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# Weed Control for the Preservation of Biological Diversity<sup>1</sup>

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**Abstract.** Invasions by non-native plants threaten the preservation of many plant and animal species and communities throughout North America. These pest species compete with and displace native plants and animals and may substantially alter ecosystem functions (e.g., fire occurrence and frequency, nutrient cycling). Awareness of these threats among wildland managers has greatly increased in the last decade. In a recent poll of National Park superintendents, 61% of 246 respondents indicated non-native plant invasions were moderate or major problems at their parks. Likewise, over 60% of Nature Conservancy stewards nationwide polled in 1992 indicated weeds were among their top 10 management problems, listing nearly 200 problem species. Over 12% indicated weeds were their worst problem. Weed control programs are now in place in wildlands across the continent, employing techniques ranging from manual removal, mechanical methods, prescribed fire, judicious use of herbicides, the release of biological control agents, and encouragement of native competitors. The most successful endeavors follow an adaptive management strategy in which plans based on the goals of the preserve are developed, weeds that interfere with those goals are identified and prioritized, and control measures are selected and implemented where appropriate. Emphasis is placed on preventing new weeds from becoming established and on early detection and elimination of incipient infestations. Managers must focus on the vegetation or community desired in place of the weeds and periodically re-evaluate whether their programs are moving them toward this objective. Control of weeds in wildlands poses unusual problems not ordinarily met in other systems which offer challenging research opportunities for weed scientists and ecologists.

**Additional index words:** Biological diversity, conservation biology, exotic species, non-native species.

## INTRODUCTION

Invasions by non-native plants degrade biological communities and threaten the survival of many native species in North America and elsewhere around the world. Such plants, commonly regarded as wildland weeds, alter the ecosystems and communities they infest, using resources that would have been consumed by native species. In some cases they completely alter patterns of resource availability (47, 131). Viewed on a global scale, invasions by non-native plants, animals, fungi, and microbes are believed to be responsible for greater losses of biological diversity than any other factor except habitat loss and direct exploitation of organisms by humans (97). In fact, when biological invasion is considered as a single phenomenon, it is clear it has had greater impacts on the world's biota than more notorious aspects of global environmental change such as

rising CO<sub>2</sub> concentrations, climate change, and decreasing stratospheric ozone levels (132). In addition, unlike habitat loss or pollution, invasive organisms continue to spread on their own and do not degrade with time; once introduced, they can spread from site to site, region to region, without further human assistance.

When viewed at the scale of a national park or nature preserve, it is clear some invaders reduce or eliminate the species and communities that these sites were set aside to protect (93). Non-native species are responsible for most damaging invasions of wildlands, but in certain situations native species invade and alter habitats they did not previously occupy, outcompeting or otherwise excluding other species. For example, native woody plants have invaded many prairie remnants, especially where natural fires have been suppressed or excluded (2). Rare species appear to be particularly vulnerable to the changes wrought by non-native invaders. For example, the California Natural Heritage Database indicates that 30 of the state's 53 Federally listed endangered plant species are threatened by non-native invaders<sup>3</sup>. Even relatively common species

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<sup>2</sup>Weed Spec., The Nature Conservancy, Wildland Weeds Management & Res., Section of Plant Biology, Univ. of California, Davis, CA 95616.

<sup>3</sup>Mark Hoshovsky. 1995. Personal communications, Natural Heritage Division, California Department of Fish and Game, Sacramento, CA 95814.

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Table 1. Articles and stories on the impacts of weed invasions in wildlands that have appeared in the popular press (newspapers, magazines) and radio since 1993.

Source	Title of article or program	Author	Date
Worldwatch	Bio-invasions: the spread of exotic species.	Bright (15)	Jul/Aug. 1995
Newsweek	Diversity disappears in Florida: our native species are being pushed out by foreign invaders.	Schmitz (113)	March 13, 1995
Northwest Parks & Wildlife	Exotic weeds: biological pollutants.	Richter (110)	October 1994
Audubon	Invasion of the aliens.	Williams (139)	Sept./Oct. 1994
Whole Earth Review	Slow-motion explosion: the exponential spread of exotic species.	Schneider (114)	Summer 1994
Sierra	Botanical barbarians.	Devine (27)	Jan./Feb. 1994
Los Angeles Times	Exotics plants, animals imperil U.S. ecosystems	Clary (20)	Dec. 5, 1993
National Public Radio [All Things Considered, segment #4]	Alien species threaten native wildlife.	NPR (85)	Aug. 9, 1993
Hartford Courant	Not all the pests come unwinvited: Species imported to benefit man can be a menace to established life.	Grant (38)	May 30, 1993
Hartford Courant	Stowaway species taking their toll on life, property.	Grant (37)	May 30, 1993
The Atlantic Monthly	The cheagrass problem.	Devine (26)	May 1993

which included warnings that still have not been heeded (95).

Charles Elton's 1958 book, *The Ecology of Invasions by Animals and Plants* (31), finally brought the issue into the mainstream of ecology. Elton clearly described the issue in his first chapter, stating "we are living in a period of the world's history when the mingling of thousands of kinds of organisms from different parts of the world is setting up terrific dislocations in nature. . . . The larger ecological explosions can . . . often be traced to a breakdown in the isolation of the continents and islands built up during the early and middle parts of the Tertiary period." Although most wildland managers recognize the problem, many other people in the larger "environmental community" and among the public at large, are unaware of the damaging impacts of weed invasions. Many hold the view that Nature "knows best" and should be allowed to run its course in a natural area. Most are unaware that even some of the largest parks and preserves have been heavily disturbed by human activities or that some species invade pristine habitats. There is good reason, however, to believe that more and more people are beginning to recognize that weed invasions degrade ecosystems just as pollutants do. Table 1 contains examples of articles and stories on the topic that have appeared in newspapers, magazines, and on the radio since 1993. The Office of Technology Assessment's (93) report on Harmful Non-Indigenous Species also generated a flurry of television and newspaper reports

may be driven to rarity or near-extinction by particularly disruptive invaders, as evidenced by the fate of the American chestnut [*Castanea dentata* (Marsh.) Borkh.] following the introduction of the chestnut blight [*Cryphonectria parasitica* (Murr.) Barr.] (83). Fortunately, plant invasions into wildlands can be halted or slowed and, in certain situations, even badly infested areas can be restored to relatively healthy communities dominated by native species (10). Thus, control of invasive plants has become recognized as a necessary management activity in many wildlands.

Concern about and interest in invasions by non-native plants and other organisms has increased greatly in the last decade and several reviews of the topic have been published reporting devastating impacts on every continent, except Antarctica (22, 28, 29, 42, 53, 68, 78, 81, 93, 99, 119). The problem has been recognized since at least the mid-1800s. Charles Darwin (24) commented on the spectacle of hundreds of square miles of the pampa of Argentina and Chile rendered impenetrable to horse or human by an invasion of the cardoon (*Cynara cardunculus* L.). Likewise, Frederick Law Olmstead (94) filed a report on the need for protection of Yosemite in 1865 noting that unless actions were taken, its vegetation would likely be pushed out by common weeds from Europe as had happened "in large districts of the Atlantic States." In 1898 the USDA's Yearbook of Agriculture included an article on the danger of introducing birds and other animals to North America

on the topic and helped educate federal legislators and policymakers.

Because the terms biological diversity, natural area, wildland, weed, and pest may be poorly understood and/or have slightly different meanings in agricultural settings, I will first define how they will be used in this paper. Following the definitions I will: (a) describe how weed invasions degrade biological communities and displace native species; (b) outline how wildland managers approach weed control, and; (c) present examples of difficult and unusual weed problems wildland managers face in the hope of encouraging more weed scientists and ecologists to develop research programs designed to address these problems.

### DEFINITIONS

Biological diversity, or "biodiversity" may be defined as the variety of life on earth (140). This variety has several components (54, 103): (a) genetic diversity, or variations in genetic structure among individuals of a species or population; (b) species diversity, or the variety of species (and subspecific taxa) in a given area (from local to global); (c) higher taxonomic diversity, or the variety of higher taxonomic levels (e.g., families or orders) in a given area; (d) community diversity, or the variety of identifiable groups of species that occupy and interact in the same habitats; and (e) ecosystem diversity, or the variety of ecological units composed of biological communities interacting with the physical environment.

With rare exceptions, conservation programs are dedicated to the preservation of native species and communities. The addition of non-native species rarely contributes positively to this unless they alter the environment in ways that favor native species as some grazers and biological control agents do.

The term *natural area* refers to lands and waters set aside to protect and preserve undomesticated organisms, biological communities and/or ecosystems. Examples include most national parks, state and federally designated wilderness areas and preserves held by private organizations such as The Nature Conservancy (TNC)<sup>4</sup>, and the National Audubon Society. *Wildlands* include natural areas and other lands managed at least in part to promote game and/or non-game animals or populations of native plants

<sup>4</sup>Abbreviations: BLM, Bureau of Land Management; TNC, The Nature Conservancy.

and other organisms. Examples include federal wildlife refuges, some National and State Forests and portions of Bureau of Land Management (BLM)<sup>4</sup> holdings, including some areas used for grazing.

The terms *pest plant* and *weed* are used interchangeably below to refer to native and non-native species, populations, and individual plants that are unwanted because they interfere with management goals and objectives. Plants regarded as pests in a particular wildland may be valued or viewed with indifference in other situations. For example, the Chinese tallow tree [*Sapium sebiferum* (L.) Roxb.] is a pest in wetlands and bottomland forests in northern Florida and across the Gulf coastal plain to southern Texas (17, 57, 58) but it is not known to escape from cultivation in California where it is used as an ornamental landscape tree. On the other hand, some species that are troublesome in agricultural or urban areas rarely, if ever, become wildland pests. The term *environmental weeds* is used by many Australians (41, 53) to refer to wildland pest plants but few authors in North America use this term.

Most wildland weeds are invasive and non-indigenous. Invasive species are those that can move into an area and become dominant numerically or in terms of cover, resource use, or other ecological impacts (103). Non-indigenous species were defined by the U.S. Congress Office of Technology Assessment (93) as species beyond their natural range or natural zone of potential dispersal including all domesticated and feral species and all hybrids except for naturally occurring crosses between native species. Other terms which are often used as synonyms of non-indigenous include exotic, alien, introduced, non-native, non-aboriginal, and naturalized. Careful consideration of these terms reveals that each carries different connotations (101).

### IMPACTS OF WEED INVASIONS ON WILDLANDS

Plant invasions can have a variety of effects on wildlands. Their impacts include: alteration of ecosystem processes; displacement of native species without otherwise changing the structure of the system; support of non-native animals, fungi, or microbes; and hybridization with native species and subsequent alteration of gene pools. Invasions by native species are not included in the examples below although they too can have extremely detrimental impacts on valued species and communities. Invasions by natives often appear to be triggered by human-induced changes in

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the primary reason the South Florida Water Management District has been a leader in controlling the species. *Melaleuca* also alters fire frequency and intensity, promoting extremely hot burns (34). One study indicated it provides little or no habitat for many native wildlife species including white-tailed deer (*Odocoileus virginianus*) (61). Salt cedars (*Tamarix chinensis* Lour.; *T. ramossissima* Ledeb.; *T. pentandra* Pallas), which invade wetland and riparian areas in the American southwest also are believed responsible for lowering water tables at some sites (50). This may result in significant reductions or elimination of surface water habitats required by native plants and animals (16, 87). Salt cedar infestations also can trap more sediments than stands of native vegetation and thus alter the shape, carrying capacity and flooding cycle of water-courses (12). *Tamarix aphylla* (L.) Karst. has invaded riparian areas in arid central Australia with the same impacts described above (40). Ironically, *T. aphylla* is widely planted in the American southwest but is not generally regarded as invasive there.

Other wetland and riparian invaders and a variety of beach and dune invaders dramatically alter rates of sedimentation and erosion. One example is saltmarsh cordgrass (*Spartina alterniflora* Loisel.), a species native to the U.S. Atlantic and Gulf coasts that was introduced to the Pacific coast where it invades intertidal habitats. Sedimentation rates may increase dramatically in infested areas, while nearby mudflats deprived of sediment erode and become open water areas (112). The net result is a sharp reduction in the area of the open intertidal areas where many migrant and resident waterfowl feed (96).

Coastal dunes along the Pacific coast from central California to British Columbia have been invaded and altered by European beachgrass [*Ammophila arenaria* (L.) Link]. Dunes in infested areas are generally steeper and oriented roughly parallel to the coast rather than nearly perpendicular to it as they are in areas dominated by *Leymus mollis* (Trin.) Hara, *L. pacificus* (Gould) Dewey, and other native species (9). These changes in dune morphology alter the hydrology and microclimate of the swales and other habitats immediately inland, affecting species that occupy these areas. In addition, species richness on foredunes dominated by European beachgrass may be half of that on adjacent *Leymus* spp. dominated dunes (8). Another invader with the capacity to alter shoreline morphology is Australian pine (*Casuarina equisetifolia* L.). This tree infests sandy shorelines along the Atlantic and Gulf coasts

environmental factors such as the suppression of wildfires or the construction of impoundments that prevent seasonal flooding. Thus, where possible, they can be best addressed by restoring or mimicking these factors.

**Ecosystem effects.** The invasive species that cause the greatest damage are those that alter ecosystem processes such as nutrient cycling, the intensity and frequency of fire, hydrological cycles, sediment deposition, and erosion (131, 133, 134, 137). Firetree (*Myrica faya* Ait.) invasion in Hawaii is one of the best studied examples of an invader altering ecosystems processes. This actinorhizal nitrogen fixer sharply increased rates of nitrogen accumulation in young volcanic soils on the island of Hawaii (133). Greater nitrogen availability, in turn, will likely alter patterns of succession and ultimately favor invasion by other non-native plants and animals that thrive in nitrogen rich soil (7, 133).

Downy brome (*Bromus tectorum* L.) is another well-studied, and perhaps more familiar, example of an invader that has altered ecosystem processes. This annual grass invaded millions of acres of rangeland in the Great Basin leading to widespread increases in frequency of fires from once every 60 to 110 yr to once every 3 to 5 yr (69, 137). Native shrubs, which do not recover well from the more frequent fires, have been eliminated or reduced to minor components in many of these areas. Similarly, native vegetation in Hawaii has been severely impacted by alterations in the natural fire regime caused by the rapid spread of non-native grasses, particularly broomsedge (*Andropogon virginicus* L.), molasses grass (*Melinis minutiflora* Beauv.), bush beardgrass (*Schizachyrium condensatum* (Kunth) Nees], and fountain grass [*Pennisetum setaceum* (Forsk.) Chiov.] (23, 116, 125). Fires are believed to have been extremely rare in most Hawaiian vegetation before the arrival of humans. Fire severely retards or kills many native Hawaiian species and individuals that survive often compete poorly with non-native invaders, especially those stimulated by fire.

Several wetland and riparian area invaders alter hydrology and sedimentation rates. The punk tree [*Melaleuca quinquenervia* (Cav.) Blake] invades herbaceous wetlands in south Florida and can convert them into nearly monospecific swamp forests (61, 109). Plant/soil/water relations change as an area is invaded. Soil temperatures are moderated under the deeper shade cast by the forest and water tables may be drawn down if *Melaleuca* uses more water than the herbaceous communities it replaces, as is believed (61). Indeed *Melaleuca*'s reputation as a water-waster is

of southern Florida (56), where it reportedly facilitates erosion which results in steeper, narrower beaches (25).

Some upland habitat invaders also alter erosion rates. Lacey et al. (59) found that runoff and sediment yield under simulated rainfall were 56% and 192% higher on plots in western Montana dominated by spotted knapweed (*Centaurea maculosa* Lam.) than on plots dominated by the native bunchgrasses bluebunch wheatgrass [*Agropyron epicatum* (Pursh.) Scribn.] and/or rough fescue (*Festuca scabrella* Torr. in Hook.). They concluded that spotted knapweed invasion of bunchgrass rangelands in the region is detrimental to the protection of soil and water resources.

**Habitat dominance and displacement of native species.** Grave damage is also caused by invaders that move into and dominate habitats without obviously altering ecosystem properties. They may outcompete native species, suppress native species recruitment and thus alter community structure, degrade or eliminate habitat for native animals, or provide food and cover for undesirable non-native animals (see below). Norway maple (*Acer platanoides* L.) has invaded forested preserves in the northeastern U.S. and is likely to become a canopy dominant in some (135).

Invasive vines are troublesome in forested areas across the continent. The most destructive climb into the canopy and shade out or topple overstory trees. One well known example is kudzu [*Pueraria lobata* (Willd.) Owhi], which forms large monospecific stands in open sites, disturbed areas, and along forest edges in the southeastern U.S. (35, 36). Japanese honeysuckle (*Lonicera japonica* Thunb.) thrives in forest openings and edges from New York to Georgia but it also can invade deeply shaded sites where it spreads slowly until a treefall, blowdown, or other disturbance opens the canopy (33, 121, 122). English ivy (*Hedera helix* L.) is troublesome in forest fragments and disturbed forests at scattered sites in the mid-Atlantic states and the Northwest (120, personal observation). Skunk vine (*Paedaria foetida* L.) infests scattered forests in central Florida and Hawaii<sup>5</sup> (126). German ivy (*Senecio mikanooides* Walp.) infests riparian areas in coastal California (30). Even in situations where vines do not climb into the canopy they may blanket and displace native understory trees, shrubs, and ground layer herbs. For example, Japanese

honeysuckle infestations of the forest floor at two sites in South Carolina threaten to smother and eliminate populations of rare native *Trillium* sp. (102).

Several non-native subcanopy trees and shrubs invade forest understories, particularly in the eastern and midwestern states. Non-native bush honeysuckles [*Lonicera maackii* (Rupr.) Maxim, *L. morrowii* Gray, *L. tatarica* L. and *L. × bella* Zabel] and buckthorns (*Rhamnus cathartica* L. and *R. frangula* L.) notoriously form dense monospecific stands (44, 46, 66, 67, 92, 138). In some areas these species have done such a thorough job of excluding native shrubs, that some native songbirds appear to have become dependent on them for food and nesting sites (55, 136). In fact, Whelan and Dilger (136) advised wildland managers to control shrub infestations in midwestern forests slowly, section by section, to insure nesting sites were available for songbirds until native species re-colonized or were restored on cleared sites. Additional research is needed to determine how bush honeysuckle invasions have impacted populations of resident birds in these forests and on populations of invertebrates that feed on native plants. Barberries (*Berberis thunbergii* DC., *B. vulgaris* L.) and privets (*Ligustrum sinense* Lour. and *L. vulgare* L.) also invade forests in the eastern half of the nation while oneseed-hawthorn (*Crataegus monogyna* Jacq.) and Scotch broom [*Cystisus scoparius* (L.) Link] infest forests and adjacent openings in the northwest (13, 82, 111).

Many herbaceous species colonize and dominate the groundlayer in forests. Garlic mustard [*Alliaria petiolata* (Bieb) Cavara & Grande], a member of the mustard family, invaded and now dominates the forest groundlayer on preserves from New England through the midwest and from southern Ontario to Tennessee (18, 89, 91). Populations of native herbs typically decline slowly following garlic mustard invasion. Nuzzo (90) found that cover of the native ephemeral toothwort [*Cardamine concatenata* (Michx.) Sw.] in an Illinois forest declined from an average of 79% to 31% in infested plots. It is not clear whether such declines are due to competition for resources, from the release of allelopathic compounds by garlic mustard or both. Garlic mustard also may, in the long term, affect species composition of the overstory by suppressing the regeneration of certain tree species. Other herbaceous groundlayer invaders include: periwinkle (*Vinca major* L.) which infests mid-elevation riparian forests in Arizona<sup>6</sup>; *V. minor* L. in midwestern and northeastern forests (5, 117); black swallowwort [*Cynanchum nigrum* (L.) Moench] in mesic forests in central New York state (personal observa-

<sup>5</sup>Gann, G. and D. Gordon. n.d. Element Stewardship Abstract for *Paedaria foetida* (skunk vine) and *P. cruddasiana* (sewer vine): threats and management strategies. Unpublished document on file at The Nature Conservancy, 1815 North Lynn St., Arlington, VA 22209.

<sup>6</sup>Tom Wood. 1994. Personal communication. Preserve Manager, Ramsey Canyon Preserve, Hereford, AZ 85615.

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sweetclover [*Melilotus alba* Medik. and *M. officinalis* (L.) Lam.] are among the worst pests of many midwestern prairie preserves (21) and tall fescue (*Festuca arundinacea* Schreb.) invades and alters prairies in northern Texas, Arkansas and Oklahoma (19). Wetlands are likewise subject to damaging invasions. Purple loosesite (*Lythrum salicaria* L.), with its vibrant purple flowering spikes, is one of the most conspicuous invasive species in North America (71, 120). It was introduced from Europe in the early 1800s and has since invaded wetlands throughout the northern U.S. and southern Canada from the Atlantic to the Pacific. It forms large monotypic stands that displace native species including those that provide food and cover for many waterfowl and other wildlife (123). It also eliminates shallow open-water areas that some waterfowl and other animals require for feeding. Large, spreading infestations threaten many endangered plants and animals, including the butrush (*Scirpus longii* Fern.) in Massachusetts, dwarf spikerush [*Eleocharis parvula* (Roemer & Schultes) Link] in New York and the bog turtle (*Clemmys muhlenbergii*) in the northeastern U.S. (71).

**Hybridization with native species.** Some non-native plants hybridize with natives and could, in time, effectively eliminate native genotypes. Non-native white mulberry (*Morus alba* L.) which is widespread in eastern North America, hybridizes with the native red mulberry (*Morus rubra* L.), a threatened species in Canada (1). Other native plants, like reed canarygrass (*Phalaris arundinacea* L.) may hybridize with non-native commercial cultivars developed from European or Asian populations and widely distributed for forage in North America (6).

**Promotion of non-native animals.** Many non-native plants facilitate invasions by non-native animals and vice versa. *Myrica faya* invasions of volcanic soils in Hawaii promote populations of non-native earthworms which increase rates of nitrogen burial, accentuating the impacts these nitrogen fixing trees have on soil nutrient cycles (7). *Myrica faya* is in turn aided by the non-native bird Japanese white-eye (*Zosterops japonica* Temminck), perhaps the most active of the many native and non-native species that consume its fruits and disperse its seeds to intact forest (133). Litter from the Chinese tallow tree, which invades bottomlands and swamps along the U.S. Gulf and lower Atlantic coasts, also alters rates of nutrient cycling and promotes populations of the non-native isopod *Armadillium vulgare* while it depresses populations of native soil invertebrates (17, 79).

(ton) and; eupatory [*Ageratina adenophora* (Spreng.) King & H. E. Robins] in riparian forests along California's southern and central coast. Impacts of these groundlayer invaders have not been well studied but it is suspected that like garlic mustard, they displace native herbs and disrupt recruitment of trees.

Grassland and prairie wildlands across the nation are subject to severe infestations by non-native species, many of which also are serious crop and rangeland pests. Two of the most damaging invaders are leafy spurge (*Euphorbia esula* L.) and yellow starthistle (*Centaurea solstitialis* L.). Leafy spurge is a perennial that readily establishes on disturbed sites but also can invade areas subject to little or no human disturbance. It is most troublesome on wildlands in the northern Plains and adjacent Rocky Mountains where it displaces native herbs and grasses (11). Wildlands it infests include Teddy Roosevelt National Park in North Dakota (4), TNC's Pine Butte Swamp Preserve along the Rocky Mountain front in Montana<sup>8</sup> and other TNC preserves on the Plains of western Minnesota and the eastern Dakotas<sup>9</sup>. TNC's Altamont Prairie in South Dakota is so badly infested that it is no longer regarded worth managing as native prairie and cannot be sold as cropland. Instead, the site is now being used to test the efficacy of sheep and goats for leafy spurge control and prairie restoration.

Yellow starthistle is an annual that produces large numbers of seeds and grows rapidly as a seedling (98). It is favored by soil disturbance but invades areas that show no sign of being disturbed by humans or livestock for years and has colonized several relatively pristine preserves in California, Oregon, and Idaho (102). Yellow starthistle has expanded its range in California at a roughly exponential rate since the late 1950s, increasing from 1.2 to 7.9 million acres between 1958 and 1991 (70, 124). It is also a severe problem in Oregon, Washington, and Idaho, especially in and around the Hell's Canyon area.

Unlike these two pests, which are regarded as troublesome by land managers of almost every type, some species that are regarded as valuable livestock forage can be severe pests in native grassland and prairie. Yellow and white

<sup>7</sup>Tony Bomkamp. 1994. Personal communication. California Native Plant Soc. & California Exotic Pest Plant Council, Anaheim, CA 92805.

<sup>8</sup>David Carr. 1994. Personal communications. Preserve Manager, Pine Butte Swamp Preserve, Choteau, MT 59422.

<sup>9</sup>David Breyfogle. 1995. Personal communications. Northern Tallgrass Prairie Steward, TNC, South Dakota Field Office, Sioux Falls, SD 57104. Joseph

Satrom. 1994. Personal communication. State Director, TNC, North Dakota Field Office, Bismarck ND 58501. Brian Winter. 1995. Personal communication.

Western Minnesota Preserves Manager; TNC, Western Minnesota Preserves Office, Glyndon, MN.

Table 2. Species most frequently reported as pests of TNC preserves in 1992 Weed Survey, from (102, Randall unpublished data).

Species	Life history	Number of states reporting
<i>Lonicera japonica</i>	Semi-evergreen vine	13
<i>Alliaria petiolata</i>	Forest understory, biennial forb	11
<i>Lythrum salicaria</i>	Wetland emergent (perennial dicot)	11
<i>Melilotus alba</i> & <i>M. officianalis</i>	Biennial forbs	10
<i>Phragmites australis</i> <sup>a</sup>	Wetland emergent (perennial grass)	10
<i>Robinia pseudoacacia</i> L.	Tree, canopy dominant	10
<i>Ailanthus altissima</i> [P. Mill.] Swingle	Tree, canopy dominant	9
<i>Cirsium arvense</i> [L.] Scop.	Rhizomatous perennial forb	8
<i>Tamarix</i> spp.	Riparian tree (canopy dominant)	8
<i>Sorghum halepense</i> [L.] Pers.	Perennial grass	7
<i>Centaurea maculosa</i>	Biennial forb	6
<i>Elaeagnus angustifolius</i> L.	Shrub	6
<i>Microstegium vimineum</i> [Trin.] A. Camus	Annual grass	6

<sup>a</sup>Native species, all others are non-native to the sites they infest.

Non-native feral pigs (*Sus scrofa*) in Hawaii destroy native plants and promote non-native invaders in a variety of ways (118). While rooting to unearth tubers and grubs, feral pigs kill and damage native species not adapted to vertebrate herbivores and disturb the soil, creating excellent seed beds for ruderal species. The pigs, in turn, benefit from the spread of fruit producing invasive plants, particularly guava (*Psidium guajava* L.), strawberry guava (*P. cattleianum* Sabine) and lillikoi [*Passiflora mollissima* (Kunth) Bailey]. They return the favor by avidly consuming the fruits and dispersing the seeds in their scat. Hollows created by pig rooting harbor introduced mosquitos that carry bird malaria, an introduced pathogen to which many native birds succumb because they lack resistance (130).

**THE EXTENT OF WILDLAND WEED PROBLEMS IN THE U.S.**

When U.S. National Park superintendents were surveyed about conditions in their Parks, 61% of the 246 respondents indicated that non-native plants were a moderate or major problem (63). Parks with severe plant invasions problems include Everglades, Great Smoky Mountains, Zion, Channel Islands, Hawaii Volcanoes, and Haleakala (3, 43, 60, 62, 63, 64, 65, 126).

Similarly, when TNC stewards from around the nation were surveyed in 1992, 59% ranked pest plants among their

top-ten conservation concerns, including 13% who considered it the greatest challenge they face (102). Stewards from 46 states reported pest plant problems, but those from California, Florida, and Hawaii reported the greatest numbers of pests. A total of 197 non-native pest species was reported. Several of these species are native to North America but were reported as pests beyond their original ranges [e.g., *Robinia pseudoacacia* L., *Hemizonia pungens* (Hook. & Arn.) Torr. & Gray]. The status of one species [*Phyla nodiflora* (L.) Greene] is unclear. Several native species were also listed as pests. The most common report of this type involved *Phragmites australis* (Cav.) Trin. ex Steud. which is native to the northeastern U.S. and adjacent Canada, where it is regarded as severe problem in many wetlands, and to western North America where it is rarely regarded as a pest (14, 72, 88). Pests reported in the 1992 survey included ferns, gymnosperms, and flowering plants ranging from annual, biennial, and perennial herbs, floating, emergent, and submersed aquatics, vines, shrubs, understory trees, and canopy dominants (102). The species reported most frequently in the survey are listed in Table 2. Another 14 non-native pest species were reported from TNC preserves informally or in earlier surveys.

The continuing spread of weeds on BLM acreage constitutes what a research coordinator for the agency, Jerry Asher, has termed an "explosion in slow motion."<sup>10</sup> The area of BLM lands infested with weeds increased from an estimated 2.5 million acres in 1985 to roughly 6 million acres in 1991 and an estimated 8.5 million acres in 1994 (127, 128, 129). These estimates are considered conservative because careful inventories have not been carried out

<sup>10</sup>Jerry E. Asher. 1995. Personal communication. Research Coordinator, Bureau of Land Management, Oregon/Washington State Office, Portland, OR 97208.

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plant the fact that it is nonnative?). It facilitates assessment of the success or failure of management actions. It provides continuity of goals and actions when site managers change. It facilitates thoughtful reconsideration and revision of the plan as knowledge is gained, or as conditions or values change (115).

Establishing management goals for a wildland requires agreeing upon and clearly explaining what organisms, communities, and conditions the area has been set aside to protect. Goals might include protecting or enhancing a certain species or community, preserving a vignette of pre-Columbian America, or allowing ecosystem attributes like seasonal flooding or periodic wildfires to go on undisturbed. Once goals are established it is often easy to identify species that prevent their attainment or threaten to do so. It is also important to distinguish other non-natives that only temporarily colonize roadsides and other disturbed sites or which are otherwise innocuous. In other cases, impacts of a species may not be clear and careful monitoring of its numbers or areal coverage and of its impacts on other species may be required to determine whether it should be controlled.

Commonly, there are many non-native species established on a wildland but only enough resources to attempt control of a few of them and it is important that the most detrimental be identified so that control priorities can be set. This can be extremely difficult because many factors need to be considered, but it must be done to minimize total, long-term workloads (48). I have found that it helps to group those factors into the following four categories: (a) current extent of the pest species on or near the preserve; (b) current and potential impacts of the pest species; (c) value of the habitats/areas that the pest species infests or may infest; and (d) difficulty of control. These categories may be thought of as four "filters" which can be used in sequence. The categories may be used in any order, but I emphasize the importance of the first, current extent of the pest species, because, in the long run, it is usually most efficient to devote resources to preventing new problems and immediately addressing incipient infestations (80, 141). On some preserves, one or more of these categories will be of little importance and may be ignored. All available control options and combinations thereof need to be considered because each course of action, including inaction, carries some risk. If no action is taken the pest may continue to spread and to reduce or eliminate valued native species, at worst drastically altering the community and ecosystem functions. Herbicides may di-

in many regions, but taken at face value they indicate a 14% annual increase in area infested. If weeds continue to spread at this rate, it is predicted that 19 million acres of BLM land will be infested by the year 2000 (129).

### CONTROL OF WILDLAND WEEDS

**Philosophy and strategy of weed management to promote biological diversity.** Wildland managers promote certain sets of species just as farmers, ranchers, and foresters do. Wildland managers, however, differ in that they usually focus on promoting or protecting large numbers of species, perhaps all those native to a site. Although specific objectives may differ, land managers of all kinds use many of the same tools and methods to control weeds. Fire, for example, may be used by a farmer to clear fields for planting, by a rancher to eliminate litter and stimulate forage growth, by a forester to eliminate shrubs that compete with timber species, and by a wildland manager to eliminate woody species invading a prairie. The need for wildland managers to minimize negative impacts to a wide range of non-target species, however, often requires them to use labor-intensive, highly target-specific control methods. Detailed examples of varied pest control approaches used in wildlands are provided in several recent volumes (78, 86, 119).

Many wildland managers have adopted an "adaptive management" strategy for weed control as follows: (a) establish and articulate management goals and objectives for the wildland; (b) identify any plant species that threaten or have the potential to threaten the management objectives ("weeds") and assign priority based on the severity of their impacts; (c) consider control methods available and, if necessary, re-order priorities based on likely impacts of control actions on the weed(s) and non-target species; (d) develop and implement a management plan designed to move conditions toward the goals and objectives; (e) monitor and assess impacts of the management actions in terms of their effectiveness in approaching the goals and objectives; and (f) use this information to modify and improve control priorities, methods and plans beginning the cycle again (115). This type of approach has many virtues, especially when accompanied by a written plan. It focuses on the species and communities desired, rather than on simply eliminating the weeds, thereby placing weed control in the context of a restoration program for the area. It exposes assumptions (e.g., is the only reason given for controlling a certain

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rectly kill valued non-target plants and/or indirectly impact native animals by reducing food supplies, eliminating cover, or otherwise altering the environment. Mechanical methods often disturb the soil and destroy vegetation allowing ruderal plants and "weedy" pioneer animal species to gain a foothold. Use of biological control and other biologically-based methods carries the risk that control agents will attack or otherwise negatively impact non-target species. In addition, once established, biological control agents cannot be recalled and may undergo genetic or behavioral changes that allow them to feed on new hosts<sup>11</sup>. In wildland settings it is also crucial to consider the setting: is the weed in an old field or a pristine natural area with highly valued species and communities. No matter what method is selected, it should be clear that the risks of using it are outweighed by the potential benefits of controlling the weed.

There is the risk that when one pest is eliminated another will take its place, i.e., the infestation is merely the symptom of a more fundamental problem. For example, in Douglas County, Oregon, St. Johnswort (*Hypericum perforatum* L.) populations were sharply reduced by biocontrol agents only to be replaced by tansy ragwort (*Senecio jacobaea* L.) which was in turn sharply reduced by biocontrol agents only to be replaced by Italian thistle (*Carduus pycnocephalus* L.)<sup>12</sup>. Eric Coombs, an entomologist with the Oregon Dep. of Agriculture, believes that while biological control may eventually reduce Italian thistle, there is a good chance the thistle will be replaced by another pest and then another in an endless series, unless cultural practices in the area are changed<sup>12</sup>.

No matter what control methods are chosen, wildland managers are encouraged to monitor their impacts objectively. Monitoring may be intensive, involving a fully replicated experimental design, or consist of as little as

photo-monitoring from designated points on pre-determined dates. The important factor is that analysis of the information will help the manager to determine whether the objectives established for the control program are being met and whether any modifications are necessary.

**Established wildland weed control programs and their costs.** Weed control, like other wildland management activities, is generally underfunded, but it nonetheless consumes a substantial portion of the resources available to many managers. Over 2.8 million ha of land managed by the National Park Service are infested with invasive weeds<sup>13</sup>. Some 448 control projects encompassing roughly 0.6 million ha of the infested lands are deemed necessary<sup>14</sup>. Completion of this work would require a total of \$79 million over the next 4 yr, but under current projections, only \$6.5 million will be available during that period. In fact, during fiscal year 1995 the National Park Service spent only \$1.8 million on invasive weed control nationwide<sup>15</sup>.

Much of the funding for weed control goes to a few parks with especially severe problems including Everglades, Great Smoky Mountains, Channel Islands, Hawaii Volcanoes, and Haleakala. For example, the National Park Service has treated 4.3 million stems of *Melaleuca quinquenervia* on 31,000 ha in South Florida at a total cost of \$2.4 million since 1988. Seventy-five percent of this money came from a wetland development mitigation fund established by the state of Florida and currently all funding for the program is from this source. Other parks have sharply increased spending on weed control in recent years as the severity of the problem has become more widely recognized. Funding rose from approximately \$20,000 in FY 1992 to \$93,000 in FY 1994 in Yellowstone where control efforts focus on 24 of the 164 non-native species present<sup>16</sup>. Weed control in Yellowstone also benefited from support by volunteer crews and increased emphasis on early detection and treatment in recent years.

The BLM budgeted approximately \$1.1 million for weed control on its lands in FY 95<sup>17</sup>. Funding for weed control has remained fairly constant for the past decade, ranging from roughly \$0.9 million to \$1.1 million annually, despite the alarming increase in infested area discussed previously.

Weed control programs also are established on privately managed wildlands. In a 1992 survey, TNC stewards from around the U.S. reported that they control weeds by pulling, cutting, using a host of mechanical means including chainsaws and backhoes, by flooding impounded areas,

<sup>11</sup>Peter McEvoy. 1994. Personal communications. Professor, Department of Entomology, Oregon State University, Corvallis, OR 97331.

<sup>12</sup>Eric Coombs. 1994. Personal communications. Entomologist, Oregon Department of Agriculture, Salem, OR 97310.

<sup>13</sup>Gary H. Johnston. 1995. Personal communications. Chief, Natural Resources Programs Branch, National Park Service, P.O. Box 32127, Washington, DC., data from National Park Service Resource Management Plan database.

<sup>14</sup>Gary H. Johnston. 1995. Personal communications. Chief, Natural Resources Programs Branch, National Park Service, P.O. Box 32127, Washington, DC., data from National Park Service RMAP database.

<sup>15</sup>Terry Cacek. 1995. Personal communication. Natural Resources Staff, National Park Service, Fort Collins, CO 80525.

<sup>16</sup>Greg McClure. 1995. Personal communication. Box 86, Yellowstone National Park, WY 82190.

<sup>17</sup>Buck Waters. 1995. Personal communications. Bureau of Land Management, Washington, DC.

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widely available following World War II, Yosemite workers began spraying thistles, *Ribes* spp., mullein (*Verbascum thapsus* L.) and *St. Johnswort* with 2,4-D [(2,4-dichlorophenoxy)acetic acid] and 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid] pumped from a fire truck. Spraying of *St. Johnswort* ended and a biocontrol program began in 1950 when 12,500 *St. Johnswort* beetles (*Chrysolina quadrigemina* Suffr.) were released. Additional releases were made in 1951 and populations of *St. Johnswort* and the beetles were monitored. *Ribes* control continued through 1967 but other herbicide use was discontinued by 1957, apparently due to a lack of funds (100).

A limited hand-spraying program was revived for one season in 1968, but since that time environmental concerns prevented the use of herbicides in Yosemite. After *Ribes* control was halted, it was determined that white pine blister rust was less virulent than originally thought (84). After a long hiatus in weed control efforts, a well-organized program to control bull thistle by pulling and cutting was re-instituted in 1991 and continues today<sup>18</sup>. Prescribed fires were also set in many meadows in order to kill native ponderosa pine (*Pinus ponderosa* P. & C. Lawson) and incense cedar [*Calocedrus decurrens* (Torr.) Florin] seedlings that colonized and would otherwise convert the meadows to forests as they grow (32, 45, 100).

### DIFFICULT AND UNUSUAL CHALLENGES OF WILDLAND WEED CONTROL

Some of the problems caused by weeds in natural areas are qualitatively different from those in other settings. When weeds are controlled or eliminated from a natural area, do desirable species return? Does the original community rebound or are some species missing? Examples of the type of studies needed include those done for the *St. Johnswort* and tansy ragwort biological control programs (49, 51, 73, 74, 75, 76, 77) and research on plant community diversity following herbicidal control of spotted knapweed (107).

In certain areas it is apparent that invasive, non-native plants have become an important, and in extreme cases, an essential food source for native birds and mammals (136). When this occurs should the invasive species be left in place? What supported these animals before the non-natives invaded? Is there a way to restore native species that would be adequate food sources and can this be done in a way that maintains food supplies while restoration is underway? It is clear that some weeds in the Hawaiian Islands

judiciously using prescribed fire, herbicides and grazing animals including sheep, goats, and cattle, and by releasing biocontrol agents and encouraging native competitors (102). Among programs that used herbicides, glyphosate [N-(phosphonomethyl)glycine] and triclopyr [(3,5,6-trichloro-2-pyridinyloxy)acetic acid] were most commonly utilized, although picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) and clopyralid (3,6-dichloro-2-pyridinecarboxylic acid) were used on a limited basis. Although TNC stewards use herbicides, rates of use are relatively low. I conducted an informal survey on annual use of glyphosate among TNC stewards around the nation in 1993 and their replies indicated they purchased and used less than 950 L altogether.

A total of 21,412 h time was devoted to weed control by 63 weed survey respondents, their co-workers) and volunteers in 1991 (102). Funds totaling \$171,128 were spent for weed control by 50 survey respondents. In 1990 the totals were 16,082 h and \$109,560. The increases from 1990 to 1991 are magnified by the fact that some respondents moved into their jobs after 1990 or could not remember how they spent their time and money in 1990. It is clear, however, that TNC stewards are spending increasing amounts of time and money to control weeds. This results from the expansion of management programs, new invasions, the expansion of old infestations, and increased awareness of threats posed by weeds.

**An example of weed control in a natural area—Yosemite National Park.** A history of weed control in Yosemite is presented below to offer an example of the concerns wildland managers face and the variety of techniques they may use. This example also makes it clear that some wildland managers recognized the threats weeds invasions pose to desirable native vegetation decades ago.

The earliest records of pest control in Yosemite date to the 1930s when Civilian Conservation Corps workers pulled tens of thousands of non-native bull thistles [*Cirsium vulgare* (Savi) Ten.] and (probably native) cockleburts (*Xanthium strumarium* L.) from meadows (100). Workers also pulled hundreds of thousands of native gooseberry and currant bushes (*Ribes* spp.) to control the introduced fungal pathogen *Cronartium ribicola* Fisch. (39). The pathogen uses *Ribes* spp. for part of its life cycle, and is also responsible for white pine blister rust which kills and damages native pines. Shortly after organic herbicides became

<sup>18</sup>Elizabeth Waldow, 1995. Personal communication. Resources Management, Yosemite National Park, CA 95389.

benefit from their interactions with feral pigs (131). How widespread is the phenomenon of invasive animals facilitating the establishment and spread of invasive plants and vice versa? One example, overlooked until recently, is that some non-native plants may benefit because they are more likely to be pollinated by introduced honeybees than are the native species with which they compete<sup>19</sup>.

Some pest species are favored by natural disturbances such as hurricanes, floods, and landslides, as well as by human caused disturbances. In many cases it has been suggested that these invaders alter the course of succession. If so, can anything be done to insure that native communities have a chance to recover?

Several recent studies offered generalizations about characteristics that distinguish invasive plant species from those that do not spread on their own when introduced to a new area (52, 104, 105, 106, 108). Much of this work stems from a renewed interest in predicting which species will become invasive so policies can be devised to exclude them. Can we, in fact, develop predictive schemes that will allow us to prevent the entry of at least some invasive species? Should such a program be coupled with efforts to improve our capability to detect and eliminate newly establishing species?

Such questions offer exciting possibilities for research as do the more straightforward needs for improved control methods for many species that invade wildlands. It is my hope that more weed scientists and ecologists will be drawn to study wildland weeds and contribute their skills and knowledge to this important work.

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