel ridges and valleys formed within the folds of Paleozoic sediments. The ridge and valley topography results from differential erosion of alternating layers of resistant sandstone and less-resistant limestone (McKnight 1997). This geologic pattern results in the numerous ridges, caves and sinkholes found throughout the Research Park.

The Ridge and Valley Province is located within the Temperate Mesophytic Forest Region (Daubenmire 1978). Upland sites are characterized by second- and third-growth oak-hickory forest stands, with *Quercus* spp., *Carya* spp., and *Acer* spp. the dominant overstory species.

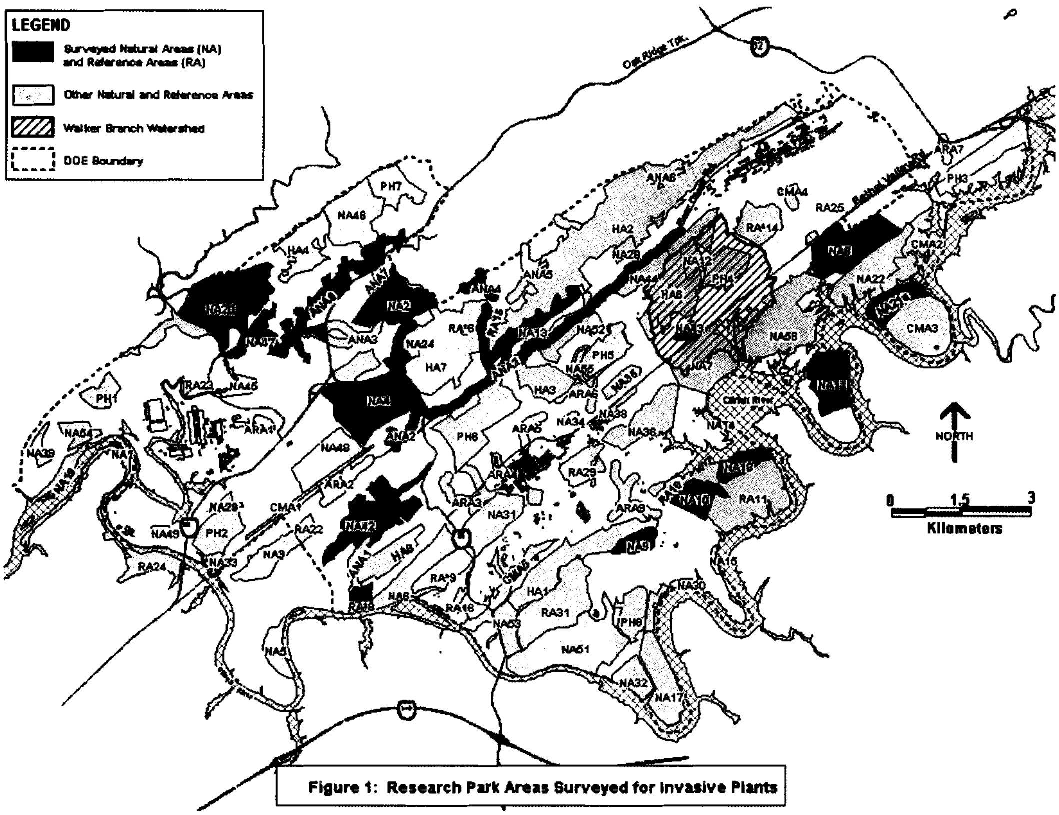

Figure 1. Management Areas on the National Environmental Research Park designated by the Tennessee Nature Conservancy (Pounds, Parr, and Ryon 1993).

Stands of pines (*Pinus echinata* Miller, *P. virginiana* Miller and *P. taeda* L.) occupy ridges, abandoned agricultural fields, and pine plantations. Mesophytic hardwoods (*Tilia* and *Liriodendron*) dominate the lower slopes.

Climate in this region is characterized by cold winters and long frost-free summers. Mean annual temperature is about 14°C, and mean annual precipitation is about 1300 mm (Hanson et al. 1998). Soils are generally acidic and well weathered, and are classified primarily as typic paleudults (Hanson et al. 1998).

METHODS

Management Areas on the Research Park

We arbitrarily selected a total of 16 individual management areas that were distributed throughout the Research Park for a total of 1,457 ha. The 16 management areas include Research Park Natural Areas, a Research Park Reference Area, and the Walker Branch Watershed (Figure 1). Research Park Natural Areas encompass habitats that contain state and/or federally listed rare plant or animal species, or species considered "at risk" by the state of Tennessee (Oak Ridge Reservation Threatened and Endangered Plants 2001). Rare species include tall larkspur (*Delphinium exaltatum* Aiton), Appalachian bugbane (*Cimicifuga rubifolia* Kearney), northern bush-honeysuckle (*Diervilla lonicera* Miller), golden seal (*Hydrastis Canadensis* L.), Canada lily (*Lilium canadense* L.), and northern tubercled rein-orchid [*Habenaria flava* (L.) R. Br. var. *herbiola* (R. Br.) Ames and Correll] (Oak Ridge Reservation Threatened and Endangered Vascular Plants 2001). Natural Areas surveyed included mesic deciduous forest, palustrine forested wetlands, a palustrine emergent marsh, limestone outcrops, a cedar barren, and power transmission line rights-of-way. Site descriptions of individual management areas are in Drake, Weltzin, and Parr (2002).

Research Park Reference Areas include areas that represent vegetational communities of the southern Appalachian region or that possess unique biotic features (Pounds, Parr, and Ryon 1993). The single Reference Area surveyed in this study, a cedar barren (or glade) on a limestone outcrop, was selected because it is a unique example of this plant community on the Research Park, and because it contains plant taxa uncommon to the region (e.g., *Yucca* spp. and *Opuntia* spp.).

Walker Branch Watershed is a research watershed that consists of two subcatchments with a total area of approximately 100 ha. Similar to other upland sites on the Research Park, the watershed is dominated by second- and third-growth stands of oak and hickory, pine, and mesophytic hardwoods established on former pastures or croplands. The underlying soils are acidic, cherty, infertile, and permeable to water. There is a long and relatively well known history of anthropogenic disturbance and research on the site, which is characterized by long-term, intensive environmental studies at the watershed scale (Walker Branch Watershed, Oak Ridge, Tennessee 2000).

Ranking Procedure

We used a quantitative ranking system developed by the US Geological Survey (APRS Implementation Team 2000) to rank the 18 subject species assessed in this study (Table 1). Generally, the "Alien Plant Ranking System" uses a query system to compile information about the characteristics of each invasive species, as well as the attributes of the invaded community. The rationale behind this approach is based on limited evidence suggesting that the invasion of a community by a non-native plant species is controlled by the biological characteristics of the species in question, the number of propagules entering the community, and the susceptibility of the community to invasion (Lonsdale 1999). In turn, the susceptibility of a plant community to invasion is likely influenced by its disturbance regime, the competitive abilities of native species, and the prevailing climatic conditions (Lonsdale 1999).

The query list for each species consists of 23 "multiple-choice" questions arranged in three sections (Appendix I). Section I, "Significance of Threat or Impact," is designed to determine the relative distribution and abundance of each species, and its potential effect on native communities. Section II, "Innate Ability to Become a Pest," determines the autecological characteristics of the plant and Section III, "Difficulty of Control," describes the feasibility and effects of control measures. Responses to queries for the Research Park as a whole are in Appendix II. Responses to queries for each management area are in Drake, Weltzin, and Parr (2002).

Queries in Section I (Significance of Threat or Impact) were answered based on field surveys, interviews with managers knowledgeable about the sites and species, and reviews of existing literature. Field surveys and interviews were conducted during the 2000 growing season. Field surveys were conducted primarily to estimate the distribution and abundance of each species in each management area for queries 1 through 3 (Appendix I). Species distributions relative to disturbance regimes were determined based on the distribution of each species relative to the type, intensity, scale, and history of disturbance in the subject area. For example, *Microstegium vimineum* and Japanese honeysuckle (*Lonicera japonica*) were often found in areas that have not been disturbed for at least 50 years, whereas Chinese lespedeza [*Lespedeza cuneata* (Dum. Cours.) G. Don.] and field garlic (*Allium vineale* L.) were found in areas more recently disturbed by either roads or power line clearings.

We determined areal extent and numerical dominance of each species by visually estimating the proportion of each site occupied by each species. When determining the association of each species with the native community, we selected the response that best indicated the successional level of that portion of the management area that contained the species in question. In contrast, when ranking each species within the Research Park as a whole, we selected the response that best indicated the stand at the latest successional stage occupied by that species on the Research Park. The potential for hybridization with native species was determined from the literature. Threats, impacts, and effects of each species on management goals were determined based on 1) conversations with managers and scientists familiar with the area and 2) observations of the density and distribution of each species at each site.

Answers to the first nine queries in Section II (Innate Ability to Become a Pest) were based on literature reviews. However, for most of our subject species, there is a paucity of data on competitive ability. Therefore, for the query regarding competitive ability (query #15), we answered "unknown" for all species except kudzu. Similarly, the effects and impacts of these invasive species on native ecosystems are largely unknown, which mirrors the general dearth of scientific understanding of effects of invasive plants worldwide (Parker et al. 1999). Nonetheless, we estimated ecological effects and impacts based on reviews of the literature and our knowledge of the autecology and synecology of these species.

Queries in Section III (Difficulty of Control) were answered through reviews of the literature, field observations, and interviews with managers familiar with physical, chemical, and biological control techniques.

RESULTS AND DISCUSSION

Species Ranks for the Research Park

Out of the 18 species ranked in this study, *Microstegium* was identified as the most problematic non-native, invasive species on the Research Park as a whole (Table 2). *Microstegium* was ranked highest, or most problematic, because of its potential impact on natural systems, its tendency to become a management problem, and how difficult it is to control. *Microstegium* is present in numerous, dense stands across the Research Park, in both disturbed, early-successional habitats as well as relatively undisturbed, late-successional forest communities. In addition, it was present across a broad range of environmental conditions, from shallow flowing-water habitats to margins of gravel roads along dry ridge-tops.

Although there is little published information about the effect that *Microstegium* has on native plants and natural ecosystems, it has been suggested that it may exclude native plants, or prevent them from becoming established (Barden 1987). *Microstegium* may become even more problematic in the near future because it produces large numbers of seeds each year, and its seeds may remain viable in the soil for 3 to 5 years (Virginia Department of Conservation and Recreation 2002). In addition, control of *Microstegium* populations is relatively difficult; successful control will likely require multiple application of herbicides, or labor-intensive hand-pulling. Small patches of *Microstegium* have reportedly been controlled through a combination of herbicide application, mowing, and hand removal (K. Johnson, Great Smoky Mountains National Park, pers. comm. 2001). Additional information on the autecology and synecology of *Microstegium* (and other species ranked herein) are in Drake, Weltzin, and Parr (2002) and The Nature Conservancy's Element Stewardship Abstracts (2001).

Our ranking of *Microstegium* is similar to other recent qualitative assessments of this particular species as a problematic invasive plant. For example, managers at the Great Smoky Mountains National Park in Tennessee and North Carolina have qualitatively ranked *Microstegium* highest in potential impacts on natural ecosystems in the Park (out of a total of 35 problematic non-native, invasive plants), and lowest in feasibility of control because so little is known of its autecology or synecology (National Park Service 1999). Similarly, 18 of 35 federal, state, and private agencies in the Southern Appalachian region reported that of a total of 218 invasive plant species, *Microstegium* was one of their greatest ongoing or potential management problems, behind only kudzu and multiflora rose (which were reported by 21 and 19 agencies, respectively; Kuppinger 2000). Finally, the Tennessee Exotic Pest Plant Council considers *Microstegium* in its "Rank 1, Severe Threat" category, which includes a total of 24 "exotic plant species which possess characteristics of invasive species and spread easily into native plant communities and displace native vegetation ... include[ing] species which are or could become widespread in Tennessee" (Tennessee Exotic Pest Plant Council 2001).

Japanese honeysuckle (*Lonicera japonica*) was ranked as the second-most problematic non-native, invasive plant on the Research Park (Table 2). Japanese honeysuckle is present in

Table 2. Non-native, invasive species on the Research Park ranked by this study. Raw scores for each section of the ranking system (i.e., potential impact on natural systems, its tendency to become a management problem or pest, and how difficult it is to control) are summed to provide a total raw score. The final rank (1 is most problematic overall) was assigned based on the total raw score

Scientific Name	Common Name	Impact	Pest	Control	Total	Rank
Microstegium vimineum	Japanese grass	60	67	44	171	1
Lonicera japonica	Japanese honeysuckle	58	60	40	158	2
Ligustrum sinense	Chinese privet	44	70	33	147	3
Pueraria lobata	Kudzu	58	41	48	147	3
Rosa multiflora	Multiflora rose	36	59	35	130	5
Lespedeza cuneata	Lespedeza	36	59	33	128	6
Dioscorea batatas	Chinese yam	53	43	24	120	7
Ailanthus altissima	Tree-of-heaven	27	52	24	103	8
Allium vineale	Field garlic	24	38	31	93	9
Elaeagnus umbellata	Autumn olive	29	37	24	90	10
Celastrus orbiculatus	Oriental bittersweet	35	30	21	86	11
Paulownia tomentosa	Empress tree	18	46	19	83	12
Sorghum halepense	Johnson grass	20	41	21	82	13
Vinca minor	Periwinkle	29	21	24	74	14
Mentha spicata	Spearmint	29	25	13	67	15
Rorippa nasturtium-aquaticum	Watercress	22	21	7	50	16
Cirsium vulgare	Bull thistle	9	27	4	40	17
Coronilla varia	Crown vetch	13	17	7	37	18

numerous, dense stands across the Research Park in early-successional to mid-successional habitats. It is relatively uncommon on recently disturbed (e.g., bladed) habitats, and is only patchily distributed in closed-canopy, later-successional forest communities. It is a common ground-cover in more open habitats, such as decadent pine stands, along road margins, and in canopy gaps. Of the three ranking subcategories—potential impact on natural systems, tendency to become a management problem, and difficulty of control—it ranked second-, second-, and third highest, respectively.

Japanese honeysuckle is widely recognized as a problematic invasive species throughout the region. It is in the Tennessee Exotic Pest Plant Council "Rank 1, Severe Threat" category (Tennessee Exotic Pest Plant Council 2001), and was reported by 17 of 35 management agencies in the Southern Appalachian region as an ongoing or potential management problem (Kuppinger 2000).

Chinese privet (*Ligustrum sinense* Lour.) and kudzu (*Pueraria lobata*) tied for the third most problematic species surveyed on the Research Park (Table 2). Chinese privet is most abundant along margins of gravel and paved roads, where it often forms dense, impenetrable stands with relatively dark understories. Although it can persist in shaded understory habitats, it is less abundant in relatively undisturbed, later-successional stands on the Research Park. It is also common in floodplains adjacent to streams and smaller watercourses, and is occasionally present on drier upland sites. Chinese privet reproduces both asexually and sexually, and produces copious quantities of fruits and seeds that are consumed and dispersed by birds. Although it vigorously resprouts from roots and cut stumps, it can be eradicated though a combination of top removal and application of glyphosate herbicide to the stump (Virginia Department of Conservation and Recreation 2002). Chinese privet is a "Rank 1, Severe Threat" species (Tennessee Exotic Pest Plant Council 2001), and was reported as a management problem by 16 of 35 management agencies in the Southern Appalachian region (Kuppinger 2000).

Kudzu (*Pueraria lobata*) is not widespread on the Research Park; in fact, it was present in only two management areas. However, it ranked highest in terms of how difficult it is to control, largely because of its deep and extensive root system and tendency to resprout after physical manipulation. In addition, kudzu ranked second-highest in terms of its potential impact on natural systems, because it is capable of overgrowing and decimating mature stands of trees. Because of this obvious tendency to overtop even tall vegetation, we assigned kudzu a high competitive ability (query #15, APRS Implementation Team 2000), whereas all other species were considered to have "unknown" competitive abilities because of insufficient data. In contrast with its potential impact and difficulty of control, kudzu ranked relatively low (i.e., 10th) for its tendency to become a management problem, because it does not tend to spread from site to site without human intervention. Further, kudzu produces few viable seeds, so it has little potential for long-distance dispersal outside of human activities.

Kudzu was the most commonly reported plant management problem (by 21 out of 35 management agencies) in the Southern Appalachian region, likely because of its widespread distribution, its obvious impact on natural systems, and its difficult nature to control (Kuppinger 2000). It is a "Rank 1, Severe Threat" species (Tennessee Exotic Pest Plant Council 2001).

Multiflora rose (*Rosa multiflora* Thunb.) was the fifth-most problematic species (Table 2). This species is present along fence rows and in early to mid-successional habitats. Although it is somewhat shade-intolerant, small populations are present within closed-canopy forest. Multiflora rose is present across a broad range of edaphic and environmental conditions (i.e., dry ridges to mesic floodplains). When present, it often forms dense, impenetrable thickets. Multiflora rose seeds are dispersed by wildlife, particularly birds, and they remain viable in the soil for up to 20 years. Once established, it can resprout readily after top removal, and can reproduce from roots and by layering. As such, multiflora rose ranked relatively high in terms of its tendency to spread rapidly and become a management problem. Multiflora rose was reported as a management problem by resource managers in the Southern Appalachians more often than Japanese honeysuckle and microstegium, perhaps because its upright and clumped growth form make it relatively apparent on landscapes (Kuppinger 2000). Multiflora rose is classified as a noxious weed in several US states, and is ranked as a "Severe Threat" to natural ecosystems in Tennessee (Tennessee Exotic Pest Plant Council 2001).

Chinese lespedeza (*Lespedeza cuneata*) ranked sixth in our survey of invasive species on the Research Park. Similar to field garlic, which ranked 9th and Johnson grass [*Sorghum halepense* (L.) Pers.], which ranked 13th, Chinese lespedeza tends to establish only in early successional sites with abundant sunlight. As such, it is present along roads, power transmission line rights-of-way, along waterfronts and in other natural and human-made clearings and openings. When present, it can form dense thickets that may exclude small-statured (e.g., herbaceous) native plant species. Chinese lespedeza produces abundant seeds that are dispersed by wildlife, and its seeds remain viable in the soil for many years (Plant Conservation Alliance 1997). As such, it ranked relatively high in terms of its tendency to become a management problem. Field garlic and Johnson grass also both received a high rank for tendency to become a management problem. All three of these species are difficult to control because they are so widespread; however, Chinese lespedeza is much more prevalent across the Research Park than either field garlic or Johnson grass.

Chinese yam (*Dioscorea batatas* Decne) received an overall rank of seven and had a relatively high rank for impact because it is a climbing vine that spreads rapidly. It can reproduce both asexually and through aerial bulbils, which is another reason for its high rank in impact. However, Chinese yam received a low rank for control because it occurs in relatively few locations on the Research Park. Chinese yam is mostly found along roadsides and the edges of management areas, where it often forms large clumps and completely covers native vegetation.

Overall rankings for tree-of heaven [*Ailanthus altissima* (Miller) Swingle] (8th) and empress tree [*Paulownia tomentosa* (Thunb.) Steudel] (12th) were 8th and 12th, respectively because of their tendency to become a management problem due to widespread seed dispersal. Both tree-of-heaven and empress tree are found growing only along roadsides; however, tree-of-heaven usually occurs in clumps because it clonally reproduces, while empress tree often occurs as individuals.

Although bull thistle [*Cirsium vulgare* (Savi) Tenore] (17th) produces abundant seed that is readily dispersed by wind, it ranked low in impact because its seeds are not capable of widespread dispersal. Bull thistle occurs in minimal numbers along roadsides and fields, and is not a threat to management areas. Spearmint (*Mentha spicata* L.) (15th), on the other hand, ranked high in impact because it occurs throughout Hembree Marsh Natural Area. Although it should not be considered a management concern on the Research Park as a whole, it is important in Hembree Marsh because of its abundance therein.

Autumn olive (*Elaeagnus umbellate* Thunb.) ranked tenth, and was mostly a problem along roadsides. It is uncommon within most closed canopy forest stands, probably because it generally requires disturbance and ample sunlight for establishment and growth. Similar to autumn olive, crown vetch (*Coronilla varia* L.) (18th) also occurred in areas with high insolation. Crown vetch was found in only one location on the Research Park and should not be considered a management problem. It was included in the ranking because a population was observed and was thought to have the potential to become a problem in the future. Similarly, in a recent listing of potentially invasive plant species, crown vetch was considered to be only "occasionally invasive" in Virginia (Virginia Department of Conservation and Recreation 2002).

Oriental bittersweet (*Celastrus orbiculatus* Thunb.) (11th) and periwinkle (*Vinca minor* L.) (14th) both received their highest score in impact because they are vines and are capable of overtopping and thereby excluding native vegetation. Oriental bittersweet received a low score for control because it was found in only one location on the Research Park and was removed from that location. In contrast, periwinkle is found in several locations and is observed to form dense mats in the understory of second-growth forest stands.

Finally, watercress [*Rorippa nasturtium-aquaticum* (L.) Hayek] (16th) ranked low for control because the populations observed were small and could be easily removed by hand. It was only found in areas where running water and ample sunlight were available. Watercress should not be considered a management concern because it has a low impact in native communities and can easily be controlled.

Species Ranks for each Management Area

The relative rank of invasive plant species present within each management area tended to mirror the ranking for the Research Park as a whole (Drake, Weltzin, and Parr 2002). For example, the most problematic plant for the Research Park as a whole–*Microstegium*–was ranked first in each of the 12 management areas in which it was present. The four management areas in which *Microstegium* was not present included two power transmission rights-of-way, a marsh dominated by emergent vegetation, and a cedar barren. Although *Microstegium* could conceivably become established in each of these management areas, they do not represent habitats typically invaded by this species (Barden 1987, Redman 1995).

Japanese honeysuckle is present in 12 of the 16 management areas surveyed. Similar to *Microstegium*, it ranked second in each of these management areas as it did for the Research Park as a whole. It is particularly abundant in Natural Area 9 (Figure 1), where large clumps of vines reminiscent of kudzu hang from trees. In other Natural Areas, it is mostly present along fence rows and roadsides.

Chinese privet is present in eight of the 16 management areas surveyed. It ranked second in six of those eight management areas, even though it ranked third on the Research Park as a whole. The management areas in which Chinese privet is found are all in close proximity to streams or roadsides.

Chinese lespedeza ranked number one in the Raccoon Creek Cedar Barren management area, whereas it ranked sixth on the Research Park as a whole. In contrast with adjacent stands of closed-canopy deciduous forest on more mesic sites, insolation at ground level within the cedar barren is relatively high. These high levels of sunlight tend to favor the establishment and growth of lespedeza. In all other management areas where it was present, lespedeza was ranked relatively low.

Hembree Marsh contains a large, dense population of spearmint that could potentially affect native wetland plants. No other invasive species examined as part of this survey were found within Hembree Marsh, probably because the perennially high water-tables preclude the establishment of species less tolerant of periodic or permanent inundation. Thus, spearmint ranked first in this Natural Area. Additional details of invasive species within each management area are in Drake, Weltzin, and Parr (2002).

CONCLUSIONS

Ranking Non-native, Invasive Plants on the Research Park

The National Environmental Research Park and its component management areas contain a total of 167 non-native invasive plant species that may have potential negative effects on native plant and animal communities. Of the 18 species surveyed in this study, *Microstegium*, Japanese honeysuckle, Chinese privet, kudzu, and multiflora rose are among the most problematic invasive species on the Research Park and its component management areas. These species are abundant throughout the southern Appalachian region, and have all been ranked as particular management problems in other qualitative and semi-quantitative rankings of non-native, invasive species in the region (Tennessee Exotic Pest Plant Council 2001, Kuppinger 2000). However, results of this research can be used to prioritize management and research activities related to these invasive taxa on the Research Park as a whole, and for specific management areas.

Overall, the USGS ranking system was relatively straightforward, and contained the components thought to provide an adequate assessment of the impact of invasive species: abundance, impact per individual, and total area occupied (Parker et al. 1999). However, the ranking system does have some drawbacks. For example, in all but one case, it allows only one answer to be chosen for each question. In particular, this was a problem for the question "Distribution relative to disturbance regime," in which the options early, mid-, or late successional sites could be chosen. For species such as *Microstegium* and Japanese honeysuckle, more than one answer would have been appropriate. We dealt with this specific problem by selecting the option that portrayed the latest successional stage in which a particular species could be found.

The Need for Additional Research

As we gathered information from the literature about the traits and characteristics of individual species, it became apparent that basic autecological information on many invasive species is not readily available. This was particularly true for the less-abundant and least-problematic taxa, but even basic quantitative information on the more common taxa was sometimes lacking. In particular, data on species competitive ability, the number of seeds produced per plant, the viability and longevity of the seedbank, and the difficulty of control were often found lacking. Additional information on these topics would improve the ability to rank these species.

In addition, quantitative data on the effects of these species on invaded plant and animal communities and ecosystems were seldom available. This is not a new problem in the field of invasion biology or plant ecology, nor is it specific to the particular species in question, the Research Park, or the region. In fact, scientists seldom collect basic data directed at quantification of effects of plant invasions on native ecological systems, and most of the discussion of ecological effects of invaders is anecdotal (Parker et al. 1999). In fact, in a recent review of scientific assessments of ecological impacts of invasions, Parker et al. (1999) stated that "Despite the considerable attention invasive species receive, our lamentable paucity of data on impacts leaves us largely ignorant about the ecological changes they have brought about." Obviously, additional research focused on the general effects of individual invasive species on individuals, populations, communities, and ecosystems is much needed.

In addition, there is a great need and potential to learn more about invasive plants in the various management areas on the Research Park, in the Ridge and Valley Province, and in the southern Appalachian region as a whole. Future research should focus on individual plant characteristics and the effects of invasive species on native communities; research priorities could be guided by the results of the ranking conducted herein.

Similarly, studies of the effects of disturbance (e.g., logging, roads, and construction and maintenance of power line rights-of-way) could yield important information on the ways in which invasive species establish and spread. Research on different control methods could aid in implementing management strategies for eradication of invasive species. In all, additional research will yield information necessary to further prioritize management activities related to different invasive plant species. Finally, this ranking system could be used to similarly rank the many other non-native, invasive species present on the Research Park that we did not include in this study.

Development of Management Strategies for the Research Park

Results of this study can be used to develop a management strategy for the most problematic invasive species on the Research Park and its component management areas. Strategies for management could take one or both of two non-mutually exclusive approaches. First, management priorities could be site-specific (i.e., focused on particular management areas most threatened by a suite of invasive species). For example, sites that include large populations or many species of invasive plants, or sites with species of special concern, may be targets for particular management activities. Second, management priorities could be species-specific—focusing on a particular invasive (or native) plant of special concern—across a variety of sites. Management activities should also initially be focused on invasive species populations that are feasible to control. For example, eradication of microstegium from an area as extensive as the Research Park may represent a Sisyphean task. However, intensive monitoring and control efforts may prevent the establishment and spread of other non-native species before they become ecological or management problems.

APPENDIX I. Alien Plants Ranking System Version 5.1 (APRS Implementation Team 2000)

I. Significance of Threat or Impact (Site Characteristics)

1. Distribution relative to disturbance regime
   a. Found only within sites disturbed within the last 3 years or sites regularly disturbed
   b. Found in sites disturbed within the last 10 years.
   c. Found in midsuccessional sites disturbed 11 to 50 years before present
   d. Found in late-successional sites disturbed 51 to 100 years BP.
   e. Found in high quality natural areas with no known major disturbance for 100 years
   f. Unknown

2. Areal extent of populations
   a. Not in site, but in adjacent areas
   b. Found in less than 5% of site
   c. Found in between 5% and 10% of site
   d. Found in between 10% and 25% of site
   e. Found in more than 25% of site
   f. Unknown

3. Numerical dominance of species within a community
   a. Not found on site
   b. Usually observed as a single individual (or fewer than 5 per 5 m^2)
   c. Usually observed in numbers less than the 2 or 3 most common native species in the community (but more than 5 per 5 m^2)
   d. Usually observed in numbers approximately equivalent to the most common native species in the community
   e. Usually observed in numbers greater than the most common native species in the community
   f. Unknown

4. Association with native community
   a. Associated with weedy (early successional) species
   b. Associated with midsuccessional species
   c. Associated with dominant (late-successional) species
   d. Displaces native plant community
   e. Unknown

5. Hybridization with native species
   a. Not known to hybridize with native species
   b. Known to hybridize with native species
   c. Unknown

6. Degree of threat and impact
   a. Little or no increase in numbers of individuals and populations and no invasion of native communities
   b. Present in native communities, but static or decreasing
   c. Moderate rate of increase in numbers of individuals and populations; little or no invasion of native communities
   d. Moderate rate of increase in numbers of individuals and populations; invading native plant communities
   e. High rate of increase of numbers of individuals and populations; invading and replacing or highly modifying native plant communities
   f. Unknown

7. Effects on management goals
   a. No effect
   b. Little impact on site management goals
   c. Moderate impact on site management goals
   d. Large impact on site management goals
   e. Unknown

II. Innate ability to become a pest

8. Mode of reproduction
   a. Rarely, if ever, reproduces in area
   b. Reproduces almost entirely by vegetative means
   c. Reproduces only by seed
   d. Reproduces vegetatively and by seeds
   e. Unknown

9. Vegetative reproduction
   a. No vegetative reproduction
   b. Vegetative reproduction rate maintains population
   c. Vegetative reproduction rate results in moderate increase in population size
   d. Vegetative reproduction rate results in rapid increase in population size
   e. Unknown

10. Frequency of sexual reproduction for mature plant
   a. Almost never reproduces sexually in area
   b. Once every 5 or more years
   c. Every other year
   d. One or more times a year
   e. Bursts of sexual reproduction in response to environmental stimulus
   f. Unknown

11. Number of seeds per plant
   a. Rarely, if ever, produces seed in area
   b. Few (0–10)
   c. Moderate (11–1000)
   d. Many (>1000)
   e. Unknown

12. Dispersal ability
    a. Little potential for long-distance dispersal
    b. Great potential for long-distance dispersal
    c. Unknown

13. Germination requirements
    a. Requires open soil and disturbance to germinate
    b. Can germinate in vegetated areas but in a narrow range or in special conditions
    c. Can germinate in existing vegetation in a wide range of conditions
    d. Unknown

14. Seed banks
    a. Seeds remain viable in the soil for less than 1 year
    b. Seeds remain viable in the soil for 1 to 5 years
    c. Seeds remain viable in the soil for more than 5 years
    d. Unknown

15. Competitive ability
    a. Poor competitor
    b. Moderately successful competitor
    c. Highly successful competitor
    d. Unknown

16. Ecological effects (select all that apply)
    a. Produces persistent litter or shade that affects germination or growth of native species
    b. Produces allelochemicals
    c. Affects availability of soil nutrients
    d. Affects water availability to native plants
    e. Changes natural fire regime
    f. None of the above
    g. Unknown

17. Known level of impact in natural areas
    a. Not known to cause impacts in any other natural area
    b. Known to cause impacts in natural areas, but with different habitats and climate zones
    c. Known to cause low impact in natural areas with similar habitats and climate zones
    d. Known to cause moderate impact in natural areas with similar habitats and climate zones
    e. Known to cause high impact in natural areas with similar habitats and and climate zones and/or on the list of most invasive alien plants for the region
    f. Unknown

III. Difficulty of control

18. Likelihood of successful control
    a. This species has been eradicated in a natural area
    b. Control (populations declining) of this species has been achieved in a natural area
    c. Limited control (species is no longer spreading, but persists near pre-control levels) of this species has been achieved in a natural area
    d. Control of this species has never been achieved in a natural area
    e. Unknown

19. Saturation in surrounding region
    a. Not present in areas surrounding the site
    b. Present in few areas surrounding the site
    c. Present in several areas but not entirely surrounding the site
    d. Present in most areas surrounding the site
    e. Unknown

20. Effectiveness of community management
    a. Protection from disturbance effectively controls target species

b. Cultural techniques (burning, flooding) can be used to control target species
c. Restoration or preservation practices effectively control target species
d. The above options are not effective
e. Unknown

21. Vegetative regeneration
    a. No resprouting following removal of above ground growth
    b. Sprouts from roots or stumps
    c. Any plant part is a viable propagule
    d. Unknown

22. Biological control
    a. Biological control feasible
    b. Potential may exist for biological control
    c. Biological control not feasible (not practical, possible, or probable)
    d. Unknown

23. Side effects of control measures
    a. Control measures have little potential to affect native communities
    b. Control measures are likely to cause moderate impacts on communities
    c. Control measures are likely to cause major impacts on communities
    d. Side effects of control unknown
    e. Unknown

APPENDIX II. Responses to each ranking system question (i.e., questions 1 through 23) for each species surveyed on the Research Park. Species are abbreviated using the first two letters of the genus and the species, respectively.

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Mivi	c	e	d	b	a	e	d	d	b	d	c	b	c	b	d	a,d	e	e	d	c	a	d	c
Diba	c	c	c	b	a	e	d	b	d	a	a	b	c	d	d	a	e	e	c	c	d	d	c
Lecu	a	d	c	a	a	d	d	c	a	d	d	b	b	c	d	c	e	e	d	b	d	d	c
Alvi	a	b	c	a	a	d	c	d	b	d	c	a	a	b	d	g	d	e	b	c	b	d	c
Elum	c	c	c	b	a	c	c	e	e	d	e	c	b	d	d	a,c	e	e	c	b	b	d	b
Lisi	c	c	c	b	a	d	d	d	d	d	d	b	c	d	d	a,d	e	e	c	b	b	b	c
Rona	a	b	b	e	b	c	b	e	e	d	e	a	b	d	d	a	c	e	b	b	a	d	a
Loja	c	e	c	b	a	e	d	d	d	d	c	b	c	d	d	a	e	e	d	b	b	d	c
Pulo	c	c	e	b	a	e	d	b	d	a	a	a	c	a	c	a	e	c	c	c	b	d	c
Vimi	c	c	c	b	a	c	c	b	c	a	a	a	b	d	d	a	d	e	c	b	d	b	b
Aial	b	c	c	a	a	d	c	c	a	d	d	b	a	d	d	a,b	e	e	c	b	b	d	b
Civu	a	b	b	a	a	a	b	c	a	d	d	a	a	a	d	g	d	e	b	a	d	d	a
Mesp	c	b	c	b	b	a	b	d	e	d	e	a	b	d	d	g	d	e	b	b	d	d	b
Soha	a	c	c	a	a	c	c	d	c	d	e	b	a	d	d	g	e	e	c	c	d	d	b
Ceor	c	b	b	b	b	c	c	d	c	f	e	a	d	d	d	a	e	b	b	b	b	d	b
Romu	c	d	c	b	c	d	c	d	b	d	e	b	c	c	d	a	e	e	c	b	b	d	b
Pato	a	c	b	a	a	c	c	d	c	d	d	b	d	d	d	a	d	e	b	b	b	d	b
Cova	a	a	a	a	c	c	c	d	c	f	e	a	d	d	d	g	d	e	d	a	d	d	a

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