AN OVERVIEW OF PROBLEMS WITH INTRODUCED PLANT SPECIES IN NATIONAL PARKS AND BIOSPHERE RESERVES OF THE UNITED STATES

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ABSTRACT

Although floristic lists for a large sample of U.S. reserves have 5-25% introduced species, most introductions are confined to drastically disturbed areas and pose little or no threat to native ecosystems. A survey of Biosphere Reserves of the United States suggests that many reserves have only very minor problems or no problems at all with introduced plant species. Problems with invasive introduced species are most severe on oceanic islands, but serious problems occur in some continental areas as well. In some U.S. parks and reserves, the primary concern for introduced plant species is that they pose economic threats to adjacent agricultural lands. In extreme situations, however, introduced plants may inhibit and entirely prevent reproduction of native plant species, degrade habitat for native animal species, and/or alter otherwise natural habitats through changing nutrient, fire, or water regimes. At the highly disruptive end of the spectrum, native ecosystems may become so totally transformed by invaders that they are scarcely recognizable, although this condition is rare within U.S. parks and reserves.

INTRODUCTION

U.S. national parks are multipurpose areas, mandated to "provide for the benefit and enjoyment of the people." A major objective involves preservation of ecosystems in as natural a state as possible (Ise 1961; Houston 1971). Many parks qualify as Biosphere Reserves, but the reserve system also contains units subjected to consumptive use by humans. Nonnative species are clearly undesirable in areas set aside for preservation of native ecosystems. National Park Service management policies address the issue directly and pragmatically (National Park Service 1988):

> Manipulation of population numbers of exotic plant and animal species, up to and including eradication, will be undertaken wherever such species threaten park resources or public health and when control is prudent and

> feasible. High priority will be given to the management of exotic species that have a substantial impact on park resources and that can be reasonably expected to be successfully controlled; lower priority will be given to exotic species that have almost no impact on park resources or that probably cannot be successfully controlled.

Floristic lists for a representative sampling of U.S. national parks (Table 1) include a large number of nonnative species, *ca* 5-25% of the total number of vascular plants listed. The majority of these nonnative species are "weeds" in the sense of Baker (1974), who stated that a plant is a weed "if, in any geographical area, its populations grow entirely or predominantly in situations markedly disturbed by man (without, of course, being deliberately cultivated plants)." National parks invariably have some habitats heavily disturbed by humans, such as roadsides, trailsides, campgrounds, garbage dumps, employee housing areas, visitor accommodations, historical sites, and water catchment areas. In some parks, domestic livestock grazing or other "traditional uses" continue, usually on a phaseout basis. The resulting disturbed habitats are usually colonized by weeds, most of which are nonnative. The majority of introduced species are present because of continuing human disturbance or because they persist from disturbance in the recent past. Weeds have high reproductive rates, excellent dispersing and colonizing abilities, wide environmental tolerances, and "general purpose genotypes" (Baker 1965); they thrive in disturbed sites.

By Baker's definition, weeds would be assumed to be replaced by native species when factors of human disturbance are removed. Native plants are, in theory at least, better adapted through the fine-tuning of evolution to local environmental conditions and will thrive if left alone. Nevertheless, significant numbers of nonnative species in parks and other natural areas of Hawai'i and elsewhere fit Baker's characterization of "weed" in most respects, except that they do not disappear when disturbance factors are removed. (An example is Hilo grass (*Paspalum conjugatum*) within an exclosure (Anderson *et al.*, this volume).) Many introduced species also continue to spread due to natural disturbance factors, *e.g., Melaleuca quinquenervia* (LaRosa, this volume), and some may even invade undisturbed systems. In this paper, comparative information on alien plant problems in U.S. national parks and reserves is provided, with the hope of shedding light on Hawai'i's problems.

WHY ARE INTRODUCED PLANT SPECIES CONSIDERED "PROBLEMS" IN PARKS AND RESERVES?

Effects of introduced species in parks and reserves range along a gradient from negligible to highly disruptive. Even in Hawai'i, perhaps 90% of the alien species on floristic lists for a given reserve are of very little consequence. Although out of place and thus an aesthetic intrusion in an area devoted to preservation of native biota, such species seem to have little more negative effect than occupying ground that might have been available to native species. The threshold of concern is probably crossed

Table 1. Total number of vascular plant species and number and % of introduced species for selected areas managed by the National Park Service.[1]

Area	No. vascular plant species	No. introduced or (No. undetermined) vascular species	% introduced or introduced and undetermined species
Denali	615	27(14)	4-7
Glacier	1258	112(17)	9-10
Yellowstone	1101	120(12)	11-12
Rocky Mountain	967	67(15)	7-8
Sequoia-Kings Canyon	1331	82(38)	6-9
Pinnacles	410	51(9)	12-15
Redwood*	630	136(11)	22-23
Olympic	1344	260(22)	19-21
Mount Ranier	789	95(18)	12-14
Crater Lake*	588	20(9)	3-5
Death Valley	1049	84(20)	8-10
Grand Canyon	1473	118(21)	8-9
Organ Pipe Cactus*	517	32(9)	6-8
Big Bend	997	49(11)	5-6
Acadia	1042	222(55)	21-27
Isle Royale	689	95(18)	14-16
Indiana Dunes	1209	172(47)	14-18
Shenandoah	1138	221(55)	19-24
Great Smoky Mountains	1485	249(61)	17-21
Congaree Swamp*	327	23(7)	7-9
Big Thicket	1204	120(18)	10-11
Everglades	876	133(42)	15-20
Channel Islands*	383	62(10)	16-19
Haleakala	ca. 684	334	49
Hawaii Volcanoes	ca. 915	602	66

[1]Species lists and evaluation of introduced species (except for Hawaii Volcanoes and Haleakala) provided from current databases by Dr. Gary Waggoner, U.S. National Park Service, Denver, Colorado. Data for Hawaii Volcanoes based on Higashino *et al.* (1988). Data for Haleakala based on an unpublished species list by A.C. Medeiros and L.L. Loope. Parks marked with an asterisk (*) are those for which numbers are judged to be unusually low due to inadequate collections. A certain number of species for most parks fall in the category "undetermined," a status characterizing many widespread species of unknown original distribution (Baker 1972).

when the introduced species results in significant decline in populations of one or more native species, significantly alters ecosystem processes, causes aesthetic damage perceived to be unacceptable, or poses perceived threats to agriculture on adjacent lands. Effects of introduced plant species on native species and on ecosystem processes are not well understood and are poorly documented.

Inhibition of Prevention of Reproduction and/or Survival of Native Plant Species

I am unable to cite a single instance where an introduced plant species is believed to have contributed significantly to the extinction of a native species outside Hawai'i. However, Loope and Dunevitz (1981) considered shading effects of Brazilian peppertree, also known as Christmas berry (*Schinus terebinthifolius*), to threaten rare endemic herbaceous understory species of limestone rockland pine forests of the Miami rock ridge in southeastern Florida.

Smith (1985) has discussed the tendency of certain introduced plants in Hawai'i to form monotypic stands -- catastrophically reducing species diversity and threatening rare species (*e.g., Cyanea superba* on O'ahu). On East Maui, there can be little doubt that the alien kikuyu grass (*Pennisetum clandestinum*), velvet grass (*Holcus lanatus*), and Hilo grass have contributed to the decline or extirpation of many endemic plant species. For example, the greensword *Argyroxiphium virescens*, drastically reduced in distribution and numbers by foraging of domestic cattle, did not survive after 1959 in Haleakala National Park in spite of protection from cattle. A dense growth of velvet grass was probably a decisive factor in its demise. Loope, Nagata, and Medeiros (this volume) have addressed some of the specific effects of introduced plant species at Haleakala.

Degradation of Habitat for Native Animal Species

Tamarisk (*Tamarix* spp.), through lowering water tables and drying up water sources (Vitousek, this volume), degrades habitat for desert bighorn sheep (*Ovis canadensis nelsoni*) and various fishes. Scarcity of water sources is a major factor contributing to the decline of bighorn in Death Valley National Monument (National Park Service 1981). In Hawai'i, red mangroves (*Rhizophora mangle*) destroy habitat for endangered Hawaiian stilts (*Himantopus mexicanus knudseni*) in wetland areas (F. Kuailani, pers. comm.).

Alteration of Ecosystem Properties

Vitousek (this volume) has cited examples of introduced plant species that have lowered water tables, hastened aquatic succession, intensified fire regimes, and altered local biogeochemical cycles. Other examples of plants that modify ecosystems will be mentioned in subsequent sections of this paper.

Aesthetic Damage

Control of some introduced weeds in national parks and reserves is done primarily for aesthetic reasons. Thistles seem to fall in this category, although in some instances (especially in the case of the Canada thistle, *Cirsium arvense*) they form dense enough stands to crowd out native species. Thistles are probably controlled in parks more often than any other group of plants. For example, Pestana (1985) recorded the presence of thistles (Canada thistle, bull thistle (*Cirsium vulgare*), and/or musk thistle, *Carduus nutans*) in 15 National Park Service areas in the Midwest Region. Seven of the areas had thistle control programs.

Degradation of Agricultural Value of Adjacent Rangeland

Concern over introduced plant species is, in some cases, greater outside parks and reserves than within them. Park managers often receive requests from agricultural interests to eradicate certain "pest" species within park boundaries so that the park will not serve as a refuge from which the "pest" can invade or reinvade rangeland. "Weeds" on rangelands "interfere with grazing, lower the yield and quality of forage, increase costs of managing and producing livestock, slow livestock [weight] gains, and reduce quality of meat, milk, wool, and hides" (Klingman and Ashton 1982). Some weeds are poisonous to livestock. Many of these "pests" or "weeds" are introduced plants; many others are native. For example, two native species of tall larkspur (*Delphinium barbeyi* and *D. occidentale*), which are common in aspen (*Populus tremuloides*) and open subalpine habitats of the Intermountain West, are responsible for more cattle poisoning than any other range plant in that area (Williams and Cronin 1966). Locoweeds (*Astragalus* spp.), dozens of species of which are native to western U.S., are also notorious for their toxicity to livestock. Several "noxious" introduced species have been reduced in parks and reserves as well as on rangelands through biological control, invariably as a result of agricultural concerns (*e.g.*, Klamath weed (*Hypericum perforatum*), tansy ragwort (*Senecio jacobea*), spotted knapweed (*Centaurea maculosa*)). Mechanical and chemical control of introduced weeds has been conducted in many parks in response to external pressures.

A BIOGEOGRAPHIC OVERVIEW

An evaluation of the nature and severity of effects of introduced plants is attempted on a biogeographic basis in this section. Where generalizations are made below without citation of references, the Appendix is the source of supporting documentation.

Arctic and alpine vegetation is rarely invaded by introduced plant species, even if severely disturbed. Studies of revegetation of sites disturbed by oil and gas development in Alaskan Arctic tundra indicate that only native graminoids establish without fertilization. Attempts to seed such areas with introduced grasses have failed repeatedly (van Cleve 1977; Chapin and Chapin 1980). Willard and Marr (1971), working in the alpine tundra of Rocky Mountain National Park, found no tendency of introduced plant species to invade areas heavily trampled by visitors. Reinvasion of vegetation on the bare areas was slow but consisted entirely of native species. Likewise, Greller (1974) found no invasion of introduced plants on roadcuts in the alpine tundra of the same park.

Boreal and subalpine coniferous forests of North America experience little invasion by introduced plant species. More temperate coniferous forest ecosystems harbor numerous introduced species when disturbed (*e.g.*, high percentages of aliens in floras of Olympic and Acadia National Parks), but such aliens are seldom far from heavy disturbance. Tansy ragwort, spotted knapweed, white field daisy (*Chrysanthemum leucanthemum*), dandelion (*Taraxacum officinale*), smooth brome (*Bromus inermis*), and timothy (*Phleum pratense*) are the most

serious invaders in northern Rocky Mountain and Pacific coniferous forests, but even these are generally associated with disturbed sites.

The native perennial grassland of California's Central Valley has been so altered by grazing, fire, and cultivation that its former nature is only sketchily known (details given by Heady 1977). Introduced species of Mediterranean origin (Jackson 1985) dominate it more than they do in any other potential natural vegetation type in the continental U.S. (A few relict areas with native valley grassland species remain (Heady 1977), with none in national park areas. Only in much of Hawai'i have the native plants and animals been obliterated to this extent.)

California coastal reserves (*e.g.*, Point Reyes National Seashore and Channel Islands National Park) appear to have more problems with invading plant species than other U.S. coastal areas. Invaders include sea-rocket (*Cakile edentula, C. maritima*), ice plant (*Mesembryanthemum chilense, M. edule*), and a number of annual grasses and forbs (Barbour and Johnson 1977). European beach grass (*Ammophila arenaria*) has been widely planted and is highly invasive today north of San Francisco. It substantially modifies dune topography, may harbor nitrogen-fixing bacteria, and forms a dense cover that appears to exclude many native taxa (Barbour and Johnson 1977). California chaparral and "coastal scrub" are largely free of shrub invaders (data in Hanes 1977 and Mooney 1977) but have an important introduced component (primarily annuals) in the understory (*e.g.*, Pinnacles National Monument; parts of Point Reyes National Seashore; and Sequoia and Kings Canyon National Parks).

Terrestrial ecosystems of the Channel Islands have been severely degraded by grazing animals and invasion of introduced plants. Philbrick and Haller (1977) commented: "In spite of grazing pressures, the four larger islands still contain fairly significant areas of at least depauperate native grasslands. Small areas of San Miguel and Anacapa also support native grasslands." There appear to be fairly good opportunities for eventual partial restoration of Channel Island ecosystems in the national park if grazing animals can be eliminated. Halvorson (this volume) treats the Channel Island situation in detail.

Cheatgrass (*Bromus tectorum*), Russian thistle (*Salsola kali*), bumble-mustard (*Sisymbrium altissimum*), and other annuals have changed succession throughout the Great Basin sagebrush desert wherever it has been degraded by severe overgrazing (Mack 1986). These annuals form such dense stands in wet years that they close the communities to recruitment by seedlings of native perennial grasses (Young *et al.* 1977). Halogeton (*Halogeton glomeratus*) is another introduced annual poisonous to livestock, which persists on overgrazed or otherwise disturbed lands in the Great Basin and Colorado Plateau. The importance of annual grasses and other weedy introduced species declines southward in these vegetation types. Humphrey and Mehrhoff (1958) reviewed data on marked historical vegetation changes involving shrub invasion in southern Arizona grasslands. All invading species mentioned were natives. Recent comprehensive vegetation surveys of the Grand Canyon (Warren *et al.* 1982) and the Santa

Catalina Mountains (Niering and Lowe 1984) in Arizona make scarce mention of introduced species.

By far the most serious introduced plant problem in the southwestern desert areas is tamarisk. Tamarisk, native to Eurasia, was introduced to the western U.S. in the late 1800s, arrived in southern Utah in 1925-1960 and in Death Valley in the late 1940s and 1950s (determined from historical, photographic and tree-ring evidence). It has spread and thrives along watercourses throughout the southwestern U.S. (Christensen 1962; Harris 1966; Robinson 1969; National Park Service 1981). The abundant seeds of this drought-resistant phreatophyte are mainly water-dispersed (also wind-dispersed), and spread is particularly rapid following infrequent flooding events. It grows rapidly (up to 12 in. or 30 cm/week) and attains heights of 10 ft (3 m) or more. Tamarisk is still spreading in Death Valley, where it is a potential invader of all streams, ponds, marshes and wet ground below 5,230 ft (1,585 m). It lowers the water table through evapotranspiration and displaces native species of plants and animals (including fish). It threatens many biologically important areas that have not yet been affected. About 198 a (80 ha) in Death Valley National Monument (National Park Service 1981) and 74 of 180 springs in Big Bend National Park are affected. Control is feasible but expensive, using mechanical cutting at ground level with chainsaws, brush-cutters, and other powered equipment, followed by application of herbicide (Tordon, a mix of picloram and 2,4-D) to the stump. Tamarisk occurs in dozens of areas managed by the National Park Service in the Southwest, including Zion, Canyonlands, Arches, Capitol Reef, and Grand Canyon National Parks.

Very little intact tallgrass prairie vegetation remains, but where it does remain (*e.g.*, Konza Prairie in Kansas), problems with invasive species are minimal. A number of introduced plants (*e.g.,* leafy spurge (*Euphorbia esula*), Canada thistle, *Centaurea* spp., and annual grasses) present problems for economic use of shortgrass prairie rangelands and are at least nuisances in parks and reserves in and adjacent to shortgrass prairie.

Introduced plant species present problems in parks and reserves in U.S. eastern deciduous forests and the related southeastern coniferous forest, but most are replaced in the course of succession and none invade undisturbed forests. Japanese honeysuckle (*Lonicera japonica*) and kudzu (*Pueraria lobata*) are among the most persistent in the southeastern U.S.

Several invasive aquatic weeds, including water hyacinth (*Eichhornia crassipes*), hydrilla (*Hydrilla verticillata*), and water milfoil (*Myriophyllum* spp.), pose problems in many wetland parks and reserves in Florida, though more often than not these are highly disturbed ecosystems. Biological control has proved at least partially successful for the first two species. Purple loosestrife (*Lythrum salicaria*) is a formidable invader of wetlands in the Midwest and Northeast (Wilcox and Seeling 1986).

After a century of repeated introductions of tropical species to southern Florida, some introduced tree species are beginning to attain local dominance, not only on highly disturbed sites, but in native plant communities of Everglades National Park. Establishment and spread of at least three major problem species -- melaleuca or cajeput, Brazilian peppertree, and casuarina (*Casuarina equisetifolia*) -- seem to guarantee that major vegetation changes will take place in Everglades National Park in the coming decades unless there is active intervention by managers (Olmsted and Loope 1984). Myers (1983) has proposed a "judiciously timed" (based on the plant's life cycle), integrated approach to control of melaleuca using chemicals, mechanical means, and fire. LaRosa (this volume) details these problems in southern Florida.

THE ROLE OF INTRODUCED UNGULATES AS VECTORS FOR ALIEN PLANT ESTABLISHMENT

Introduced ungulates have accentuated problems with introduced plant species both in the Hawaiian Islands and in continental situations. Mueller-Dombois *et al.* (1981), Loope and Scowcroft (1985), and others have stressed the fact that introduced plant species do not normally invade undisturbed Hawaiian ecosystems (exceptions do occur, however). Effects of overgrazing by domestic livestock in the western U.S., leading to range deterioration and establishment of nonnative plants, have also been well documented (*e.g.*, Mack 1981). Yet on the U.S. Mainland many situations of severe damage by ungulates apparently do not lead to invasion of introduced plant species.

In Olympic National Park, a population of about 1,000 individuals of the introduced mountain goat (*Oreamnos americanus*) has altered plant communities at high elevations and has affected the distribution, abundance, and morphology of endemic plant species (Schreiner 1984; D.B. Houston, pers. comm.). This introduced ungulate has apparently not exacerbated problems with introduced plants, however.

Feral burros (*Equus asinus*) may have a role in encouraging annual alien grasses in habitats where they thrive in the southwestern U.S., but such grasses are not considered a major problem at Death Valley, Grand Canyon, and other areas plagued by burros. The only relationship between burros and tamarisk is that use of springs and other water sources by burros intensifies negative effects of water table reduction by tamarisk on native wildlife, especially the desert bighorn.

Feral pigs (*Sus scrofa*) in the Great Smoky Mountains are highly destructive to the native early spring-blooming flora (Bratton 1974, 1975), but no significant invasion of introduced plants is occurring on the denuded areas. Baron (1982) found that feral pig rooting at Horn Island, Gulf Islands National Seashore, Mississippi, caused little alteration of native plant communities.

WHY ARE CERTAIN ECOSYSTEMS PARTICULARLY SUSCEPTIBLE TO BIOLOGICAL INVASION?

There is little question that islands or island-like situations invariably are more susceptible to invasion than comparable continental situations. The only areas identified in the Biosphere Reserve survey (Appendix) as having massive invasions of more than one introduced plant genus are Everglades,* Channel Islands, Haleakala, and Hawaii Volcanoes National Parks. The greater invasion of islands is not likely to surprise anyone. Darwin (1859) stated over one hundred years ago in *The Origin of Species*:

> He who admits the doctrine of the creation of each separate species, will have to admit that a sufficient number of the best adapted plants and animals were not created for oceanic islands; for man has unintentionally stocked them far more fully and perfectly than did nature.

Loope and Mueller-Dombois (1989) have reviewed possible reasons why island biotas in general, and the Hawaiian biota in particular, are highly vulnerable to invasions. These reasons can be summarized as follows:

1. **Evolution of oceanic island organisms in isolation from many of the powerful selective forces that continually shape most continental systems.** -- The Hawaiian biota and its ecosystems have evolved with disturbance of volcanism, windthrow, and landslides, but without grazing and trampling of ungulates and with a reduction in frequency and intensity of fire relative to most continental systems. Disturbance has been such an important evolutionary force over time in continental situations that opportunistic species have evolved that are adapted to persistence, dispersal, and colonization of unoccupied areas. The Hawaiian biota is well adapted to local disturbances related to volcanism, but fire does not appear to have played an important role in most native ecosystems of Hawai'i; few native plants of the Hawaiian Islands possess adaptations to it. Fires in modern Hawai'i, carried mainly by introduced grasses, are generally highly destructive to native plant species (Smith and Tunison, this volume). Opportunistic invasive plant species, on the other hand, spread rapidly following fire or other disturbance, notably on mineral soil exposed by pig digging. Island biotas have proved vulnerable to many other types of changes in conditions after the arrival of man. Unquestionably, the lack of such ecologically important native groups as ants, rodents, mammalian carnivores, and herbivorous ungulates in the Hawaiian Islands and other isolated island groups nas resulted in vulnerability of endemics when members of these groups are introduced.

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*The island-like nature of the Florida Everglades, a subtropical island at the end of a temperate peninsula, has been noted by Myers (1983). Its recent emergence from the sea and isolation from neotropical biota may result in lack of what Myers calls a complete species complement.

2. **The high degree of modification of island environments by humans.** -- The Hawaiian Islands were heavily exploited by the colonizing Polynesians, and much more so by continental man after 1778. Such exploitation is typical of islands in general, but the number of alien plants introduced to Hawai'i has been extraordinary.

3. **Increased invasions due to a small number of species and taxonomic disharmony of island biotas.** -- The total number of species per unit area is lower on islands than in continental situations. Island biotas also generally have low species numbers in certain taxonomic groups in relation to their relative proportions in continental areas of the world. "Disharmony" is a term often used in the context of island biology to denote a taxonomic balance that differs from continental norms. Low species numbers and disharmony appear to contribute in at least a minor way to vulnerability of islands to invasions. A dearth of species in certain functional groups or guilds, such as climax species and gap replacement species, probably also increases vulnerability.

4. **Reduced aggressiveness and vulnerability to extinction of island biotas.** -- Numerous workers have noted that native island species have reduced "aggressiveness" or increased vulnerability to extinction even under optimal environmental conditions. A theory first proposed by E.O. Wilson (1961) in describing this phenomenon for the Melanesian ant fauna is the concept of the taxon cycle. According to this theory, a continental taxon invading an archipelago undergoes increasing habitat specialization and fragmentation of populations accompanied by increasing vulnerability to extinction over evolutionary time. This theory has been neither fully supported nor refuted.

The genetic basis of the phenomenon of reduced aggressiveness with progressive island evolution is almost unexplored, but the extensive work with Hawaiian drosophilids by H.L. Carson and colleagues provides a basis for educated speculation. Carson (1981) stated that the levels of genetic variation found within a series of endemic and introduced species of *Drosophila* are basically similar to their continental counterparts. But continental species have many local populations, whereas island populations have few. Total genetic variance carried in a continental species should be far greater than that found in insular ones. A continental deme will be able to draw variability from adjacent demes, given a capacity for gene flow between demes. The isolated nature of most island demes may be conducive to the evolution of "restrictive specializations," whereas continental conditions are capable of giving rise to "general purpose genotypes."

One genetic factor, other than small population size, that could lead to increased vulnerability of island species through evolutionary time is the repetition (and compounding) of founder events in the genetic history of many island species. The rigor of natural selection in such an evolving insular system may be relaxed by the large number of genetic bottlenecks (founder events) that some groups have undergone in island-hopping.

CONTROL OF INTRODUCED SPECIES

The control of invasive introduced plant species in parks and reserves is too complex to be more than touched upon here. Control methods can be manual, mechanical, chemical, or biological. Manual control is rarely used in modern agriculture in the United States but is commonly feasible in management of natural areas. It is generally effective primarily for small areas but has been used with some success over large areas as well. Control of woody plants often involves a combination of manual, mechanical and chemical methods; small trees are uprooted, and larger trees are cut with chain saws and herbicides applied to stumps to prevent resprouting. Most government agencies, including the National Park Service, are committed to "Integrated Pest Management," which means the use of two or more control methods with appropriate integration to control a given pest with the least long-term environmental damage (Klingman and Ashton 1982). For Park Service management and many others, Integrated Pest Management implies control using minimal pesticides at critical times and stages. Important also is continual evolution of treatment efficiency and determination of pest impact levels.

Biological control has rarely been used for control of invaders in natural areas, undoubtedly because of the substantial investment in time and money involved in research and monitoring. The recent successful control of tansy ragwort in Redwood National Park and other reserves of Oregon and California (McEvoy 1985; Mastrogiuseppe *et al.*, n.d.; Holden, n.d.) stands out, but the momentum for the control of this weed came from the agricultural community. The first significant initiatives by the Park Service toward biological control are those against alien *Rubus* spp., firetree (*Myrica faya*), and banana poka (*Passiflora mollissima*), through participation in a cooperative program in Hawai'i (Markin *et al.*, this volume; Markin and Yoshioka, this volume). Much opportunity seems to exist in Hawai'i (Gardner and Davis 1982; Markin 1989) and in California (Pemberton 1985) for controlling some of the more serious invaders. Although biological control has some fine success stories in agriculture, it has its critics as well (*e.g.*, Krebs 1972; Howarth 1983). If done properly, with painstaking experimentation to ensure specificity for the target host, the only serious drawback to attempting it seems to be its cost and the time it takes for effectiveness (typically, 5-10 years for testing and another 5-10 years after release for population buildup, spread, and impact on host, according to Markin 1989). It succeeds about 50% of the time (Krebs 1972; Pemberton 1985; Markin 1989).

That there is much current interest in the topic of control of invasive introduced species in nature reserves is suggested by information disseminated in the *Natural Areas Journal* (*e.g.*, Evans 1983, 1984a, 1984b), *Restoration and Management Notes* (*e.g.*, Lawrence 1981; Galitz 1984), and *Fremontia* (*e.g.*, Boyd *et al.* 1984; Pemberton 1985). Some excellent pertinent reviews are available in more traditional journals (*e.g.*, Swan 1982; Trumble and Kok 1982; Lym and Messersmith 1985). Regional offices of The Nature Conservancy offer to provide computer printouts ("Stewardship Abstracts") regarding management of certain introduced plant species (*Fremontia* 13(2), p. 30, 1985). The Park Service is

producing an "Integrated Pest Management Information Manual" (*e.g.*, National Park Service 1984). Some Park Service regional offices are trying to compile information on introduced species problems (Pestana 1985).

THE FUTURE

The severity of problems with introduced plant species in national parks and reserves ranges from overwhelming (Everglades, Hawaii Volcanoes) to negligible (Alaska parks, Isle Royale). In some instances (Haleakala, Channel Islands, Hawaii Volcanoes), feral ungulate damage has been the primary cause of massive invasions by introduced plant species. In other instances (Great Smoky Mountains, Death Valley, Olympic), serious damage to native vegetation by introduced ungulates has not appreciably exacerbated alien plant problems. Problems with alien organisms are formidable and will require larger political and financial commitments than currently exist to adequately cope with them. Because of far-reaching, ecosystem-level effects on water tables, the tamarisk problem in riparian areas of the desert southwest stands out as one of the worst nationwide and one of the most promising targets for biocontrol. Otherwise, alien plant problems in the Everglades, the Hawaiian parks, and perhaps the Channel Islands appear greater by an order of magnitude than those of other U.S. parks and reserves. Our knowledge of exactly what effects alien plants are having on our natural heritage is, however, quite meager and needs to be strengthened, if the needed stronger support for effective control measures is to be obtained.

Alien plants are apparently damaging native species and ecosystem processes less than alien animals (especially pigs, burros, goats, and insects) in U.S. parks and reserves. However, plants are persistent and more difficult to control than most vertebrate animals; their long-term effects are often difficult to predict and need to be explored further. The real cause for alarm in the continental United States is the progressive fragmentation and "insularization" of natural areas (Wilcove *et al.* 1986), combined with increasing establishment of alien species in the expanding matrix of disturbed habitats. Mooney *et al.* (1986) call attention to the rapid increase in invasive alien plants in California as suggested graphically by Frankel (1977). Even parks and reserves with minimal problems now may have serious problems in the future.

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APPENDIX: A COMPARATIVE SURVEY OF SEVERITY OF INTRODUCED PLANT PROBLEMS IN SELECTED RESERVES, BASED ON MANAGERS' PERCEPTIONS

METHODS: Essentially identical letters were sent to each U.S. Biosphere Reserve, requesting information on the severity of introduced species problems in the reserve. The rationale for requesting the information from Biosphere Reserves was that 1) these areas have been selected by the U.S. Man and the Biosphere Committee to provide as satisfactory a coverage as possible of the major "biogeographic provinces" of the U.S. (Risser and Cornelison 1979); 2) these areas have agreed to participate in a worldwide reserve network, cooperating in conservation, research, and education; part of such cooperation involves exchange of information (Batisse 1982); and 3) Biosphere Reserve areas were selected in part because of their relatively long history of ecological information-gathering. Addresses of reserve managers were obtained from a UNESCO document received accompanying a U.S. Department of State Man and the Biosphere Newsletter in December 1984. Letters were sent to 40 reserves. Responses were received from 70% of the reserves. Responses dealing with introduced plants, grouped by ecosystem location, are evaluated below. Supplementary evaluation based on the literature and personal knowledge has been added as deemed appropriate, especially to fill major information gaps.

Arctic

Managers of Denali National Park (J. Dalle-Molle) and Noatak National Preserve (G.R. Bane) replied that their reserves have essentially no problems with introduced species.

Rocky Mountains

The project leader of Fraser Experimental Forest in Colorado reported no problems with biological invasions (R.R. Alexander).

For Rocky Mountain National Park, Colorado, (H.E. McCutchen), the severity of impact from invading species was regarded as "low." Introduced plants obtained a foothold through settlement of private lands in this park prior to its establishment in 1915. An aggressive land acquisition program has allowed restoration of most disturbed sites, followed by natural plant succession. Three invading plants (*Cirsium arvense, Euphorbia esula*, and *Verbascum thapsus*) are controlled (mechanical and chemical methods) and monitored. At present, 19 areas totalling 62 ha (in a park of 110,400 ha) have been identified as needing treatment. [I must note that the park's new Chief of Resource Management feels that alien plants present a highly significant threat to the resources of Rocky Mountain National Park (C.C. Axtell, pers. comm. July 1986), illustrating that perceptions differ among knowledgeable individuals.]

Yellowstone National Park has minimal problems with introduced species. Houston (1982) has noted the presence of nonnative grasses such as *Agropyron cristatum* and *Bromus tectorum*, and several forbs in the heavily grazed northern Yellowstone elk winter range especially in the "boundary line area." *Cirsium arvense* invades thermal areas of sparse vegetation around hot springs in Yellowstone.

For Glacier National Park, Geographer C.H. Key stated that a number of introduced vascular plants (*Centaurea maculosa, Euphorbia esula, Bromus inermis, Chrysanthemum leucanthemum, Trifolium* spp., *Taraxacum officinale*, and *Phleum pratensis*) persist in, and sometimes invade, natural sites in the absence of

disturbance. However, management attention is concentrated on the first two listed -- largely because neighboring agricultural interests are concerned about their economic impact. A project is under way by R.W. Tyser (1985) to assess success of biological control of *Centaurea maculosa*. Several biocontrol insects have been introduced in adjacent Canada to combat this species and have spread to western Montana (Maddox 1982; Story and Nowierski 1984). Weaver and Woods (1985) have assessed the overall impact of Glacier's introduced flora. These problems involving introduced plants seem to warrant concern and surveillance but appear to be modest in scale.

Northwestern Conifer Forests/Cascades

The responses from reserves in maritime northern California and Oregon indicated a definite awareness of and interest in problems with biological invasions and a competence and confidence in dealing with them.

California Coast Ranges Biosphere Reserve (3 units)

Landels Hill-Big Creek Preserve (Univ. Calif., Santa Cruz): Manager D.J. Usner reported the following introduced plant species as warranting special concern: *Cytisus monspessulanus*, *Cortaderia jubata*, *Silybum marianum*, *Foeniculum vulgare*, and *Conium maculatum*. *Cytisus* and *Cortaderia* are being removed by hand. Prescribed burning is planned to encourage an increase of native grasses at the expense of numerous introduced grasses.

Northern California Coast Range Preserve (The Nature Conservancy and Bureau of Land Management, Branscomb, California): Preserve Managers C. and K. Barrows reported concern with *Phalaris tuberosa*, which invades areas disturbed by feral pigs and outcompetes native bunchgrasses. Pigs are shot as the opportunity arises, and their impact remains modest. *Phalaris* is being controlled successfully by mowing during the period of active growth. *Cytisus scoparius* and *Verbascum thapsus*, plant invaders which tend to increase unless managed, are successfully controlled manually through assistance from volunteers.

Redwood National Park: Superintendent D. Warnock listed introduced plant species in order of decreasing concern: *Senecio jacobea, Cytisus scoparius, Pinus radiata, Cortaderia jubata*, and *Ammophila arenaria*. Warnock feels the severity of impact by introduced plants is "low to medium." *Senecio* is of special concern "not so much for its impact to park values, but rather for its toxicity to livestock outside the park." After years of "pulling, mowing, plowing, and burning," biological control is now proving effective on *Senecio*.

Cascade Head Experimental Forest and Scenic Research Area, Oregon (U.S. Forest Service): Scientist Sarah Greene stated that the major introduced pest at this Biosphere Reserve is tansy ragwort and that it has been partially controlled by biological control.

H.J. Andrews Experimental Forest, Oregon (U.S. Forest Service): Site Manager A. McKee stated that *Senecio sylvaticus* and *Cytisus scoparius* are invaders of minor concern.

Olympic National Park, Washington, has a high percentage (over 19%) of introduced taxa in its flora (see Table 1). Franklin (1985) stated:

Most introduced species are from relatively moist regions of Europe and Asia. In some areas, exotic plants are important components of the vegetation on extensive park areas. For example, *Agrostis stolonifera* and *Ranunculus repens* are dominants in the herbaceous meadow communities of lowland river valleys [D.B. Houston stated that these areas were formerly grazed by livestock and influenced by old homesteads.] Ruderal weeds such as *Senecio jacobea* or *Cirsium arvense* are ubiquitous in the park in areas disturbed by park facilities or operations. Other species (for example, *Cytisus scoparius*) are severe problems on lands adjacent to the park and have become established because of nearby land use patterns. Several species of east-Asian origin are found in undisturbed habitats of lowland areas of the park. Present management attention to exotic plant infestations is limited to occasional, qualitative observations of problem areas. Minor control efforts have been undertaken. The Park Resources Management Plan expresses concern about exotic plant control management, but it is not given a high priority for funding.

Sierra Nevada

Sequoia and Kings Canyon National Parks (B. Evison and D. Graber) characterized the severity of impact of known alien species as "minimal and localized, with the exception of the long-established Mediterranean annual grass flora below 2,000 m." Above 2,000 m, introduced plants are restricted to a few small developed areas.

California Chaparral, Grasslands, and Coastal Habitats

D.A. Duncan of San Joaquin Experimental Range replied that in the California "annual plant" (described by Talbot *et al.* 1939) and "oak-woodland" types, the great majority of the herbaceous plants are exotics, and have been for a long time. Most of the natives were replaced over 100 years ago, soon after the introduction of livestock. The substantial range livestock industry in the California annual plant rangelands is based on managing and utilizing these "invaders," and the experimental range has been mainly involved in assisting this type of management. San Joaquin Experimental Range's Research Natural Area, protected from grazing and burning for 50 years, has had a great increase in native woody plants, but the herbaceous vegetation is still primarily introduced annuals.

Southwestern Deserts and Mountains

At Death Valley National Monument, part of the Mojave and Colorado Deserts Biosphere Reserve, the two primary problems with introduced species are feral burros (*Equus asinus*) and *Tamarix* spp. Other problems exist but in comparison to these are quite minor. The area's resources management plan (National Park Service 1981) mentions need for localized control of introduced *Salsola kali*, *Phoenix* spp. and *Washingtonia filifera*, and *Ceratophyllum demersum*, an aquatic weed which crowds out native aquatic plants in one of the area's springs.

Organ Pipe Cactus National Monument: Several introduced plant species with histories of severe invasiveness elsewhere are or have been present in Organ Pipe Cactus National Monument without, as yet, serious consequences. *Tamarix ramosissima* and *T. aphylla* are present in the area but are not frequently encountered in the reserve. Whenever tamarisk establishes in intermittent watercourses from seed washed in from outside the reserve, it is removed by hand pulling. *Nicotiana glauca* has been recorded within the reserve but has been pulled whenever seen and is not known to currently persist within the

reserve. *Pennisetum setaceum* is sufficiently widespread as to be regarded as uncontrollable (H.J. Smith and R.L. Anderson).

Big Bend National Park (C.R. LaFrance, Acting Superintendent) considered the potential impacts of *Tamarix* spp. very great, particularly when associated with backcountry water sources such as springs and seeps. Tamarisk has already invaded 74 of approximately 180 springs in the park and is considered to threaten the existence of available water for wildlife. Frequent use of springs by trespass cattle intensifies the problem. The current management strategy at Big Bend is to control tamarisk at springs where invasion is only beginning.

Great Basin Desert/Colorado Plateau

Information on Arches and Canyonlands National Parks is being used here in lieu of a natural area Biosphere Reserve in the area. More accessible areas of these parks underwent severe range deterioration through overgrazing by cattle prior to park establishment (maximum grazing pressure in the year 1900), but many portions were relatively or entirely inaccessible due to highly dissected topography (W.L. Loope 1976). Virginia Park, in Canyonlands, is believed to be a pristine grassland which has never been grazed. Kleiner and Harper (1971) found only subtle differences between *Hilaria jamesii*-dominated grassland vegetation of Virginia Park and of grazed Chesler Park. Introduced plant species were absent in both areas. Only four introduced species (*Bromus tectorum*, *Descurainia sophia*, *Lappula redowskii*, and *Salsola kali*) vs. 39 native species were encountered in vegetation sampling of over 200 sites in Canyonlands National Park by W.L. Loope (1976). Aliens (primarily *Bromus tectorum*) comprised an average of 50% of the plant cover in one physiographic situation, 22% in another, but were absent or had negligible cover in the four remaining physiographic situations. Riparian areas (not sampled by Loope 1976) of Canyonlands and Arches National Parks have been occupied by tamarisk.

Grasslands

Grasslands of the central U.S. have been drastically modified through cultivation, removal of the bison (*Bison bison*), and alteration of the fire regime, but a few nearly intact prairie areas remain. The reply from L.C. Hulbert, Director of Konza Prairie Research Natural Area in Kansas, indicated a noteworthy optimism regarding problems of biological invasions in this tallgrass prairie site. He responded:

> Konza Prairie Research Natural Area is a tallgrass prairie area of 3,487 ha. About 4% was plowed in the past when it was a cattle ranch, about 6% is forest, and the rest is unplowed native prairie, mostly in good to fine condition. Fire was a common natural part of the ecosystem, and the ranchers have commonly burned since settlement.
>
> We have some exotic plants on Konza Prairie, but they are of no serious trouble. Two are *Bromus japonicus* and *B. tectorum*, but they are present only where the land has been seriously disturbed, such as along trails or around salt boxes. Regular burning keeps them from invading the prairie. *Poa pratensis* is similar, although a perennial. It is native to the country, probably, but was not a normal part of the prairie. It takes over on unburned, ungrazed prairie, but is kept out by burning. We have it

only where there has been appreciable grazing and little or no burning, so it is not a problem.

Carduus nutans was present in colonies in heavily grazed areas when The Nature Conservancy acquired the area. Because it is a legally noxious weed, and owners are liable to eliminate it on their land, we have worked to remove it on the perimeter areas where it would likely invade adjoining private land. On the first 371 hectares acquired by The Nature Conservancy in 1971, I cut off each plant in the dozen or so colonies with a hand pick, doing so every week or 10 days for the first half of the growing season. The first year there were about 4,000, about half that number the next, and it was eliminated in 5 years. When a much larger addition was purchased by The Nature Conservancy in 1977 (3,116 ha) there were many more plants present than on the original acquisition. We spend a number of days cutting off below the crown the plants on areas near the perimeter, but have not done so on colonies farther from the perimeter. One of the entomologists at Kansas State has been using these colonies for research on biological control with insects from Europe from which the plant came. However, under good management these biennial plants are disappearing without control. We have removed them by hand only to avoid problems with the authorities and neighbors.

Melilotus spp. and a few other species invade mowed areas but do not succeed where we burn. This seems to be the same for most all alien species. They are opportunists on disturbed and unburned areas. Therefore, except for the musk thistle we have spent no time on eradication and are not having problems with them.

M.C. Shoop, Range Scientist at Central Plains Experimental Range in Colorado, characterized the severity of biological invasions in the experimental range and surrounding rangelands as "moderate," overall. However, he expressed great concern over the potential invader *Euphorbia esula*:

> This weed could reduce the grazing capacity of our grasslands by an estimated 40 to 70%, if it were to invade. It is now spreading rapidly on the irrigated area 25 miles away. Our first approach to control would probably be through spot herbicidal control with Tordon of the initially invading plants. If the invasion becomes severe, then broadcast treatments would probably be undertaken. Tordon is moderately effective for controlling this weed, but very expensive.

Until now, the most invasive weed at Central Plains has been *Cirsium arvense*, which if not controlled (through annual spot applications of Tordon), "could reduce the grazing value of our lands by 10 to 20%, because it would become a severe competitor on the mesic sites." Two *Centaurea* species (*C. repens* and an unidentified species) are also noteworthy invaders.

Northern Coniferous-Deciduous Forest/Great Lakes

Acting Superintendent S.L. Croll of Isle Royale National Park, Michigan, responded that the park "has been fortunate thus far in its relative isolation from biological invaders." No alien plant problems were mentioned.

Eastern Deciduous Forest

Assistant Superintendent R. Wauer and Scientist P. White of Great Smoky Mountains National Park enumerated an abundance of concerns with introduced species, with the European wild hog (*Sus scrofa*), the rainbow trout (*Salmo gairdneri*), and the balsam woolly aphid (*Adelges piceae*) topping the list. The following introduced plants are considered to warrant concern (in order of decreasing concern): "moderate severity" -- *Pueraria lobata, Lonicera japonica, Microstegium vimineum*; "low severity" -- *Albizzia julibrissin, Paulownia tomentosa, Populus alba, Ailanthus altissima, Sorghum halpense, Rosa multiflora, Rosa wichuriana, Celastrus orbiculatus, Cirsium arvense, Ligustrum vulgare, Hedera helix, Vinca minor, Berberis thunbergii, Holcus lanatus, Lysimachia nummularia, Mentha spicata, M. piperata,* and *Nasturtium officinale*.

Most of the above-mentioned species are associated with old homesites, abandoned when the park was established in the 1930s. Kudzu (*Pueraria lobata*), a smothering vine (Leguminosae) causing the greatest concern, occurs in some 80 local patches (mostly along roads at the edge of the park or at old homesites) and is said to be capable of replacing native vegetation through rapid vegetative expansion. Fortunately, the species apparently sets seed seldom, if ever. Although the threat from kudzu is substantial, core resources (virgin forest) seem to be secure. Small-scale herbicidal control is being undertaken to hold populations in check. A control feasibility study has been carried out by Rosen (1982).

Superintendent R.S. McDaniel provided a preliminary list of introduced plant species of concern in Congaree National Monument, a newly acquired (1978) National Park Service area: *Albizzia julibrissin, Melia azedarach, Lonicera japonica, Ligustrum sinense, Nelumbo lutea*, and *Myriophyllum* spp. The problems appear to him significant but manageable.

Manager W. Miley stated that the Central Gulf Coastal Plain Biosphere Reserve, near Apalachicola in northern Florida, escapes the severity of biological invasions that characterize the central and southern portion of the state. The reserve has two problem plant species -- water hyacinths (*Eichhornia crassipes*) and Eurasian water milfoil (*Myriophyllum spicatum*) -- and feral hogs. *Eichhornia* control is carried out by the Northwest Florida Water Management District.

Former resource manager R.J. Krumenaker made the following observations regarding Big Thicket National Preserve:

> Chinese tallow [*Sapium sebiferum* -- Euphorbiaceae] . . . is an introduced hardwood tree species, extremely abundant, very prolific, and currently not subject to any serious control afforts. Since Preserve boundaries are so irregular and the areas protected are small and discontiguous, it is unlikely any efforts could be successful. Another exotic plant of interest . . . is slash pine (*Pinus elliottii*), which has been planted throughout the area as a commercial timber tree.

T.D. Moore, Executive Director of the New Jersey Pinelands Commission, stated that the impacts of biological invasions on the Pinelands National Reserve, "are not too obvious." Cosmopolitan vascular plant species have been introduced, but their effect in undeveloped portions of the Pinelands is usually limited to roadsides.

R.V. Kopple, Resident Biologist, states that threats from introduced species seem to be lacking in both terrestrial and aquatic communities at The University of Michigan

Biological Station. Plant communities there are still slowly recovering from large-scale logging and burning during 1880-1920, but exotics play only a very minor role.

Florida Everglades and Vicinity

Superintendent J. Morehead and his staff of Everglades National Park confirmed the severity of introduced species problems in southern Florida. They stated:

> Exotic plants are probably the greatest threat to the South Florida environment. They have demonstrated ability to displace entire communities of native plants and animals. The full extent of the problem is not really known as no assessment has been made of populations. However, the impacts to South Florida are already severe, and without action soon, they will be irreversible, if not already so.

Opportunistic control measures are taken locally against *Schinus terebinthifolius*, but no control actions are reported planned for *Melaleuca quinquenervia* and *Casuarina equisetifolia*.

Islands

Aleutian Islands National Wildlife Refuge: Although introduced animals (primarily the Arctic fox (*Alopex lagopus*), but also numerous herbivores--Arctic ground squirrel (*Citellus undulatus*), tundra vole (*Microtus oeconomus*), Greenland collared lemming (*Dicrostonyx groenlandicus*), reindeer (*Rangifer tarandus*), caribou (*Rangifer arcticus*), and domestic cattle) have had "a tremendous and lasting impact on the natural fauna and flora of the Aleutian Islands" (Refuge manager C.F. Zeillemaker), introduced plant species were not mentioned as a problem. These oceanic islands of volcanic origin were originally lacking in land mammals, so that the vegetation underwent several million years of evolution without the selective force of mammalian herbivory. Perusal of Hulten (1968) confirms the absence of high numbers of introduced plant species in the Aleutian Islands, however.

Channel Islands National Park: Superintendent W. Ehorn stated that all the islands in Channel Islands National Park have had major, ecosystem-changing, impacts from alien species. These impacts have been primarily due to land use practices before the Islands came under the administration of the National Park Service. The main impact has come from grazing and browsing organisms: cattle, sheep (*Ovis aries*), pigs, horses (*Equus caballus*), rabbits (*Oryctolagus cuniculus*), and donkeys (*Equus asinus*). Introduced annual grasses (*Avena* spp., *Hordeum* spp., etc.) have replaced the native perennial grasses in grasslands of all Islands. Many other introduced plant species have become established and are thriving under continued grazing disturbance. They dominate the vegetation over large areas. Among the more troublesome invaders are the introduced annual ice plants (*Mesembryanthemum crystallinum* and *M. nodiflorum*). These species accumulate salt and exclude other vegetation by increasing the salt content in the soil above the tolerance of potential competitors (Vivrette and Muller 1977).

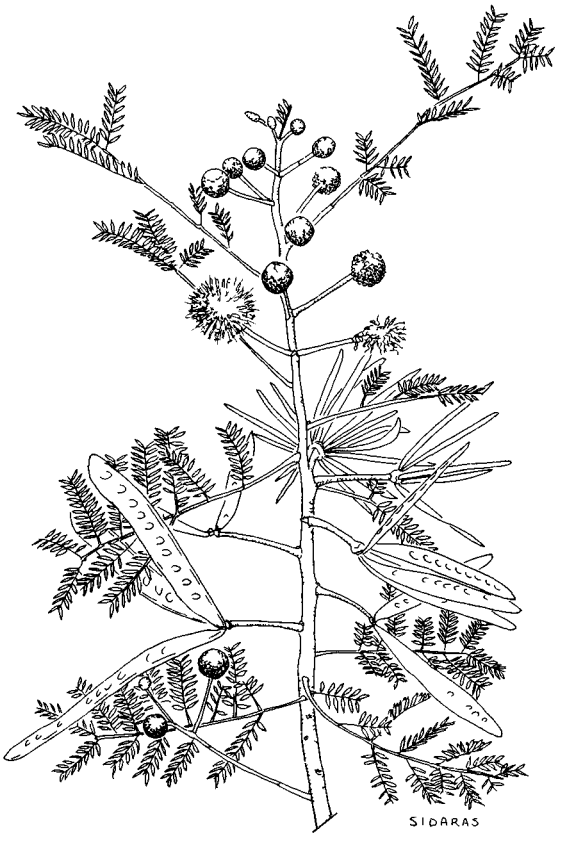
Biological invasions into the waters of Channel Islands National Park/ Marine Sanctuary/ Biosphere Reserve have occurred but have had much less of an impact than terrestrial invasions. The alga *Sargasso muticum* is believed to have been introduced on the bottom of a freighter coming into Los Angeles harbor. It is well established around Anacapa Island and is moving westward.

Recent acquisition of Santa Rosa Island by the National Park Service and most of Santa Cruz Island by The Nature Conservancy provides opportunities for major conservation efforts. Ungulate control is already underway on Santa Cruz and the national park is planning a management and research program for Santa Rosa.

Luquillo Forest Reserve: Project Leader A. Lugo stated that although some introduced animals pose a problem to wildlife, "plants are not much of a problem except along highways."

Haleakala National Park: Detailed information is given in Loope *et al.* (this volume) and Anderson *et al.*, (this volume). Problems with introduced plants at Haleakala appear more manageable that those at Hawaii Volcanoes and Everglades but more difficult than other U.S. Reserves.

Hawaii Volcanoes National Park: Detailed information is given in chapters of this volume by Tunison and Zimmer, Whiteaker and Gardner, Stone *et al.*, and others. Introduced plant species have been controlled with mixed success. Many moderately aggressive species have been brought under control. The current approach emphasizes control of the more widespread, community-disruptive plant species only within designated Special Ecological Areas, biologically rich, relatively intact areas (see Tunison and Stone, this volume).



Literature Cited

Anderson, S.J., C.P. Stone, and P.K. Higashino. [this volume] Distribution and spread of alien plants in Kipahulu Valley, Haleakala National Park, above 2,300 ft elevation.

Baker, H.G. 1965. Characteristics and modes of origin of weeds. In *The genetics of colonizing species*, ed. H.G. Baker and G.L. Stebbins, 147-172. New York: Acad. Pr., Inc.

Baker, H.G. 1972. Migrations of weeds. In *Taxonomy, phytogeography, and evolution*, ed. D.H. Valentine, 327-347. London: Academic Pr., Inc.

Baker, H.G. 1974. The evolution of weeds. *Ann. Rev. Ecol. Syst.* 5:1-24.

Barbour, M.G., and F. Johnson. 1977. Beach and dune. In *Terrestrial vegetation of California*, ed. M.G. Barbour and J. Major, 223-261. New York: John Wiley & Sons.

Baron, J.S. 1982. Effects of feral hogs on the vegetation of Horn Island, Mississippi. *Amer. Midl. Nat.* 107(1):202-205.

Batisse, M. 1982. The biosphere reserve: a tool for environmental conservation and management. *Environ. Conserv.* 9(2):101-111.

Boyd, D., E. McClintock, J.H. Kerbauaz, S.S. van Hook, D. Hillyard, and W.M. Neill. 1984. Status reports on invasive weeds. *Fremontia* 12(4):16-23.

Bratton, S.P. 1974. The effect of the European wild boar (*Sus scrofa*) on high-elevation vernal flora in the Great Smoky Mountains National Park. *Bull. Torrey Bot. Club* 101:198-206.

Bratton, S.P. 1975. The effect of the European wild boar (*Sus scrofa*) on grey beech forest in the Great Smoky Mountains. *Ecology* 56:1356-1366.

Carson, H. 1981. Microevolution in insular ecosystems. In *Island ecosystems: biological organization in selected Hawaiian communities*, ed. D. Mueller-Dombois, K.W. Bridges, and H.L. Carson, 471-482. Stroudsburg, Penn: Hutchinson-Ross Pub. Co.

Chapin, F.S., and M.C. Chapin. 1980. Revegetation of an arctic disturbed site by native tundra species. *J. Appl. Ecol.* 17:449-456.

Christensen, E.M. 1962. The rate of naturalization of *Tamarix* in Utah. *Amer. Midl. Nat.* 68:51-57.

Darwin, C. 1859. *The origin of species*. Repub. in Vol. 49, *Great books of the western world*. Encyclopedia Britannica, Inc.

Evans, J.E. 1983. A literature review of management practices for multiflora rose. *Nat. Areas J.* 3(1):6-15.

Evans, J.E. 1984a. Japanese honeysuckle (*Lonicera japonica*): a literature review of management practices. *Nat. Areas J.* 4(2):4-10.

Evans, J.E. 1984b. Canada thistle (*Cirsium arvense*): a literature review of management practices. *Nat. Areas J.* 4(2):11-21.

Frankel, R.E. 1977. Ruderal vegetation along some California roadsides. *Univ. Calif. Publ. Geogr.* 20:1-163.

Franklin, J.F., ed. 1985. *The scientific information base and infrastructure at Olympic National Park and Biosphere Reserve*. Rep. Pac. Northwest Region, Natl. Park Serv. Pac. Northwest For. Range Exp. Sta., USDA For. Serv.

Galitz, D.S. 1984. Leafy spurge symposium. *Restoration and management notes* 2(2):86-87. Madison, Wisconsin: Univ. Wisconsin-Madison Herbarium.

Gardner, D.E., and C.J. Davis. 1982. *The prospects for biological control of nonnative plants in the Hawaiian national parks.* Tech. Rep. 45, Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit. Honolulu.

Greller, A.M. 1974. Vegetation of roadcut slopes in the tundra of Rocky Mountain National Park, Colorado. *Biol. Conserv.* 6(2):84-90.

Halvorson, W.L. [this volume] Alien plants at Channel Islands National Park.

Hanes, T.L. 1977. Chaparral. In *Terrestrial vegetation of California*, ed. M.G. Barbour and J. Major, 417-470. New York: John Wiley & Sons.

Harris, D.R. 1966. Recent plant invasions in the arid and semi-arid southwest. *Amer. Geogr.* 56:408-422.

Heady, H.F. 1977. Valley grassland. In *Terrestrial vegetation of California*, ed. M.G. Barbour and J. Major, 491-514. New York: John Wiley & Sons.

Higashino, P.K., L.W. Cuddihy, S.J. Anderson, and C.P. Stone. 1988. *Checklist of vascular plants of Hawaii Volcanoes National Park*. Tech. Rep. 64, Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit. Honolulu.

Holden, L.J. n.d. Biological control of tansy ragwort (*Senecio jacobaea*) in Redwood National Park. Draft Rep. Redwood Natl. Park.

Houston, D.B. 1971. Ecosystems of national parks. *Science* 172:648-651.

Houston, D.B. 1982. *The Northern Yellowstone elk: ecology and management*. New York: Macmillan Pub. Co.

Howarth, F.G. 1983. Classical biocontrol: panacea or Pandora's box. *Proc. Hawn. Entomol. Soc.* 24(2,3):239-244.

Hulten, E. 1968. *Flora of Alaska and neighboring territories: a manual of the vascular plants*. Stanford, Calif.: Stanford Univ. Pr.

Humphrey, R.R., and L.A. Mehrhoff. 1958. Vegetation changes on a southern Arizona grassland range. *Ecology* 39(4):720-726.

Ise, J. 1961. *Our national park policy: a critical history.* Baltimore, Maryland: Johns Hopkins Pr.

Jackson, L.E. 1985. Ecological origins of California's Mediterranean grasses. *J. Biogeogr.* 12:349-361.

Kleiner, E.F., and K.T. Harper. 1971. Environment and community organization in grasslands of Canyonlands National Park. *Ecology* 53:299-309.

Klingman, G.C., and F.M. Ashton. 1982. *Weed science: principles and practices,* 2nd ed. New York: John Wiley & Sons.

Krebs, C.J. 1972. *Ecology: the experimental analysis of distribution and abundance.* New York: Harper & Row.

LaRosa, A.M. [this volume] The status of banana poka in Hawai'i.

Lawrence, D.B. 1981. Control of common mullein. *Restoration and Management Notes* 1(1):19. Madison, Wisconsin: Univ. Wisconsin-Madison Herbarium.

Loope, L.L., and V.L. Dunevitz. 1981. *Impact of fire exclusion and invasion of* Schinus terebinthifolius *on limestone rockland pine forests of southeastern Florida.* Tech. Rep. T-645, Natl. Park Serv. So. Fla. Res. Cent. Homestead, Fla.

Loope, L.L., and D. Mueller-Dombois. 1989. Characteristics of invaded islands. In *Biological invasions: a global perspective,* ed. J. Drake, F. di Castri, R. Goves, F. Kruger, H. Mooney, M. Rejmanek, and M. Williamson, 257-280. United Kingdom: John Wiley & Sons.

Loope, L.L., and P.G. Scowcroft. 1985. Vegetation response within exclosures in Hawai'i: a review. In *Hawai'i's terrestrial ecosystems: preservation and management,* ed. C.P. Stone and J.M. Scott, 377-402. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit. Honolulu: Univ. Hawaii Pr.

Loope, L.L., R.J. Nagata, and A.C. Medeiros. [this volume] Alien plants in Haleakala National Park.

Loope, W.L. 1976. Relationships of vegetation to environment, Canyonlands National Park, Utah. Ph.D. diss., Utah State Univ., Logan, Utah.

Lym, R.G., and C.G. Messersmith. 1985. Leafy spurge control with herbicides in North Dakota: a 20-year summary. *J. Range Manage.* 38(2):149-154.

McEvoy, P.B. 1985. Depression in ragwort *Senecio jacobaea* abundance following introduction of *Tyria jacobaeae* and *Longitarsus jacobaeae* on the central coast of Oregon. *Proc. VI Internatl. Symp. Biol. Control Weeds,* 57-64. Vancouver.

Mack, R.N. 1981. Invasion of *Bromus tectorum* L. into western North America: An ecological chronicle. *Agro-Ecosys.* 7:145-165.

Mack, R.N. 1986. Alien plant invasion into the intermountain west: a case history. In *Ecology of biological invasions of North America and Hawaii*, ed. H.A. Mooney and J.A. Drake, 191-213. New York: Springer-Verlag.

Maddox, D.M. 1982. Biological control of diffuse knapweed (*Centaurea diffusa*) and spotted knapweed (*C. maculosa*). *Weed Sci.* 30:76-82.

Markin, G.P. 1989. Alien plant management by biological control. In *Conservation biology in Hawai'i*, ed. C.P. Stone and D.B. Stone, 70-73. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit. Honolulu: Univ. Hawaii Pr.

Markin, G.P., and E. Yoshioka. [this volume] Evaluating proposed biological control programs for introduced plants.

Markin, G.P., P.-Y. Lai, and G.Y. Funasaki. [this volume] Status of biological control of weeds in Hawai'i and implications for managing native ecosystems.

Mastrogiuseppe, R.J., N.T. Blair, and D.J. Vezie. n.d. Artificial and biological control of tansy ragwort, *Senecio jacobea* L., in Redwood National Park, California. Unpub. rep.

Mooney, H.A. 1977. Southern coastal scrub. In *Terrestrial vegetation of California*, ed. M.G. Barbour and J. Major, 471-490. New York: John Wiley & Sons.

Mooney, H.A., S.B. Hamburg, and J.A. Drake. 1986. The invasions of plants and animals into California. In *Ecology of biological invasions of North America and Hawaii*, ed. H.A. Mooney and J.A. Drake, 251-272. New York: Springer-Verlag.

Mueller-Dombois, D., K.W. Bridges, and H.L. Carson, eds. 1981. *Island ecosystems: biological organization in selected Hawaiian communities*. Stroudsburg, Penn.: Hutchinson Ross Pub. Co.

Myers, R.L. 1983. Site susceptibility to invasion by the exotic tree *Melaleuca quinquenervia* in southern Florida. *J. Appl. Ecol.* 20:645-658.

National Park Service. 1981. Proposed natural and cultural resources management plan and draft environmental impact statement, Death Valley National Monument, California-Nevada. National Park Serv. San Francisco, Calif.: Natl. Park Serv.

National Park Service. 1984. Thistles. *Natl. Park Serv. Integrated Pest Manage. Info. Manual* 36:1-16. Washington, D.C.: Natl. Park Serv.

National Park Service. 1988. Management policies, National Park Service. Wash., D.C.

Niering, W.A., and C.H. Lowe. 1984. Vegetation of the Santa Catalina Mountains: community types and dynamics. *Vegetatio* 58:3-28.

Olmsted, I.C., and L.L. Loope. 1984. Plant communities of Everglades National Park. In *Environments of South Florida: present and past*, ed. P.J. Gleason, 167-184. Miami Geol. Soc. Mem. 2. Miami, Fla.: Miami Geol. Soc.

Pemberton, R.W. 1985. Naturalized weeds and the prospects for their biological control in California. *Fremontia* 13(2):3-9.

Pestana, K.E. 1985. *Problem exotic plants in selected parks of the Midwest Region and a bibliography of their management.* Midwest Region, Natl. Park Serv. Res./Resour. Manage. Rep. MWR-6. Omaha, Nebraska.

Philbrick, R.N., and J.R. Haller. 1977. The southern California islands. In *Terrestrial vegetation of California*, ed. M.G. Barbour and J. Major, 893-906. New York: John Wiley & Sons.

Risser, P.G., and K.D. Cornelison, eds. 1979. *Man and the biosphere, U.S. information synthesis project, MAB-8 Biosphere Reserves*. Norman, Okla.: Okla. Biol. Survey.

Robinson, T.W. 1969. Introduction, spread, and areal extent of saltcedar (*Tamarix*) in the western states. U.S. Geol. Surv. Prof. Paper 491-A. Washington, D.C.

Rosen, A. 1982. Feasibility study: eradication of kudzu with herbicides and revegetation with native tree species in two national parks. Natl. Park Serv. Res./Resour. Manage. Rep. SER-59. Atlanta, Georgia.

Schreiner, E. 1984. Vegetation Studies. In *Mountain goat ecology and management investigations, Olympic National Park*, ed. D. Houston, B. Moorehead, E. Schreiner, and R. Olson, 29-78. Natl. Park Serv. Rep. Olympic Natl. Park, Port Angeles, Washington.

Smith, C.W. 1985. Impact of alien plants on Hawai'i's native biota. In *Hawai'i's terrestrial ecosystems: preservation and management*, ed. C.P. Stone and J.M. Scott, 180-250. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit. Honolulu: Univ. Hawaii Pr.

Smith, C.W., and J.T. Tunison. [this volume] Fire and alien plants in Hawai'i: research and management implications for native ecosystems.

Stone, C.P., L.W. Cuddihy, and J.T. Tunison. [this volume] Responses of Hawaiian ecosystems to removal of feral pigs and goats.

Story, J.M., and R.M. Nowierski. 1984. Increase and dispersal of *Urophora affinis* (Diptera: Tephritidae) on spotted knapweed in western Montana. *Environ. Entomol.* 13:1151-1156.

Swan, D.G. 1982. Long-term field bindweed (*Convolvulus arvensis*) control in two cropping systems. *Weed Sci.* 30:476-480.

Talbot, M.W., H.H. Biswell, and A.L. Hormay. 1939. Fluctuations in the annual plant vegetation of California. *Ecology* 20(3):394-402.

Trumble, J.T., and C.T. Kok. 1982. Integrated pest management techniques in thistle suppression in pastures of North America. *Weed Res.* 22:345-359.

Tunison, J.T., and C.P. Stone. [this volume] Special Ecological Areas: an approach to alien plant control in Hawaii Volcanoes National Park.

Tunison, J.T., and N.G. Zimmer. [this volume] Success in controlling localized alien plants in Hawaii Volcanoes National Park.

Tyser, R.W. 1985. Spotted knapweed in Glacier National Park: an ecological assessment. Research proposal to Glacier National Park. Biol. Dep., Univ. Wisconsin, La Crosse, Wisconsin.

van Cleve, K. 1977. Recovery of disturbed tundra and taiga surfaces in Alaska. In *Recovery and restoration of damaged ecosystems*, ed. J. Cairns, K.L. Dickson, and E.E. Henricks, 422-455. Charlottesville, Virginia: Univ. Pr. Virginia.

Vitousek, P.M. [this volume] Effects of alien plants on native ecosystems.

Vivrette, N.J., and C.H. Muller. 1977. Mechanism of invasion and dominance of coastal grassland by *Mesembryanthemum crystallinum*. *Ecol. Monogr.* 47:301-318.

Warren, P.L., K.L. Reichhardt, D.A. Mouat, B.T. Brown, and R.R. Johnson. 1982. *Vegetation of Grand Canyon National Park*. Univ. Ariz. Coop. Natl. Park Resour. Stud. Unit. Tucson, Ariz.

Weaver, T., and B. Woods. 1985. *The exotic flora of Glacier National Park: a preliminary atlas*. Bozeman, Montana: Montana State Univ. Biol. Rep. 37.

Whiteaker, L.D., and D.E. Gardner. [this volume] Firetree (*Myrica faya*) distribution in Hawai'i.

Wilcove, D.S., C.H. McClellan, and A.P. Dobson. 1986. Habitat fragmentation in the temperate zone. In *Conservation biology: the science of scarcity and diversity*, ed. M. Soulé, 237-256. Sunderland, Mass.: Sinauer Assoc.

Wilcox, D.A., and M.K. Seeling. 1986. Ecology and management potential for purple loosestrife (*Lythrum salicaria*). In *Conf. Sci. Natl. Parks, Program and Abstr.*, July 13-16, 1986, 197. Colorado St. Univ., Ft. Collins, Colorado.

Willard, B.E., and J.W. Marr. 1971. Recovery of alpine tundra under protection after damage by human activities in the Rocky Mountains of Colorado. *Biol. Conserv.* 3(3):181-190.

Williams, M.C., and E.H. Cronin. 1966. Five poisonous range weeds -- when and why they are dangerous. *J. Range Manage.* 19:274-279.

Wilson, E.O. 1961. The nature of the taxon cycle in the Melanesian ant fauna. *Amer. Nat.* 95:169-193.

Young, J.A., R.A. Evans, and J. Major. 1977. Sagebrush steppe. In *Terrestrial vegetation of California*, ed. M.G. Barbour and J. Major, 763-796. New York: John Wiley & Sons.