

MANAGING A COMPLEX EXOTIC VEGETATION PROGRAM IN YELLOWSTONE NATIONAL PARK

Tom Olliff¹, Roy Renkin¹, Craig McClure¹, Paul Miller¹, Dave Price²,
Dan Reinhart¹, and Jennifer Whipple¹

ABSTRACT.—The number of documented exotic plants in Yellowstone National Park has increased from 85 known in 1986 to over 185 today. Exotic plants are substantially impacting the park's natural and cultural resources and are a high management priority. We have adopted an integrated weed management approach with regard to exotic vegetation, emphasizing prevention, education, early detection and eradication, control, and, to a lesser degree, monitoring. The program involves over 140 staff with program expenditures averaging approximately \$190,000 annually. Prevention actions include requiring approved gravel on construction projects; banning hay in the backcountry and allowing transport of only certified weed-seed-free hay through Yellowstone; requiring construction equipment to be pressure-cleaned prior to entering the park; and native species revegetation after road, housing, and other construction projects have disturbed ground.

Over 4500 acres, primarily along roadsides and in developed areas, are surveyed annually in early detection efforts with emphasis placed on eradicating small, new infestations of highly invasive species such as sulfur cinquefoil (*Potentilla recta* L.) and leafy spurge (*Euphorbia esula* L.). Control efforts focus on about 30 priority species, such as spotted knapweed (*Centaurea maculosa* Lam.), oxeye daisy (*Chrysanthemum leucanthemum* L.), and hoary cress (*Cardaria draba* [L.] Desv.) using chemical, mechanical, and cultural techniques. A total of 2027 acres were treated during 1998, whereas control efforts for 12 species occurred on 2596 acres during the previous 3-year period, 1995–1997. Strong and expanding partnerships with other federal, state, and local agencies and private companies contribute to management efforts within the park. Future program goals emphasize increases in base funding to ensure continued weed management efforts as well as expanding survey, monitoring, and reclamation efforts. Ultimately, a more rigorous assessment of program effectiveness is desired.

Key words: exotic vegetation, Yellowstone National Park, integrated weed management.

The number of documented exotic plants in Yellowstone National Park (YNP) has increased from 85 recognized in 1986 to over 185 today, which represents about 15% of the vascular plant species in the park (Whipple 2001). Thirty of these plants are listed as noxious in 1 of 3 states (Wyoming, Montana, and Idaho) in which YNP is located. Some extremely invasive exotics that have not been found in Yellowstone, including yellow starthistle (*Centaurea solstitialis* L.) and purple loosestrife (*Lythrum salicaria* L.), are becoming serious problems in some adjoining states. On the other hand, nonnative plants that are not listed as noxious, like timothy (*Phleum pratense* L.), may be affecting native biotic communities to a greater degree than those plants deemed “noxious” (Wallace and Macko 1993).

Many biologists consider exotic plant establishment to be the largest threat to the integrity of native plant communities of the park. Non-

native plants have been demonstrated to negatively impact ecosystem structure and function by altering soil properties and related processes (Lacey et al. 1989, Olson 1999), plant community dynamics and related disturbance regimes (e.g., D'Antonio and Vitousek 1992), and distribution, foraging activity, and abundance of native ungulates (Trammel and Butler 1995, Thompson 1996) and small mammals (Kurz 1995). Geothermal habitats unique to Yellowstone have been altered by exotic plants, potentially compromising the long-term persistence of populations of Ross bentgrass (*Agrostis rossiae* Vasey), a restricted endemic plant found only in a few geothermal environments within the park. Aesthetics and viewsheds of cultural landscapes and historic districts within the park have been altered by the establishment of exotic plant species.

In response to the threat exotic plants pose to YNP's native flora and fauna, and in compliance

¹National Park Service, PO Box 168, Yellowstone National Park, WY 82190.

²Colorado National Monument, Fruita, CO 81521.

with legal and policy mandates prescribing weed control, YNP has established an aggressive program to prevent, eradicate, and control the spread of exotic plants. This program is guided by the Yellowstone National Park Exotic Vegetation Management Plan (NPS 1986). The park's Resource Management Plan (NPS 1998) lists exotic plants as one of the major threats to natural resources.

Here we describe the structure and implementation of the exotic vegetation management program in the park, summarize distribution and area information as a result of monitoring efforts for a select group of species under control, and identify actions to enhance long-term program effectiveness. For consistency here and with Whipple (2001), all plant species nomenclature follows Dorn (1992) and is provided upon initial reference to a particular plant species. Where current usage may differ from Dorn (1992), synonymy is also provided in accordance with nomenclature used by the Weed Science Society of America.

SITE

YNP is the 1st national park in the world and represents the core of the largest, nearly intact, natural ecosystem in the temperate zone of the earth. The park has been recognized as a United Nations Biosphere Reserve and a World Heritage Site. Established in 1872, the park was set aside as a "public park, or pleasuring ground" for "the preservation, from injury or spoliation, of all timber, mineral deposits, natural curiosities, or wonders within . . . and their retention in their natural condition" (1871 Bill S. 392). Through subsequent legislation and administrative guidelines, including the National Park Service Management Policies (NPS 1988), YNP's fundamental goal continues to be the preservation of its natural and cultural resources while allowing human visitation and enjoyment.

Encompassing 2,221,722 acres (3472 square miles), YNP is located primarily in the northwestern corner of Wyoming, with portions extending into southwestern Montana and southeastern Idaho. Ninety-nine percent of the park remains undeveloped (NPS 1991). While the overall footprint of developments is small, developments, including 370 miles of paved roads, 17 frontcountry developed areas, 2200 frontcountry campsites, 300 backcountry campsites, and 950 miles of backcountry trails, are

widely dispersed throughout the park. Visitation approaches 3 million people annually; about 28,000 people spend one or more nights in backcountry campsites. YNP also hosts approximately 8000 backcountry stock use nights annually.

The park consists of 5 more or less distinct vegetation zones influenced most heavily by the interaction between geology and climate (Despain 1990). Four of the 5 zones are at higher elevations between 6500 and 11,000 feet, are underlain by bedrock of volcanic andesite or rhyolite origin, and receive greater amounts of precipitation ranging from 20 to 70 inches annually. These areas generally support forests dominated by lodgepole pine (*Pinus contorta* Dougl. ex Loud.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), or white-bark pine (*Pinus albicaulis* Engelm.) interspersed with subalpine meadows or alpine tundra above timberline. The remaining zone, primarily along the Yellowstone and Lamar River valleys in the northern portion of the park, encompasses some 198,000 acres (9%) of the total park area. This low-elevation zone (5200 to 6500 feet) is underlain by glacial debris of volcanic andesite and sedimentary composition and receives less precipitation (11 to 20 inches annually). As a result, the area is dominated by sagebrush (*Artemisia* spp.) steppe and grasslands and is bordered by Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) forests. This cold-desert environment provides habitat conditions most susceptible to exotic plant invasion and establishment relative to other vegetation zones in the park. These lower elevations support large wintering herds of elk (*Cervus elaphus nelsoni* Bailey) and smaller numbers of wintering bison (*Bison bison* L.), whereas mule deer (*Odocoileus hemionus hemionus* Rafinesque), pronghorn antelope (*Antilocapra americana americana* Ord), and bighorn sheep (*Ovis canadensis canadensis* Shaw) are observed mostly during the summer or at the lowest elevations during winter. Moose (*Alces alces shirasi* Nelson) can occasionally be observed throughout the year.

PROGRAM ORGANIZATION AND RESPONSIBILITIES

The National Park Service (NPS) is mandated to prevent exotic plant introduction and to control established exotic plants by law,

executive order, and management policy (e.g., Executive Order 13112, National Park Service Management Policies [NPS 1988], Federal Noxious Weed Act of 1974 [NPS 1996]). YNP's size and ecological complexity require an effective organizational structure to develop and implement the exotic plant management program. The Exotic Plant Management Committee, composed of District Resource Operations Coordinators (ROC), the Branch Chief-Resource Operations, the Vegetation Management Specialist, and the Park Botanist, coordinates the parkwide program. The committee establishes parkwide prevention, early detection, eradication, and control priorities and protocols; establishes, tests, and refines inventory and monitoring techniques; acquires the necessary approvals for herbicide use and reports annual levels of herbicide use; seeks program funding and participates in partnership development and implementation; develops staff training workshops; and represents the park weed management program at various local, state, and federal workshops.

The Weed Management District is the core of program implementation. The park is divided into 4 weed management districts (Fig. 1) based on ecological and administrative criteria. Each district is supervised by a district ROC. The North District has an assistant ROC due to the number, size, and complexity of exotic plant invasions in the low elevations of the district. ROCs are responsible for local program development: setting district priorities within the framework of parkwide priorities, managing the district budget, hiring and training staff, coordinating district prevention and education programs, surveying and controlling exotic plants, and recording weed management activities.

District ROCs also participate in the establishment and implementation of weed management areas (WMA) with cooperating agencies across park boundaries within their respective districts. YNP is currently a partner in 4 multi-jurisdictional WMAs established in accordance with the Greater Yellowstone Coordinating Committee's Guidelines for Coordinated Management of Noxious Weeds in the Greater Yellowstone Area (GYCC Guidelines; Free et al. 1990). The Henrys Fork, Upper Madison, Upper Gallatin, and Jackson Hole WMAs were established as ecologically definable areas, irrespective of management jurisdiction, where similar weed problems exist within WMA

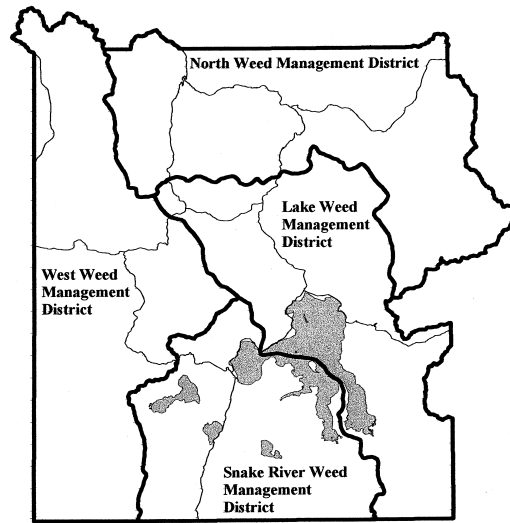


Fig. 1. Weed management district boundaries (bold lines), Yellowstone National Park.

boundaries (Fig. 2). Such recognition allows more specific weed management goals and a sharing of resources among differing administrative entities with similar weed problems.

Cooperation and participation from a variety of different individuals and park divisions are necessary for a successful weed management program in the park. Over 140 NPS staff participate in the program each year. Field and entrance station rangers assist with mechanical control of weed infestations and weed prevention by conducting hay and construction equipment inspections at entrance gates. Maintenance Division staff assist with weed prevention by cleaning construction equipment and using approved gravel in park sanding operations and construction projects. The Branch of Landscape Architecture oversees park revegetation efforts and assists with funding the exotic plant program by administering Federal Lands Highway Program funds. The Concessions Office, in conjunction with major park concessionaires, facilitates weed control in areas affected by concessionaire operations. Interpretation rangers assist with exotic plant education efforts. More than 100 short- and long-term volunteers assist annually with early detection surveys, mechanical control, and seed collection for revegetation.

Many partners from outside YNP also contribute to the program. Scientists from universities in Wyoming, Montana, and Idaho and the U.S. Geological Survey Biological Resources

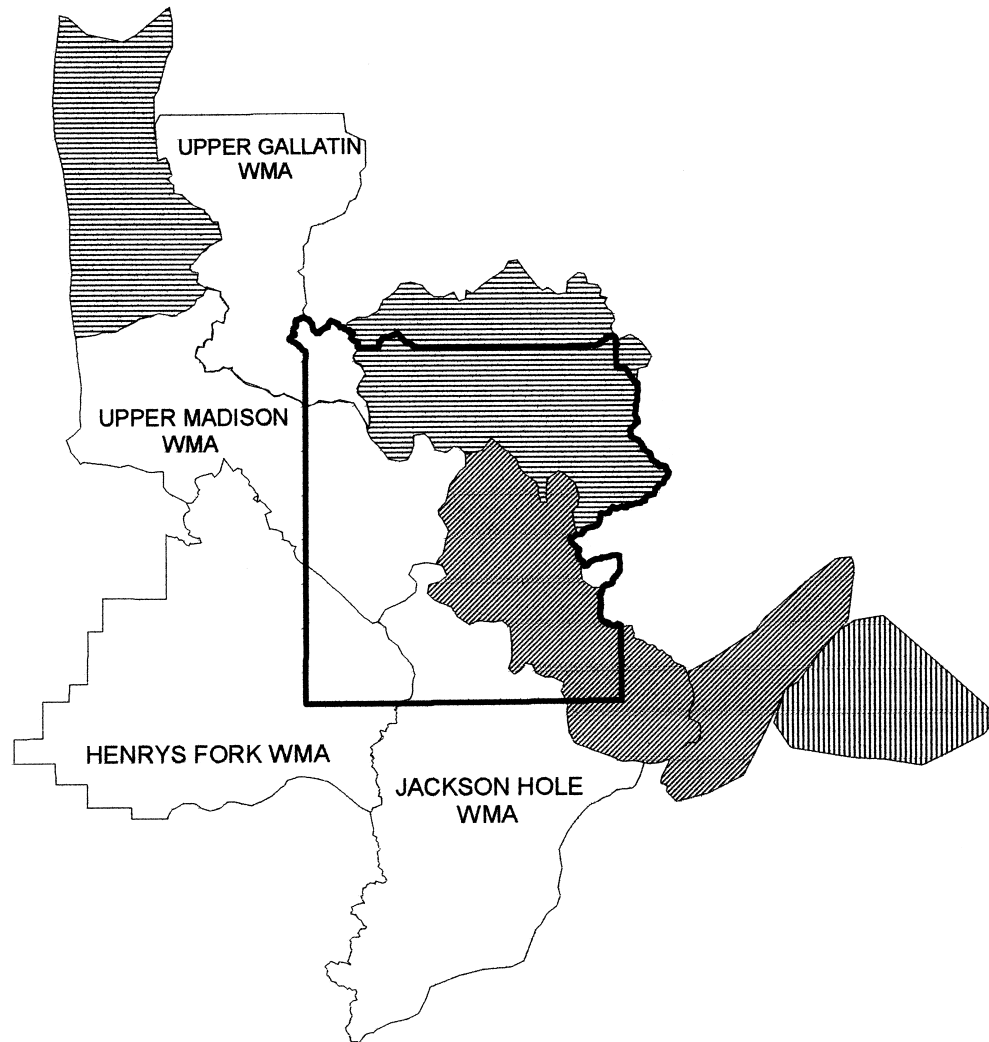


Fig. 2. Established and proposed (shaded areas) coordinated weed management areas of the greater Yellowstone region in relation to Yellowstone National Park (bold line).

Division are conducting research into the biology of weed infestations and control methods, recommending best prevention and control techniques, and assisting with staff education programs (e.g., Whitson et al. 1992). Dow Agro-Sciences and Monsanto have donated funding and herbicides for research, and have assisted with assessing and monitoring weed problems in portions of the park. Weed supervisors from counties that adjoin YNP are consulted regularly regarding local weed management issues.

Securing appropriate funds to support the weed management program has been challenging. Permanent employees with weed oversight responsibility are funded through

NPS base operating funds. All other aspects of the program, including seasonal biological technicians, equipment, supplies, and operating funds, must be funded through opportunistic, nonrecurring funding sources with no guarantee of future funding. Total annual expenditures for the weed program are approximately \$190,000. Since 1994 the Federal Lands Highway Program has funded weed monitoring and control efforts along road segments under construction. From 1994 to 1999 annual funding averaged \$80,701 and ranged from \$16,629 to \$98,624. Funds for employee housing construction also pay for some weed control. An employee housing plan and environmental

assessment (NPS 1992) states, "Two percent of actual building costs will be set aside for control and prevention of exotic plant infestations" due to the potential for invasive plants to become established after ground disturbance. Between 1995 and 1999 annual funding averaged \$16,544 and ranged from \$0 to \$26,160. Amfac Parks and Resort, the largest park concessionaire, contracts with NPS weed managers to control weeds on concessions land assignments within park boundaries. From 1996 to 1999 annual funding averaged \$2,356 and ranged from \$2,275 to \$2,700. In 1998 and 1999 the park safety committee provided \$2,200 and \$2,700, respectively, to purchase safety equipment necessary for the exotic plant management program. In fiscal year 2000 the park committed \$65,000 of Recreational Fee Demonstration Program funds to control weeds.

PROGRAM IMPLEMENTATION

YNP adopted an integrated strategy to manage exotic plants. Integrated weed management encompasses preventing weed introduction, early detection and eradication of new weed infestations, controlling and/or containing established weed infestations, educating park employees and the public about weed identification and management, and inventory and monitoring to define the extent of weed problems and assess program effectiveness (Mullin 1992, Sheley et al. 1999a).

Preventing Weed Introduction

Prevention is recognized as an initial and effective weed management strategy and requires identification of problem areas and sources of seed introduction. The vast majority of YNP's noxious weed infestations occur along park roads and in developed areas where ground-disturbing activities frequently take place. Weed seeds are transported on vehicles, equipment used in construction, and in sand and gravel used for construction and maintenance. While we have not addressed private vehicles as weed seed vectors, we are establishing a prevention program aimed at reducing weed seeds in gravel and on construction equipment. All gravel used in YNP must now either come from a source operating under an approved weed management plan or be heated to 300°F prior to being used in the park. Park weed managers are working with

local county weed supervisors and gravel pit owners to inventory gravel pits for weeds, develop weed management plans, and inspect the pits after plan implementation to monitor weed status. In addition, all equipment used in ground-disturbing construction must be pressure-washed and inspected prior to entering the park.

Recreational stock, as well as native ungulates, can also introduce and spread weeds. Seeds can be transported on animal hides or may pass through digestive systems. Weed seeds can also be dispersed through horse feed and hay. Opportunistic surveys associated with stock site inventories have not revealed high levels of noxious weeds in backcountry horse sites, and so we do not require that horses be quarantined prior to entering the park as some authors recommend (Sheley et al. 1999b). We do, however, ban all hay from being taken into the backcountry and allow only certified weed-seed-free hay to be transported through the park. YNP's Superintendent's Compendium specifies that

only weed-free pellets, cubes and/or grain, but no hay, may be taken into and used in the backcountry. Certified weed-free hay, securely wrapped, may be transported through the park for use outside the park when a permit has been obtained from the Superintendent (36 CFR 1.7[B], Section 2.16 [g]).

Even certified weed-free hay is not truly "weed-free." It is only free of weeds listed as "noxious" in its home state. The hay can legally contain many nonnative plants, including timothy, clover (*Trifolium* spp.), and yellow sweet-clover (*Melilotus officinalis* [L.] Pallas), that can become established and compromise native plant communities.

A vigorous native plant community is one of the most effective means of preventing invasion and spread of nonnative plants. We target native species revegetation on about 200 acres each year, primarily in association with road, housing, and other construction projects. Revegetation efforts have focused on careful preservation of topsoil as a growing medium and native seed source. Topsoil management is augmented by the park seed bank established in partnership with the Natural Resources Conservation Service Plant Materials Center in Bridger, Montana. Since 1987, seed has been collected within the park and increased

at the center. Seeding is done with this seed on a site-specific basis (NPS 1997).

Early Detection and Eradication of New Weed Infestations

When prevention fails, the best course of action is to identify and eradicate new species or infestations before they become well established and disperse seeds for the 1st time. We use early detection survey routes along park roads and in developed areas to accomplish this. Each year as weeds are beginning to emerge (generally June and early July), surveys are undertaken on about 4500 acres for weed infestations in the early stages of establishment. Early detection and eradication efforts are directed at 32 of 185+ nonnative plants in Yellowstone, those species that are assigned to the watch list, priority I, or priority II category (Table 1).

Controlling and/or Containing Established Weed Infestations

Many noxious weeds and nonnative plants have become firmly established in YNP because prior attempts at prevention and early detection efforts were ineffective, eradication efforts have failed, or, in the case of some nonnatives, past management practices have led to planting and protecting these species. Since the seeds of plants can remain viable for decades (e.g., oxeye daisy seeds have germinated after 39 years; Sheley and Petroff 1999), areas where weeds have dispersed seeds must be revisited for control for years, even if no plants are apparent. Thus, we have established an ongoing weed control and/or containment program that focuses on problem areas (primarily along roadsides and developed areas) and some 30 high-priority species (priority I, II, and, in limited cases, priority III species [Table 1]). Most of these high-priority species are listed as noxious in Wyoming, Montana, and/or Idaho. The majority of control effort is directed toward listed noxious species and aggressive and new invaders.

Most of our weed control effort is put into mechanical control—pulling, grubbing, mowing, or cutting weeds. Mechanical control is our first option in small infestations when the plant biology lends itself to mechanical control, and it is our only option in sensitive areas close to surface water and in thermal basins. In 1998

mechanical means were employed on 1551 (77%) of 2027 total acres treated for control.

Chemical control is a small, but important, part of our program. We employ 8 different herbicides reviewed and approved at the highest level of the NPS. Herbicides are used to eradicate and contain aggressive, high-priority species that do not respond well to mechanical control, or when staffing for mechanical control is limiting. Conservative chemical control techniques involve the use of the most selective herbicide for the target species and spot spraying individual plants over broadcast spraying. From 1989 to 1993 herbicide use averaged 34.5 pounds of active ingredient (lbs. a.i.) applied annually (Fig. 3). From 1994 to 1998 this annual average increased over fourfold to 158 lbs. a.i. Herbicides accounted for about 23% of the total area treated during 1998, where 476 acres were treated with 115 lbs. a.i., an average of less than 4 oz per acre.

Educating Park Employees and Visitors

Formal weed education efforts began in 1982 with development and circulation of a pocket-sized notebook of sketched illustrations of select noxious weeds. By 1986 color photographs were compiled, reproduced, and condensed into the “Ten Most Wanted” poster in an effort to help staff identify some of the park’s most invasive weeds. Species targeted included spotted knapweed, oxeye daisy, common tansy (*Tanacetum vulgare* L.), common mullein (*Verbascum thapsus* L.), field bindweed (*Convolvulus arvensis* L.), and houndstongue (*Cynoglossum officinale* L.). Education efforts targeting both the visiting public and park employees have grown since that time. An article entitled “Non-native Plants Impact Ecosystem” is published each spring, summer, and fall in *Yellowstone Today*, the official park newspaper, which has a circulation of approximately 775,000. Visitors traveling through the park with horses receive *Exotic Plants: Don’t Let Them Ride With You!*, a small pamphlet explaining how recreational stock users can prevent weed seeds from spreading into the park. Overnight backcountry campers receive *Beyond Road’s End*, a pamphlet with 2 full pages dedicated to identifying weeds and procedures for reporting weeds found in the backcountry.

TABLE 1. Exotic plant priority list, Yellowstone National Park. Nomenclature follows Dorn (1992) and is consistent with Whipple (2001).

Priority category	Description	Species
Watch list	Species that have not been found in Yellowstone National Park but are known to exist nearby or species that have been found in the park but removed prior to seed dispersal.	<i>Centaurea × pratensis</i> Thuill. (meadow knapweed) <i>Centaurea solstitialis</i> L. (yellow starthistle) <i>Chondrilla juncea</i> L. (rush skeletonweed) <i>Crupina vulgaris</i> Cass. (common crupina) <i>Isatis tinctoria</i> L. (dyer's woad) <i>Lythrum salicaria</i> L. (purple loosestrife) <i>Senecio jacobaea</i> L. (tansy ragwort)
Priority I	Species that have produced seed in the park, but populations are small and limited in number. These species have a high probability for eradication and are cost effective to control.	<i>Carduus acanthoides</i> L. (plumeless thistle) <i>Centaurea diffusa</i> Lam. (diffuse knapweed) <i>Centaurea repens</i> L. [<i>Acroptilon repens</i> (L.) DC] (Russian knapweed) <i>Chorispora tenella</i> (Pallas) DC. (blue mustard) <i>Dianthus</i> spp. (sweet william, grass pink) <i>Euphorbia esula</i> L. (leafy spurge) <i>Potentilla recta</i> L. (sulfur cinquefoil) <i>Onopordum acanthium</i> L. (Scotch thistle) <i>Veronica biloba</i> L. (bilobed speedwell)
Priority II	Aggressive invaders, some of which are well established in some localities, but most are confined to relatively small areas at specific locations. Containment will be the primary goal for these species.	<i>Berteroa incana</i> (L.) DC. (berteroa) <i>Cardaria</i> spp. (whitetop, hoary cress) <i>Carduus nutans</i> L. (musk thistle) <i>Centaurea maculosa</i> Lam. (spotted knapweed) <i>Chrysanthemum leucanthemum</i> L. (oxeye daisy) <i>Cirsium vulgare</i> (Savi) Tenore (bull thistle) <i>Convolvulus arvensis</i> L. (field bindweed) <i>Cynoglossum officinale</i> L. (houndstongue) <i>Hieracium</i> spp. (orange hawkweed, yellow hawkweed) <i>Hypericum perforatum</i> L. (common St. Johnswort) <i>Linaria dalmatica</i> (L.) Miller [<i>L. genistifolia</i> spp. <i>dalmatica</i> Maire & Petitm.] (dalmatian toadflax) <i>Melilotus officinalis</i> (L.) Pallas (yellow sweet-clover) <i>Silene vulgaris</i> (Moench) Garcke (bladder campion) <i>Tanacetum vulgare</i> L. (common tansy) <i>Verbascum thapsus</i> L. (common mullein, woolly mullein)
Priority III	Aggressive invaders that are dispersed over large areas of Yellowstone. Control efforts are likely to be ineffective, costly, and have deleterious effects on the park ecosystem. However, work may be done to confine the spread of these plants in sensitive areas.	<i>Bromus inermis</i> Leyss. (smooth brome) <i>Bromus tectorum</i> L. (downy brome, cheatgrass) <i>Cirsium arvense</i> (L.) Scop. (Canada thistle) <i>Elymus repens</i> (L.) Gould [<i>Elytrigia repens</i> (L.) Nevski, <i>Agropyron r.</i> (L.) Beauv.] (quackgrass) <i>Linaria vulgaris</i> (L.) Miller (yellow toadflax) <i>Phleum pratense</i> L. (timothy) <i>Poa</i> spp. (bluegrass)
Priority IV	Exotics for which no control efforts are currently foreseen. These plants, other than being nonnative, do not appear to displace native vegetation to the extent of higher-priority species. Approximately 144 species fall into this category (Whipple 2001).	

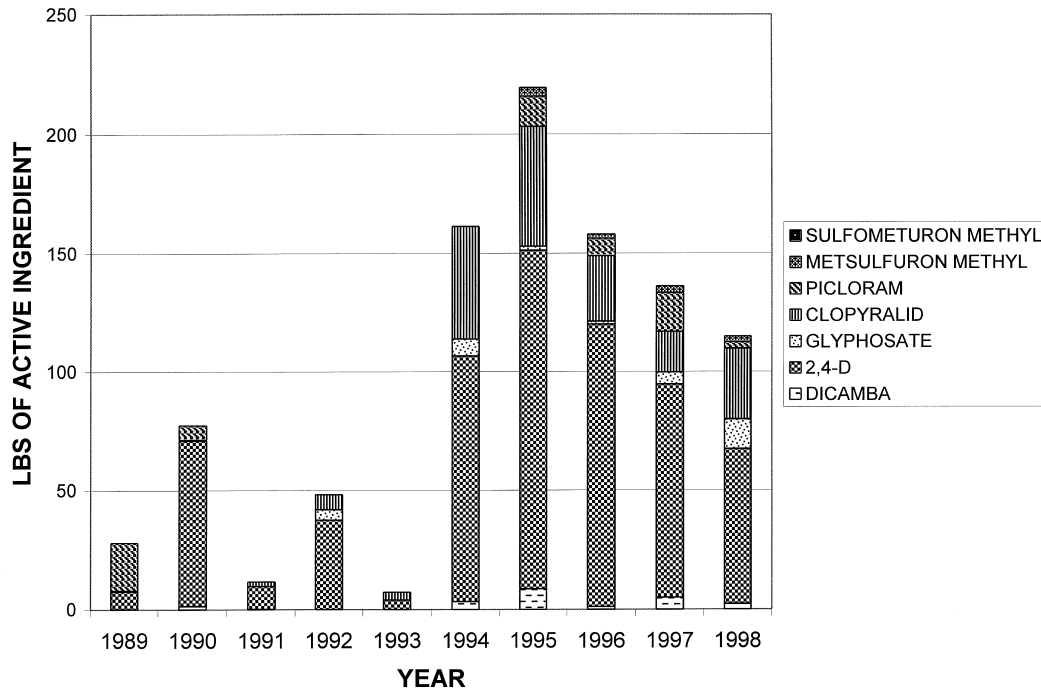


Fig. 3. Amount of herbicide, in pounds of active ingredient, applied annually from 1989 to 1998 for weed control in Yellowstone National Park.

Park employees receive updates on exotic plant identification and management at the annual Resource Management Workshop, a 3-day training session designed to share information on resource issues with park staff. In addition, the park botanist has developed a 2-hour training session on exotic plant identification that is given at field locations every 2–3 years. Since 1994, seasonal biological technicians have been required to attend a 3-day training workshop focused on weed identification and ecology, safe herbicide mixing and handling techniques, sprayer calibration, and data collection protocol. Permanent employees with weed management responsibility attend the NPS Integrated Pest Management course, maintain pesticide applicator's certification in either Wyoming or Montana, and attend continuing education courses such as state weed meetings or exotics conferences.

Inventory and Monitoring

Weed managers have emphasized the need for inventory and monitoring to quantify weed problems and evaluate program effectiveness (NPS 1986, NPS 1996, Johnson 1999). Following GYCC Guidelines (Free et al. 1990), YNP

managers developed a computerized database to monitor weed management efforts. Beginning in 1993, several aspects of management actions and weed conditions were recorded in a standardized spreadsheet on an annual basis. Most information derived from the database has been for administrative purposes, i.e., quantifying the amount of time, money, and effort put forth by resource management personnel in weed management. We have made few attempts, however, to use the database to quantify weed problems or describe characteristics of weed populations throughout the park.

The YNP weed management database encompasses 31 different fields that capture yearly survey and control efforts by weed management district. Database items include the species encountered, a UTM coordinate location obtained from 7.5-minute topographic maps or global positioning satellite technology, patch size (in ft²), a qualitative estimate of plant density (low to high), type of treatment or chemical mix/quantity where appropriate, and other secondary data relative to location (state, county, road segment, drainage, YNP jurisdictional unit, etc.). The information derives

from systematic survey efforts in the developed areas and along road corridors, as well as opportunistic backcountry observations. District weed managers and technicians regularly record pertinent information on field forms during the summer season and transfer the information into a relational database (Microsoft Access) at a later date. District-wide weed information is then pooled to represent park-wide weed management activities and conditions observed within a given year. Because of this, the database captures only those weed management activities that take place within a given year and does not necessarily reflect the totality of weed conditions within the park at any one point in time. For this analysis we used parkwide independent records by site location for the years 1995–1997 to consider all known weed patches. We further focused our analysis on 15 different weed species, all of high management priority.

The database query of independent records for 15 select weed species from 1995 to 1997 revealed 1571 records covering 2596 total acres (Table 2). The North District accounted for 46% ($n = 722$) of total records and 83% ($n = 2142$ acres) of total area affected. Musk thistle (*Carduus nutans* L.), Russian knapweed (*Centaurea repens* L. [*Acroptilon repens* (L.) DC.]), spotted knapweed, oxeye daisy, field bindweed, and hoary cress occurred in greatest proportion within the North District, occupying 77–100% of the area reported for each species. On the other hand, the West District supported the greatest proportional area for

common St. Johnswort (*Hypericum perforatum* L.), common tansy, and hawkweeds (*Hieracium* spp.), ranging from 51% to 99%. The West District also recorded the 2nd greatest proportional area for both oxeye daisy (22%) and spotted knapweed (14%). The Lake and Snake River districts each experienced <35 total acres across all species. Hawkweed, spotted knapweed, and musk thistle occupied 81% ($n = 27$ acres) of the total area reported for the Lake District. Weed problems in the Snake River District for the species reported here occurred primarily as scattered, isolated individuals.

Spotted knapweed was the most commonly reported species in all districts, accounting for 56% ($n = 878$) of total records and 64% ($n = 1664$ acres) of total area reported here (Fig. 4). Eighty-six percent ($n = 1424$ acres) of the area and 45% ($n = 398$) of the records for spotted knapweed were reported from the North District. Of 1664 acres parkwide, 70% ($n = 1167$ acres) were of low-density (<1 plant · 100 ft⁻²) compared to only 8% ($n = 90$ acres) of the total area experiencing high-density (1 plant · ft⁻²) infestations.

A frequency vs. size class distribution showed the majority (81%, $n = 714$) of records for spotted knapweed were <1 acre in size and only 3 records were for areas >100 acres. Two of these 3 records were of scattered individuals and small patches continuous with the roadside prism along major road sections. Fifty-four percent ($n = 386$) of the patches <1 acre in size were of the “incidental” variety,

Table 2. Acreage and number of records (in parentheses), by weed management district, for 12 priority weed species under control in Yellowstone National Park. Data were derived from independent records by location ($n = 1571$) for the years 1995–1997 maintained in a computerized database.

Weed species	Common name	District				Totals
		North	West	Snake	Lake	
<i>Carduus nutans</i>	musk thistle	70 (18)	5 (7)	<1 (2)	4 (17)	79 (44)
<i>Hieracium</i> spp.	hawkweeds	<1 (7)	19 (9)	<1 (8)	18 (27)	37 (51)
<i>Centaurea diffusa</i>	diffuse knapweed	0	<1 (8)	<1 (2)	<1 (1)	<1 (11)
<i>Centaurea repens</i>	Russian knapweed	3 (20)	0	<1 (1)	<1 (2)	3 (23)
<i>Centaurea maculosa</i>	spotted knapweed	1424 (398)	234 (305)	<1 (82)	6 (93)	1664 (878)
<i>Tanacetum vulgare</i>	common tansy	<1 (4)	5 (23)	<1 (13)	<1 (6)	5 (46)
<i>Chrysanthemum leucanthemum</i>	oxeye daisy	147 (45)	41 (71)	<1 (21)	2 (48)	190 (185)
<i>Convolvulus arvensis</i>	field bindweed	110 (105)	<1 (6)	<1 (1)	<1 (2)	112 (127)
<i>Cardaria draba</i>	hoary cress; whitetop	387 (120)	0	0	0	387 (120)
<i>Euphorbia esula</i>	leafy spurge	<1 (1)	<1 (5)	0	<1 (1)	<1 (7)
<i>Potentilla recta</i>	sulfur cinquefoil	<1 (3)	<1 (1)	0	<1 (3)	<1 (7)
<i>Hypericum perforatum</i>	common St. Johnswort	<1 (1)	117 (62)	<1 (4)	1 (5)	118 (72)
TOTALS		2142 (722)	421 (497)	1 (134)	32 (218)	2596 (1571)

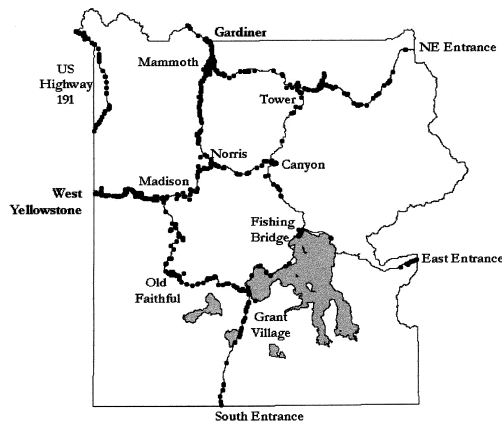


Fig. 4. Distribution of spotted knapweed in Yellowstone National Park. Data were derived from independent species records by location ($n = 878$) for the years 1995–1997 maintained in a computerized weed database.

whereby single to very widely scattered individuals were recorded in an area $<400 \text{ ft}^2$. Although these incidental records represent a costly database item with regard to field documentation and database entry/storage, they nonetheless provide a useful index of occurrence per linear mile along major road corridors (Table 3). These data are important to assess causes and trends in spotted knapweed invasion and establishment and perhaps quantify the effectiveness of prevention and early detection components of the weed management program.

CURRENT AND FUTURE CONSIDERATIONS

The exotic vegetation management program is subject to concern, scrutiny, and controversy. While relying on mechanical, cultural, and chemical control, no active program using biological control agents is employed. Differences in management philosophy and inadequate understanding of the ecological effects of purposeful nonnative introductions (e.g., Louda et al. 1997, Strong 1997, Callaway et al. 1999) have precluded an active biological control program. Historically from 1969 to 1974, a rearing-and-release program for a defoliating moth (*Calophasia lunula* Hufn.) was attempted in the park to control dalmatian toadflax (*Linaria dalmatica* [L.] Miller [*L. genistifolia* ssp. *dalmatica* Maire & Petitm.]). The program was discontinued apparently because of poor rearing

success and insufficient release stock. More recently, biocontrol agents have been released near the park, and some agents have migrated across park boundaries. Observations of ovary-feeding beetles (*Brachypterolus pulicarius* L.) have been made on both yellow toadflax (*Linaria vulgaris* Miller) and dalmatian toadflax, a capsule-feeding weevil (*Gymnaetron* spp.) was collected from yellow toadflax, and galls of seedhead-feeding flies (*Urophora* spp.) were observed on spotted knapweed. It is unlikely that biocontrol agents or emerging technologies involving plant genetics would be embraced in Yellowstone without addressing philosophical or ecological concerns weighed against current control practices.

Chemical rather than biological control generates the most controversy, ranging from appropriateness in a national park to the specific effects on wildlife, soil, and water resources. Human health and safety issues for applicators, employees, and visitors are also expressed. We try to balance these concerns with our management objectives, recognizing that (1) more passive weed management is most detrimental to overall ecosystem structure and function and has the greatest negative economic impact to individuals and agencies outside park boundaries, and (2) human health problems can be prevented. Written records are kept for areas that have been sprayed; information includes type of herbicide used and duration of human exclusion. Herbicide applicators wear full personal protective equipment, including Tyvek® suits with hoods, rubber boots and gloves, and breathing filters and goggles. We are entering into a partnership with the Environmental Protection Agency to review our herbicide storage and mixing techniques and possibly assess health effects associated with repeated herbicide handling for long-term employees in the weed control program.

Levels of herbicide use from 1994 to 1999 appear more commensurate with the degree and threat of exotic plant infestations and do not necessarily represent a continuing trend of increased reliance on herbicides for control. Rather, previous levels of herbicide use were apparently inadequate or insufficient to control incipient weed problems. Recent creative funding efforts have resulted in short-term increases in staffing, survey, and control. We anticipate a declining trend in herbicide use

TABLE 3. Number of records ($n = 386$) of spotted knapweed $<400 \text{ ft}^2$, and an index of the number of records per mile of road, along major road segments within Yellowstone National Park.

Road corridor	Linear miles of road	Number of records	Records per mile of road
Gardiner–Mammoth	5.6	40	7.1
Mammoth–Tower	18.1	14	0.8
Tower–NE Entrance	28.7	53	1.8
Tower–Canyon	18.3	6	0.3
Canyon–Norris	11.6	15	1.3
Norris–Mammoth	20.9	68	3.3
Norris–Madison	13.3	15	1.1
Madison–West Yellowstone	13.9	9	0.6
Madison–Grant	33.5	47	1.4
Grant–S Entrance	21.5	40	1.9
Grant–Fishing Bridge	20.6	10	0.5
Fishing Bridge–E Entrance	26	5	0.2
Fishing Bridge–Canyon	15.4	9	0.6
US Highway 191	20.2	55	2.7
TOTALS	267.6	386	1.4

over time with effective control unless large areas have yet to be identified or control emphasis shifts to more ubiquitous, lower-priority species.

More active revegetation of weed-infested areas to native plant communities would similarly contribute to decreased levels of herbicide use. To date, most revegetation efforts have been directed toward reclaiming construction disturbance rather than restoring weed-infested areas. We have, however, initiated experimental trials for reclamation of lands dominated by exotic crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.), desert alyssum (*Alyssum desertorum* Stapf), and/or Russian thistle (*Salsola australis* R. Br. [*S. tragus* L.]). These areas encompass some 570 acres in the core of ungulate winter range near the gateway community of Gardiner, Montana (Houston 1982). A 125-year history of human disturbance, including hay operations for ungulate forage production, cattle grazing, channeling ground water for irrigation purposes, and railroad operations, has resulted in monocultures of exotic plant communities. Experimental trials will be used to enhance native plant reestablishment as part of an overall site rehabilitation plan.

Budget limitations require the prioritization of weed species for management purposes, preclude expanded management efforts, and cast doubt on maintaining current activity beyond the short term. Given current levels of monitoring and the structure of the weed management database, no direct measure of success can be made. The information presented here, however, will be a useful baseline

from which to compare future conditions and assess program effectiveness provided comparable management effort is maintained. More emphasis on base funding would allow a structured survey and quantitative assessment of backcountry areas, inclusion of more species for aggressive control, and increased monitoring efforts to quantify the behavior of target species under control and the response of the vegetation community to herbicide application. Until then, opportunistic funding sources will be required to address these and other concerns.

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