A Survey of Exotic Plants in Federal Wilderness Areas

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Abstract—I conducted a survey of wilderness areas to provide an overview of plant invasions in the National Wilderness Preservation System. Fifteen per cent of responding mangers reported that exotic plants were among their top 10 management concerns, either because they are actively dealing with control of exotic pest plants or have prioritized prevention of their establishment. Seventy per cent of responding wilderness areas do not monitor or inventory for exotic plants. The majority of respondents reported that exotic plants have not impacted their areas, so it is important to emphasize prevention and early detection of exotic plant establishment. Responses varied greatly among regions, with the highest priority being given to exotic plants by agencies in the California Mediterranean region and the Rocky Mountain montane region. The National Park Service was most likely to monitor or inventory for exotic plants. The greatest needs for most areas are increased funding, education and training to prevent further establishment of exotic plants.

The 1964 Wilderness Act was passed to protect designated natural areas from human impacts in order to preserve research and recreation opportunities and to protect the intrinsic value of natural areas and wildlife. Although legislatively protected, all wilderness areas have been impacted to some degree by human disturbances (Cole and Landres 1996). Among these disturbances is the introduction of exotic species that have been transported by human activities beyond their native ranges, and variously referred to as nonnative, nonindigenous, or alien. Many of these plants have significant and measurable ecological effects on invaded ecosystems, and are considered pests or "weeds."

Increased global travel by humans and the resulting breakdown of geographic barriers to plant dispersal has dramatically increased the rate of intentional and accidental introductions of exotic species (Vermeij 1991, D'Antonio and Vitousek 1992, Lodge 1993, Vitousek and others 1997). Changes in species' distributions are natural phenomena that operate on various time and spatial scales (Vermeij 1991, Lodge 1993). However, human mobility allows introductions at rates that are without precedent over the past several million years. The resulting exotic plant invasions have long been recognized as serious ecological problems (Leopold 1941, Stewart and Hull 1949, Elton 1958) and are increasingly considered one of the greatest anthropogenic threats to preservation of biodiversity and the regional distinctiveness of the planet (Soulé 1990, Vitousek 1990, 1994, D'Antonio and Vitousek 1992, Dudley and Collins 1995, Huenneke 1997).

Because exotic plant management is expensive, time consuming and complex, researchers and managers need to identify priority areas to focus weed control efforts. Many researchers agree that relatively undisturbed areas should be high priorities for weed control efforts (MacDonald and others 1989, Asher and Harmon 1995, Hobbs and Humphries 1995). Relative to other managed lands, wilderness areas usually have more limited access, more natural conditions and fewer impacts of human activity. Therefore, they are an appropriate focal point for prevention and control of exotic plant invasions.

In 1997 and 1998, I conducted a survey of managers of Bureau of Land Management (BLM), Forest Service (FS), Fish and Wildlife Service (FWS) and the National Park Service (NPS) wilderness areas. The goal of the survey was to compile information on exotic plant species in order to identify research needs, generate awareness and facilitate information exchange about exotics in wilderness areas. Three immediate objectives were to document the occurrence of exotic plant species in wilderness areas and control efforts being used, identify factors contributing to exotic plant establishment and spread and characterize the quality of available data. The resulting database is available over the Internet (www.umt.edu/biology/leopold). Here I discuss the current status of exotic plants in wilderness areas in the context of identifying research priorities and appropriate management actions for wilderness preservation.

Terminology

There is no universally accepted term to describe nonindigenous plants, and human values frequently complicate terminology (Luken 1994). Terminology for exotic plants is problematic due to biological problems in defining the status of "native" or "indigenous" plants. It is difficult to define natives because of the naturally dynamic nature of species distributions and the relatively brief time frame in which we have been documenting those distributions (Webb 1985, Lodge 1993, Tausch and others 1993, Carlton 1996, Schwartz 1997). One commonly used temporal standard for determining the indigenous status of plants in North America is pre- versus post- European settlement. This is often an appropriate reference point, since European settlement marked the point when the rate of introductions was dramatically accelerated. However, it is still problematic since it overlooks the fact that indigenous people were practicing agriculture and introducing plants beginning 10,000 years ago (Webb 1985, Schwartz 1997). Nonetheless, pre- versus post-colonization is often a helpful standard to use.

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The status of a given plant could be debated indefinitely, but the relevant task is when to determine that an exotic plant has become a problem. According to Loope (1993), the threshold is crossed when the introduced species results in a "significant decline in populations of one or more native species, significantly alters ecosystem processes, (or) causes aesthetic damage perceived to be unacceptable."

"Weed" is a commonly used, subjective term for any plant that is not wanted. This term can be confusing when used by different people; but when management goals are clearly identified, defining weeds becomes straightforward (Randall 1997). It is easy to identify management goals in situations where benefits and costs can be assessed economically. When benefits of "weed" control are aesthetic, social or scientific, it becomes more difficult to say which plants interfere with management goals, and why.

For this report, "exotic" will be used for plant species that are not considered indigenous to a given area. "Weed" will be used for any exotic plant that has proven to be a nuisance or environmental threat by causing any of the problems mentioned above. This survey asked respondents to list all exotic plant species. However, the majority reported only serious weeds, making generalizations about large-scale patterns in the number of exotics difficult.

Methods

A survey was distributed to all national parks, national forests, BLM offices and national wildlife refuges that administer wilderness areas. The survey form was intended to standardize responses on attitudes and priorities toward exotic plants and to gather specific information on exotic species, management responses and control efforts. Respondents were asked whether there was a weed management plan that applied to the wilderness area, whether exotic plants were monitored in the wilderness area, and to indicate the source of the information they were providing on the survey (best guess, systematic monitoring, etc.). They were also asked to rank the problem of exotic plants relative to other management issues.

Respondents were asked to list all exotic plants that they knew of or suspected in the wilderness area, and to give a categorical ranking for the abundance and perceived threat of each plant. Space was provided to list research projects and control efforts for each species.

Survey responses were entered into a database with tables for contact information, species information (plant names, notes, pattern of infestation, control methods, and so on), and general information for wilderness areas. Examples of possible queries include "Which wilderness areas have leafy spurge present?" "Which are using herbicides to control salt cedar?" or "What are some contacts for managers in the Northwest who have sweet clover in their wilderness areas?"

Survey Results

The response rate, quality of available information and level of priority assigned to exotic species management all varied considerably within and between regions. For this report, results are discussed regionally, with each wilderness area assigned to a biome.

Overall, 322 designated wilderness areas in 30 states responded by mail, phone, or e-mail. There are 667 wilderness areas in 44 states, so the responses represent 48%. Some wilderness areas are managed by more than one unit; for example, the Lee Metcalf Wilderness in Montana is managed by the Gallatin National Forest, Beaverhead-Deerlodge National Forest and the BLM. If each unit is considered a separate wilderness area, there are 756 wilderness areas, of which 342 responded (45%). This report treats each management unit as a separate wilderness area, since available information, attitudes and projects vary from one unit to the next.

Quality of Available Information and Ranking of Exotics as a Priority Issue

In addition to nonrandom participation in our survey effort, there were large differences between regions and between agencies in the quality of available information, and in the level of importance assigned to exotic plants in general. Overall, about 31% of wilderness areas reported some kind of monitoring or documentation of exotics (42% confirmed that they did not monitor, and 27% did not respond to the question). National Park Service wilderness areas were the most likely to monitor exotic plants (table 1). Fewer than 10% of respondents have written plans for weed management in the wilderness areas.

Overall, about 15% of respondents ranked exotic plants among their top 10 concerns, and 17% reported it as one of many small problems. About 42% said that exotic plants were not much of a problem. Sometimes this was because exotics were not known or suspected to occur, but occasionally respondents indicated that management was not interested in exotic plants in general, or that wilderness areas are lower priorities for active management. The level of importance assigned to exotic plants varied greatly among regions.

Regional Organization

Wilderness areas from the Sonoran desert to the Arctic tundra reported problems with exotic plants (table 2). Organization of results by biome is intended to identify regional differences in the perception of exotic plants as a management priority and to help interested parties identify and prioritize plants that are likely to occur locally or regionally.

Table 1—Percent of wilderness areas that monitor for exotic plants, by agency.

Agency	Percent
BLM	46
FS	29*
FWS	32
NPS	80

*Excludes wilderness areas that received the first version of the survey form, which did not include this question.

Table 2—Biomes included for regional discussion (based on Barbour and Billings 1988).

Arctic tundra and boreal forest
Pacific coastal and Cascadian forests
California mediterranean
California forests
Intermountain basin
Northwest (Palouse) prairie
Sonoran and Mojave Deserts
Rocky Mountain montane forests
Central prairie
Eastern temperate forests
Great Lakes
Southwest states
Appalachian forest
Northeast states
Southeast coastal marsh, swamp, bog, forests

For convenience, the Arctic tundra and boreal forest are combined, as are the Pacific coastal and Cascadian forests, and Intermountain communities and the Palouse prairie. The Eastern temperate forest biome is very large, and I discuss it in four subsections that are geographically convenient and biologically relevant: Appalachian forests, Northeast states, Great Lakes, and the Southeast states. Those interested should also see Loope (1993) for an overview of problem exotic plants in national parks and biosphere preserves of the United States.

Arctic Tundra/Boreal Forest—All wilderness areas of this biome are located in Alaska. All respondents in this biome indicated that the low level of human disturbance and remoteness of the areas are not conducive to invasion by exotics. For example, Selawik NWR reported that no one on the current staff had visited the Selawik wilderness area. Access is very difficult, requiring foot travel through an adjacent wilderness areas or plane. It is unlikely that exotic plants have been introduced to such a remote area.

Although eight of nine wilderness areas reported that exotic plants are "not much of a problem," a few exotic plants are found there, including some that cause problems in the lower 48 states. Several places reported the presence of cosmopolitan ruderal species that do not appear to pose a threat to native plant communities, including pineapple weed (*Matricaria matricoides*), dandelion (*Taraxacum officinale*) and shepard's purse (*Capsella pursa-pastoris*). Most wilderness managers are not concerned with these species, but Denali National Park has an active exotic plant control program which includes pulling dandelion and vetch (*Vicia cracca*) (Balay, personal communication).

Serious pest plants have also been reported in this region. Bull thistle (*Cirsium vulgare*) has been found (and sprayed with herbicides) near the Izembek Wilderness. Orange hawkweed (*Heiracium scabriusculum*), ox-eye daisy (*Chrysanthemum leaucanthemum,* syn. *Leucanthemum vulgare*), timothy (*Phleum pratense*) and white sweet clover (*Melilotus alba*) have been reported in or near Denali and/or Togiak. These plants cause considerable problems for natural area management in other parts of the United States, although no large problems have yet developed in Alaska.

Pacific Coastal/Cascadian Forests—This region ranges from southeastern Alaska to northern California, and the wilderness areas range in elevation from sea level to over 8,000 feet. Only 8% of respondents ranked exotic plants among the top 10 problems. Those included Olympic National Park (WA), the Middle Santiam Wilderness (OR), and the Okanogan National Forest portion of the Lake Chelan-Sawtooth Wilderness (WA), which are actively dealing with weed problems. The Leavenworth Ranger District portion of Alpine Lakes Wilderness (WA) has taken a proactive approach to preventing weed establishment in the wilderness area (Therrell, personal communication). There is the potential for weeds to spread from heavily infested roads and trailheads leading into the wilderness area, and Forest staff have been aggressively hand pulling weeds at trailheads for the past six summers. Monitoring of weeds and control efforts are informal and unfunded.

In coastal and montane regions of northern California, Oregon, and Washington, little information was submitted for exotic plant distributions in Forest Service wilderness areas. Biologists on the Six Rivers, Deschutes and Mt. Baker-Snoqualmie National Forests confirmed that their wilderness areas have never been inventoried for exotic plants. Although respondents did not expect that weed problems existed in these wilderness areas, there was a general lack of information to assess the situation. Many biologists cited a lack of funding and staff for inventories. The Deschutes National Forest is seeking funding for weed projects and has a GIS project to identify weed locations on the entire Forest. While there is currently no information on the distribution of exotics in the wilderness, trailheads have been identified as priority spots for weed monitoring, and weed populations near wilderness areas are considered priorities for control (Grenier, personal communication).

Olympic National Park has a large amount of information on exotics and an active management program. In California, Oregon and Washington, common burdock (*Arctium minus*), ox-eye daisy (*Chrysanthemum leucanthemum,* syn. *Leucanthemum vulgare*), tansy ragwort (*Senecio jacobaea*), Scotch broom (*Cytisus scoparius*) and St. Johnswort (*Hypericum perforatum*) were the most widely reported problem species.

Biologists in southern and coastal Alaska reported that weeds were not a problem in their wilderness areas, due to their remoteness and inaccessibility. However, due to the same logistical limitations, most did not have specific information. While no exotics were reported for the Alaskan wilderness areas in this biome, biologists and managers should be aware that problem species have been found elsewhere in Alaska (see Tundra/Boreal Forest).

California Mediterranean—Wilderness areas in the California mediterranean biome were more likely to report exotic plants as a high priority than any other biome. Of those that responded, 65% considered exotic plants to be at least among the top 10 management concerns, and 11 of 19 monitor exotics in wilderness in some way. These wilderness areas are at lower elevations than in many regions, and therefore probably have more susceptible habitat. At the Phillip Burton wilderness area of Point Reyes National Seashore, exotic plants are a major management problem, especially since a large fire in 1995, which precipitated an explosion of weed populations (Cooper, personal communication).

Throughout California, native perennial grasses have largely been replaced by exotic annual grasses following European settlement. The replacement is so complete that the original grassland communities are virtually unknown (Heady and others 1992). These exotic annual grasses now also make up a significant portion of understory in chaparral/scrub communities. Biologists on the Los Padres National Forest reported that annual brome grasses have displaced native plants and are altering fire regimes, but no control efforts are underway (nor do they seem feasible). Salt cedars (*Tamarix* species) and yellow star thistle (*Centaurea solstitialis*) were the most frequently reported problem species known or suspected to occur in wilderness areas in the mediterranean biome. On the Los Padres National Forest, salt cedar is being treated by cutting and herbicide application to stumps and by manual removal by a volunteer group which has an annual work day (Austin, personal communication).

California Montane Forests—Wilderness areas of the Sierra Nevada reported few weed problems. These wilderness areas occur mostly at high elevations and all 19 that responded expected elevation to limit exotic plant invasions. However, yellow star thistle (*Centaurea solstitialis*) has been found at Tuolomne Meadows in Yosemite National Park, at an elevation of 8,600 feet (Fritzke, personal communication). Although it is uncertain whether the plants would be able to complete their life cycle at this elevation, biologists on the Sierra National Forest and in Yosemite National Park expect that strong prevention efforts will be necessary to avoid establishment of this major pest plant, even at high elevations.

The few exotics that do occur in the high-elevation portions of the wilderness areas were probably brought in with livestock and packstock (Shevock, personal communication). Musk thistles (*Carduus* species) are suspected to occur near high-elevation lakes on the Sequoia National Forest. Kentucky bluegrass *(Poa pratense*) is well established at higher elevations in Sequoia-Kings Canyon wilderness area. Many wilderness areas in the Sierra have been or are currently grazed by livestock, a disturbance that was reported to increase susceptibility to exotic plant invasion (see Dudley and Embury (1995) for an in-depth discussion of grazing in California wilderness areas).

At lower elevations, annual bromes (*Bromus tectorum*, *B. madritensis* ssp. *rubens*, *B. diandrus*) are well established. The exotic grass *Vulpia myuros* and yellow star thistle *(C. solsititialis)* are problem invaders at low elevations.

Few exotics are known to occur in California montane wilderness areas, but 16 of 19 areas that responded have not been inventoried for weeds and indicated that their data were too rough for confident assessment of the problem. However, Sequoia and Inyo National Forests both began weed inventories in 1998, which will probably include parts of some wilderness areas, and the Modoc National Forest is preparing a noxious weed Environmental Impact Statement that includes the South Warner Wilderness. The Tahoe National Forest depends on volunteers and knowledgeable hikers for reports of weed populations in the Granite Chief Wilderness. This is probably the case for other forests, too, which do not currently have funding for weed inventories. Yosemite and Sequoia-Kings Canyon National Parks have more active exotic plant inventory programs than the Forest Service wilderness areas.

Intermountain Basin and Palouse Prairie—These biomes were combined since there are relatively few wilderness areas in each. Nearly 20% of responding wilderness area ranked exotic plants as among the top 10 priorities. Nine of the 11 wilderness areas included in this biome are on the Humbolt-Toiyabe National Forest in Nevada, where an exotic plant prevention program is currently being developed. The Forest is in the process of documenting specific occurrences of weeds in wilderness. Most of the Forest's information and focus on weeds is outside wilderness areas, since problem infestations are generally thought to be outside of wilderness boundaries. The exception is cheatgrass (*B. tectorum*), which is limited to lower elevations of wilderness areas (Jean, personal communication).

Although weeds are identified as a high priority on Forest Service lands in Nevada, monitoring and documentation of exotics only occurs when staff visit wilderness areas for other purposes. In other words, this work is getting done without specific allocated funding. The Humbolt-Toiyabe National Forest reported using biocontrols and herbicides for leafy spurge (*Euphorbia esula*), Canada thistle (*Cirsium arvense*) and toadflax (*Linaria* spp.) outside of wilderness areas.

Lake Mead National Recreation Area (which is not a designated wilderness area) is dealing with many weed problems, especially salt cedar (*Tamarix ramosissima*). Other priority plants for control are the exotic palms *Phoenix dactylifera* and *Washintonia filifera*, which have spread from plantings as ornamentals. Eradication of these plants is controversial because the public finds them attractive and desirable (Powell, personal communication).

Sonoran and Mojave Deserts—This biome includes wilderness areas in California, Arizona, and New Mexico. The response rate was high from Arizona and New Mexico, but only a few responses were received from California. Since the BLM recently acquired the 69 wilderness areas in this biome under the California Desert Protection Act of 1994, there may be little information available on this vast amount of land (almost 4.3 million acres).

While fewer than 10% of respondents ranked exotic plants among their top 10 priorities, at least 40% of responding wilderness areas have no information available on exotics in wilderness areas. However, the Gila National Forest in New Mexico and most of the BLM field offices in Arizona have done exotic plant surveys in wilderness areas and have found very few exotics. In contrast, Organ Pipe Cactus National Monument and Saguaro National Park are dealing with many problem exotic species. In these parks, and in several of the Arizona BLM wilderness areas, problems with exotic plants are mostly restricted to lower elevation desert communities, whereas the higher elevation pine and chaparral communities have few weed problems.

Organ Pipe Cactus National Monument is targeting buffelgrass (*Pennisetum ciliare*) for control in 1998-99. Felger (1990) compiled an extensive list of exotics at Organ Pipe, with a discussion of the types of exotics (disturbance-dependent, capable of invading intact communities, etc.). This report is a good resource reference for the region. In 1990, the total proportion of actual and "potential" exotic species in the flora was 11.5%. Felger states that this low proportion is indicative of a healthy ecosystem. Although the proportion is low, several of those species are capable of dominating vast

acreage, with significant ecological impacts; thus, abundance, and not just the number of species, needs to be considered.

Red brome (*Bromus rubens*), fountain grass (*Pennisetum setaceum*), buffelgrass (*P. ciliare*), black mustard (*Brassica tournefortii*) and salt cedar (*Tamarix ramosissima*) were the most widely reported weeds of the Sonoran desert. Red brome, fountain grass and buffelgrass alter fire regimes, and *Tamarix* can alter hydrology. Fire suppression and subsequent big fires, along with intense grazing history, were widely reported causes of weed establishment and spread.

Rocky Mountain Montane Forests—About 45 wilderness areas in the Rocky Mountain region received an early version of the survey form that did not include all of the questions present in the final version, including the question to rank exotics plants relative to other management issues. Among those that did respond to all of the questions (24 wilderness areas), 68% ranked exotic plants among the top 10 management priorities, 58% have some kind of weed management plan that includes the wilderness area, and 87% reported that exotics are monitored in the wilderness area. Many of the surveys were completed by a "noxious weed specialist," a position rarely found in other regions.

Widely reported exotics included Canada thistle (*Cirsium arvense*), spotted knapweed (*Centaurea maculosa*), hound's tongue (*Cynoglossum officinale*), leafy spurge (*Euphorbia esula*), smooth brome (*Bromus inermis*), timothy (*Phleum pratense*), toadflax species (*Linaria dalmatica*), mullein (*Verbascum thapsus*) and sulfur cinquefoil (*Potentilla recta).* Many wilderness areas reported manual control efforts, regular herbicide treatments, and biological control of these and other plants in and immediately adjacent to wilderness areas. Control efforts with user groups are also in place. For example, the Frank Church- River of No Return has a hand-pulling campaign along the Salmon River. The river corridor is a heavily used area where many of the weed problems are focused, so the volunteer pulling program has two benefits. It results in some weed control in the heavily impacted areas, and it helps to educate wilderness users about exotic plants as a conservation problem (Anderson, personal communication). Researchers on the Frank Church-River of No Return Wilderness Area also conducted a trial using remote sensing for early detection of noxious weeds, with mixed results (Lake 1996a,b).

Central Prairie—Prairie systems are poorly represented in the National Wilderness Preservation System, with only 10 federal wilderness areas (Landres and Meyer, 1998). Of the five responding, two ranked exotics as significant problem, and three out of the five do some kind of monitoring of exotics in the wilderness. The fact that these are at lower elevations probably contributes to weed problems. Canada thistle (*Cirsium arvense*) was the most widely reported (by 4 of the wilderness areas), followed by smooth brome (*Bromus inermis*), Kentucky bluegrass (*Poa pratense*) and leafy spurge (*Euphorbia esula*). The extent of invasion seems to be small enough that these could be addressed; however, populations of spotted knapweed, Canada thistle (at Badlands) and leafy spurge (at Medicine Lake) are increasing despite biological and mechanical control efforts. Populations of salt cedar and sweet clover are expanding in places where there are no control efforts.

Eastern Temperate Forests—This is a tree-dominated biome, in which the woody taxa are mostly winter deciduous (Greller 1989). This biome covers most of eastern US, and is usually divided into many subregions (see Greller 1989). Response rate was low overall for this biome, and exotic plants are not as widely perceived as a problem in Eastern states. Many agency employees, including the Forest Service's Eastern Regional Wilderness Coordinator, said that there are few weed problems in Eastern states; however, The Nature Conservancy and a few federal biologists reported several exotic plant concerns.

For convenience, I discuss 4 subsections (Great Lakes, Southwest, Appalachian, and Northeast). Overall, about 20% of wilderness areas ranked exotics as a significant problem, although this varied greatly among subregions.

Great Lakes (Michigan and Wisconsin Wilderness Areas)—Seven of 14 areas ranked exotics as a significant problem. Although most wilderness areas had not been inventoried, several had lists of exotic plants likely to be found there. The invasive plant list for the Forest Service Eastern Region has 57 exotic invasive species, 10 native invasive species and over 150 widespread exotics that are not considered invasive. Of these, 37 were known or suspected in wilderness areas on the Hiawatha National forest (14 of these are considered invasive).

Nordhouse Dunes Wilderness in Michigan has a noxious weed program and is manually removing exotic poplars (*Populus nigra*) and St. Johnswort (*Hypericum perforatum*), which are not thought to be spreading anymore. About 50 acres of spotted knapweed (*Centaurea maculosa*) were manually cleared in 1997. Although it is still early to determine the effectiveness, the populations seem to be spreading despite these efforts. This is also the case for spotted knapweed in the Round Island, Big Island and Horseshoe Bay wilderness areas on the Hiawatha National Forest in Michigan, where spotted knapweed has been hand pulled for the last 1-3 years. The Hiawatha National Forest does not have staff available to prepare a noxious weed plan, although it seems like this is justified (Shultz, personal communication).

In northern Wisconsin, at least 44 exotics have been verified in wilderness areas, including the major pests spotted knapweed and Japanese barberry (*Berberis thunbergii*). All five Forest Service wilderness areas in Wisconsin are small, surrounded by roads and have been logged at some point (Sheehan, personal communication). There are no control efforts for exotics, and exotics are not monitored.

Southwest States (Alabama, Arkansas, Kentucky)—No wilderness areas in these states ranked weeds among their top 10 priorities, and exotics are monitored in only one of the nine responding areas. An interesting aspect of the species list from Arkansas is that many of the pest species are native plants that have become invasive. Botanists in this area complained that many agencies are actively planting aggressive exotic species for wildlife forage and erosion control. For example, the Ouachita National Forest and other agencies in Arkansas widely plant lespedeza (*Lespedeza cuneata*) for wildlife forage. Yet the Forest has spent several thousand dollars trying to control this same plant in the last few years (Owen, personal communication) Widely reported problem species were mimosa (*Albizia*

julibrissina), rose (*Rosa multiflora*), privet (*Ligustrum* species), Russian olive (*Elaeagnus* species), kudzu (*Pueraria montana,* also reported under the synonym *P. lobata*; see Ward [1998]) and Japanese honeysuckle *(Lonicera japonica*). The latter three species were originally intentional introductions, which later became invasive. Wilderness areas in Kentucky are adjacent to wildlife management areas, where aggressive exotics are planted as wildlife forage as well (Taylor, personal communication). Although agencies have not prioritized exotic plants as a management concern, several respondents considered exotic plants pose a serious threat to natural areas in this region.

Appalachian Forest (Georgia, Pennsylvania, South Carolina, Virginia, West Virginia)—Hickory Creek Wilderness in Pennsylvania is included in this section for convenience; this is the only Forest Service wilderness area that had any information on exotic plants. The other 16 that responded confirmed that they had no information on exotics in the wilderness areas, but they were not expected to be a problem there. A botanist in West Virginia estimated that 60% of the Monongahela National Forest flora is composed of naturalized exotics, and considerably fewer than that are considered problem "weeds" (Concannon, personal communication). However, they had no information on exotic plant distribution in wilderness areas, since weed surveys are done in conjunction with rare plant surveys and at silvicultural sites, neither of which occur in wilderness.

In contrast, exotics in Shenandoah National Park in Virginia are considered a significant management concern, and are monitored in the wilderness portion. The aggressive weeds garlic mustard (*Alliara petiolata*), kudzu (*Pueraria montana)*, Japanese knotweed (*Polygonum cuspidatum*), Japanese honeysuckle (*Lonicera japonica*) and tree-of-heaven (*Ailanthus altissima*) have all been found in this in wilderness area. Some of these plants are treated or monitored, but the garlic mustard is too widespread for either.

Perhaps Shenandoah has a worse weed problem than other in wilderness areas in the Appalachians, because as a national park it may receive more visitors. Several studies have shown that the number of visitors to a natural area is correlated with the number of exotic plants present (MacDonald 1985, Lesica and others 1993). Although it seems likely that in wilderness areas throughout the Appalachians have similar exotic plants, other agencies have not attempted to document exotic species in their in wilderness areas.

Northeast States (New Jersey, New York, Vermont, New Hampshire, Maine, Massachusetts)—None of the 17 federally designated in wilderness areas in the northeast states responded. One Forest Service biologist in Vermont indicated it would be difficult to respond to the survey without a better definition of "exotic," since a large component of their flora is composed of naturalized species. Fortunately, Adirondack State Park, a large in wilderness area managed by the state of New York, did submit information on their exotic plant concerns. Historically, there has been little attention given to exotic or invasive species in the Park except for the Lake Champlain area and the St. Lawrence Valley, which are outside the in wilderness areas, and have problems with water milfoil (*Myriophyllum spicatum*) and purple loosestrife (*Lythrum salicaria*). The wilderness areas of Adirondack Park fortunately do not currently have many problem exotic plants, and The Nature Conservancy staff is prioritizing prevention for these in areas. While those exotics that are present appear to be restricted to roads and trails, Conservancy staff expect that some problem plants may be establishing in remote areas. They are conducting a survey of exotics this year in order to identify problems and preventative actions needed to maintain the natural plant communities (Brown, personal communication). Their "watch out" list includes crown vetch (*Coronilla varia*), garlic mustard (*Alliaria petiolata*), Eurasian water milfoil, and black locust (*Robinia pseudoacacia*).

Southeast Coastal Marsh, Swamp, Bog, Forests—Seven of 14 responding wilderness areas in this biome monitor exotics, and 29% of respondents ranked exotics as a significant problem. Biologists in this region were aware of and concerned about exotics. Managers knew where their exotic plant problems were and could confirm confidently that there were few weed problems in wilderness areas. Almost all respondents were using combinations of mechanical and herbicide treatments to control weeds in and near wilderness areas. Tom Wilmers at the National Deer Key Refuge reported that they have successfully controlled exotics by detecting problems early, acting quickly and following up on treated sites.

Wilderness areas on the Apalachicola and Ocala National Forests in Florida are checked for exotics and are not known to have any weeds. However, aggressive exotic species are close enough to be considered a serious threat. Japanese honeysuckle (*Lonicera japonicum*), Chinese tallow tree (*Sapium sebiferum*) and privet (*Ligustrum sinense*) were the most widely reported problem species throughout the region.

Mechanisms of Spread in Wilderness Areas

Both natural disturbance and disturbances associated with human activity contribute to the establishment and spread of exotics in wilderness areas. Common human disturbances listed as causal agents included livestock use, trail use, camping and existing roads adjacent to wilderness areas. Not surprisingly, land use history prior to wilderness designation had a large effect on the extent of nonnative plant distribution. Historical and active grazing allotments were often cited as a source of exotic plants (Rutman *in press*, Isle, personal communication). Dudley and Embury (1995) discuss grazing impacts in California wilderness areas in detail.

Natural disturbances, including gopher pockets, floods, storms and fire were also reported to contribute to weed establishment or spread. There is a growing understanding of the role of natural disturbance in shaping natural communities and ecosystems (Sprugel 1991, Cole and Landres 1996). Paradoxically, reintroducing natural disturbances into wilderness ecosystems may facilitate exotic plant invasions.

Many respondents reported fire as an important factor of weed spread, both in areas that are not adapted to fire (for example, desert communities) and in areas that area adapted to fire (Rocky Mountain states) (Anderson, Sanger, Rutman, Fritzke, personal communications). There are documented cases that some exotics will respond positively to a fire, then alter the fire regime to the exotic species' favor, resulting in

a positive feedback loop that maintains the exotic community (D'Antonio and Vitousek 1992). There also appears to be a plethora of anecdotal evidence on the relationship between fire and exotic plant invasion, as far back as an essay by Aldo Leopold (1941). Biologists from the Mojave and Sonoran deserts, Great Basin, and California mentioned that exotic annual grasses cause more frequent fires, which promote exotic grass expansion and suppress native species. Similar feedback loops have been documented for soil nutrients (Vitousek and others 1987) and soil salinity (Brotherson and Winkel 1986, Shafroth and others 1995).

The phenomenon of plant invasions is so complex that it is difficult to identify any single or few factors that are responsible across large scales. Sue Rutman, plant ecologist for the National Park Service, pointed out that many things contribute to the current distribution of exotic species at Organ Pipes National Monument. While areas with grazing impacts are often the most impacted by exotics, other problem areas exist where fires have destroyed native plant communities. Furthermore, species that depend on soil disturbance can colonize rodent mounds or other completely natural disturbances, and some species, include fountain grass (*Pennisetum ciliare*) will move into areas that have no apparent disturbances at all (Rutman, personal communication).

It is important to emphasize that although many invasive species depend on some level of disturbance to establish, the disturbance does not have to be large, and it does not have to be the result of human activity. We should not assume that the lack of recent disturbance precludes invasion by exotic weeds.

Appropriate Management Responses

Prevention and Early Detection

It is generally better to spend time eradicating a newly arrived exotic that might not have become a weed than to wait until a certain problem has developed (Randall 1991, Schwartz and Randall 1995, Hobbs and Humphries 1995, Reichard and Hamilton 1997, Reichard 1997). Early detection and prevention are the best ways to avoid huge sinks of financial and human resources in the long term.

Many survey forms were returned with success stories of early detection and containment. While the cost of controlling invasions may initially be more expensive than doing nothing, the long-term benefits of early action far outweigh the costs.

Education and Training

To minimize further spread of exotics in protected natural areas, awareness of the problem must increase substantially. This will require training agency personnel to recognize exotics early. In addition, increasing the general public's awareness of the problem is an important step (Krummerow 1992, Asher and Harmon 1995, Marion and others 1996, Marcus and others 1998). Several wilderness areas depend on casual observation and reports by nonstaffers for detection of weeds. Asher and Harmon (1995) outlined 5 strategies, including incorporating weed awareness into the "Leave No Trace" mentality. In fact, with funding from state and federal agencies, Forest Service personnel at the Lolo National Forest in Montana have developed a "Leave No Weeds" campaign directed at elementary school students (Kulla, personal communication).

Many survey respondents pointed out that there is little to no funding at this time for weed monitoring or inventories and that data are collected opportunistically while other work is being conducted. The Selway-Bitterroot, Absaroka-Beartooth, Glacier National Park and other wilderness areas provide weed identification training for backcountry rangers and carefully document weed populations in the backcountry. This is a time- and cost-effective strategy for obtaining data on remote locations (Krummerow 1992, Marcus and others 1998).

Prioritization of Exotics

Only 6% of responding wilderness areas reported using some system to rank exotic plants for priority. Of the national parks wilderness areas, almost 30% use a ranking system to prioritize exotics. The National Park Service developed a generalized ranking system for exotic plants in 1993 (Hiebert and Stubbendieck 1993, Hiebert 1997). The system ranks each species in terms of (1) significance of impact, (2) feasibility of control, and (3) urgency of action. These should be considered in combination with the amount of habitat that is susceptible. The purpose of the ranking system is to separate real threats from benign species, so efforts can be directed most effectively.

Communication

Awareness and communication are key in avoiding mistakes of others and detecting problem species early. One of the most important tools of weed management is information exchange. It is important to know which plants are likely to become problematic and what to do about it once they have established. As previously mentioned, the best predictor of whether a plant will become invasive is whether it has invaded in other areas (D'Antonio and others 1994, Reichard 1997). This accounts for a significant portion of a species' ranking in the Park Service system. Communication and access to centralized information can clearly keep managers informed of which species are likely to cause problems.

The database compiled from the results of this survey is accessible over the Internet (www.umt.edu/biology/leopold) for wilderness area managers and other interested parties. The database can be queried by species (to see which wilderness areas reported it), by wilderness area name (to find out what species were reported). Ideally, access to information on what species are problems, which control methods have been used and contact information will help managers identify priorities for control.

Intentional Introduction of Exotics

Researchers have estimated that 99% of all exotic plants in North America were introduced intentionally (Reichard 1997, OTA 1993). Japanese honeysuckle, Russian olive,

purple loosestrife, kudzu and tree-of-heaven are a few examples of plants that were introduced intentionally and are now widespread problems for land managers. Surprisingly, agencies continue to introduce nonnative species for erosion control or wildlife forage. In many cases, exotics known to be aggressive are used. While most mangers are not actively seeding any plants within the wilderness boundaries, exotics can and do spread across political boundaries.

In a 1997 survey of Forest Service Ranger Districts in Montana, Lesica and Miles (1998) found that over 80% of total area revegetated in Forest Service projects completed in 1994-96 used nonnative (or predominately nonnative) species. Some of the plant species used are considered aggressive, including smooth brome (*Bromus inermis*), crested wheatgrass (*Agropyron cristatum*), orchard grass (*Dactylis glomerata*) and yellow sweet clover (*Melilotus officinalis*). Collectively, these species were seeded on 1,529 acres in 1994-96 (Lesica and Miles 1998).

Many exotic plants used for revegetation projects do not appear to be invasive. However it is important to consider that (1) many species seem benign at first and subsequently "explode" after an initial lag phase, and (2) such revegetation projects are a chance to promote native species. Species that we plant now for immediate benefits may become serious problems in the future. Revegetation projects near wilderness areas should especially stay away from nonnative species.

Research Needs

The general lack of information in most wilderness areas suggests that basic surveying and monitoring should be prioritized. Many wilderness areas have successful monitoring and data management programs; perhaps general guidelines could be agreed upon for what kind of information to collect, how often to collect it, and how to store it.

The Nature Conservancy has identified early detection and action as one of the biggest needs in their weed program (Randall 1991). Part of their response is to maintain stewardship abstracts and a regularly updated database on weeds in their preserve system, as well as make information on new invaders available to their preserve managers. Government agencies should follow their example and promote awareness and communication on this issue.

Wilderness areas are high priorities for weed control, and rigorous monitoring should accompany efforts. Monitoring is an overlooked but important part of research that contributes to knowledge of effective management, which must be based on science to be effective. Few of the respondents in this survey were able to determine objectively whether their control efforts were effective, because monitoring is rarely funded. Monitoring is necessary to detect changes from a current state or following a treatment (such as plant removal, herbicide treatment, population response to prescribed burns and so on) and should be designed as rigorously as a controlled experiment (Huenneke 1995, Morrison 1997). This is an area where academic ecologists and those directly involved in management plans can collaborate.

We need to consider how to restore natural disturbance regimes if they increase the chance of surrounding aliens establishing (Cole and Landres 1996). For example, reintroduction of fire to natural areas in the Rocky Mountains, an ecosystem adapted to fire, may have a positive effect on weed spread. Several respondents mentioned concern over this possibility. The Frank Church-River of No Return Wilderness has initiated a long-term study of weed populations in prescribed burn areas, but no other wilderness areas reported such projects.

Finally, we do not understand all of the ecological effects of plant invasions. There are well-documented examples of significant ecological changes resulting from exotic plant invasions (increased soil nitrogen input, decreased fire intervals, altered phosphorus cycling, loss of species diversity and so on) but many more remain. This is an active area of research, with endless possibilities for investigating interactions between plants and an environment in which they did not evolve. Most of the plants that have been introduced cannot be eradicated, and we need to understand the ecological impacts of these species.

Conclusions

This survey indicated that exotic weeds are increasingly invading wilderness areas. Most wilderness area managers are not aware of major weed problems, and therefore it is important to emphasize prevention and early detection. However, 70% of responding wilderness areas do not monitor for exotic plants, and several had no information at all on exotic plant distribution. Thus, to some extent, the real status is still unknown. Even though 15% of wildernesses ranked weeds as a top priority, most management units cited lack of funds and staff to deal with weed issues, and many reported that they could not confidently assess the situation.

Almost all of the information compiled in this survey is anecdotal. This illustrates the need for standardized data collection, or at least for common objectives across agencies for wilderness areas. Increased funding, awareness and training, and regular monitoring and treatment at trailheads would be helpful starting points.

Most importantly, prevention, early detection and rapid response are necessary to deal with this problem, and exotic plants should be a top priority for wilderness management. Exotic plants do not require a large disturbance to spread, and managers should not assume that exotic species are absent from wilderness areas in general. The database and findings of the survey can be used to promote awareness of the issue, help prioritize areas and species for attention, and facilitate communication and discussion of weeds in our wilderness areas.

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