Extension/Outreach

Evaluating Montana's Dyer's Woad (*Isatis tinctoria*) Cooperative Eradication Project

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Eradication is often stated as an essential element of weed management. Assessing the costs and benefits of eradication programs is often difficult because doing so requires speculation about the impacts and spread of weeds if eradication measures were not undertaken. The objective of this article is to describe and assess the Montana Dyer's Woad Cooperative Project, a program aimed at eradicating dyer's woad from Montana. The Project comprises four key components: early detection, treatment technologies, repeated site visits with monitoring, and education. To evaluate the success of the Montana Dyer's Woad Cooperative Project, we used monitoring data to observe the change in the number of counties where dyer's woad is present, plotted the trend in population size over time, and evaluated change in infestation size. We also predicted population spread based on the 1999 population size and demographic characteristics of dyer's woad. Dyer's woad has been eradicated from 9 of 13 infested counties in Montana, and infestation sizes have decreased in the remaining infested counties. In some counties, a containment effort was needed in conjunction with repeated inventories and treatment applications to prevent spread while depleting the seedbank to the point where eradication is possible. If not for the Project, our analysis suggests that some dyer's woad populations might consist of millions of plants, potentially covering 39,021 ha in Montana and costing $1.9 million/yr to manage. In comparison, the Project has reduced the total area infested in Montana to 2.6 ha and cost the state only $142,000 for the past 7 yr of management. In Montana, dyer's woad eradication from individual counties has been successful because of persistence and ongoing cooperative efforts.

Nomenclature: Dyer's woad, *Isatis tinctoria* L. ISATI.
Key words: Cost–benefit analysis, early detection, prevention, rapid response.

In some cases, a weed introduction is discovered relatively early, its invasive potential is well documented, and an eradication program is initiated before the species expands to the point where containment may be the only management option. Land managers fortunate enough to be in this position must develop effective programs to eradicate known weed infestations, locate unknown infestations, and prevent their expansion and establishment into weed-free areas.

Central to developing an effective eradication program is clarifying the difference between eradication and control. Eradication is complete elimination of the species from a site, including depletion of its propagules from the soil (DiTomaso 2000). Control, on the other hand, is containment of large infestations, combined with reduction of the population below an acceptable level (Zamora and Thill 1999).

Recognizing the similarities between eradication and prevention is also central to developing an effective eradication program. An effective eradication program is closely tied to prevention, although the initial conditions of each are somewhat different. Initial conditions during eradication require weeds and their propagules to already be present in a designated area, with the goal being complete removal of the weed and its propagules from that area. The initial conditions for prevention require weeds and their propagules to be absent in the designated area, and the goal is to maintain weed-free areas.

A key element in an eradication plan is early detection and rapid response. If weed infestations are detected early and responded to rapidly, they are usually small and it is still feasible to treat them with highly efficacious methods with limited expense. Early detection and rapid response reduces or prevents reproduction that can lead to further spread. Also critical to an eradication plan is continued monitoring of sites to treat plants that were missed or that germinated from the seedbank since previous site visits. Control options are usually limited to mechanical removal and herbicides because the infestations are small and often isolated (DiTomaso 2000). Compared with eradication programs, prevention programs take a relatively more comprehensive approach and focus on limiting weed seed dispersal, containing neighboring weed infestations, minimizing soil disturbance, establishing competitive plants, and properly managing plants in addition to early detection and monitoring (Sheley et al. 2002).

Education is another critical component of eradication programs. Education programs increase the awareness of land mangers and the general public and increase the likelihood of detecting infestations early, so they can be responded to rapidly. Weed awareness and weed identification skills can be improved through media such as brochures, posters, newspaper articles, websites, radio announcements, and scientific papers. Educational events like workshops, field tours, community weed pulls, and bounty programs can be directed toward local landowners and public land managers. An effective educational program will facilitate cooperation among public land managers, university personnel, landowners, industry, and the general public.

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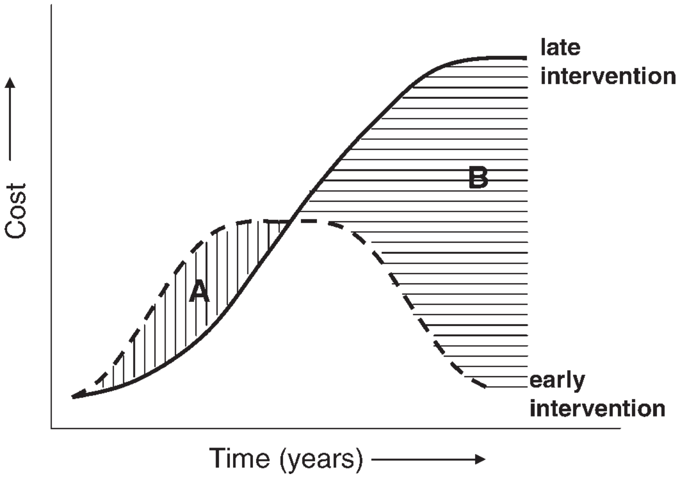

Figure 1. Cost of weed invasion (economic loss due to invasion + control costs) over time for infestations where intervention (dashed line) occurs early vs. late (solid line). Early intervention may be more expensive at first, area A (vertical shading), but resulting benefits, area B (horizontal shading), outweigh initial costs (Adapted from Chippendale 1991; Hobbs and Humphries 1995).

Eradication is often stated as an essential element of weed management (DiTomaso 2000; Sheley and Petroff 1999). More often than not, though, eradication is not attempted, even when feasible, because weed managers tend to be reactive rather than proactive and because there is a high level of cooperative effort and expense required for eradication programs. Eradication should be attempted if a cost–benefit analysis suggests the cost of eradication is less than cost of long-term control efforts (Zamora and Thill 1999). Assessing the cost–benefit of an eradication program is often difficult because it requires speculation about the impact and spread of the weed if eradication measures were not undertaken. If the species has a high potential to become invasive based on its behavior in other areas, the rate of reintroduction is low, and adequate, inexpensive technology is available to carry out the eradication plan, it will be easier to convince potential cooperators that eradication is the most desirable management option. Even though managers may be apprehensive about diverting resources from other more apparent, pressing weed problems (Hobbs and Humphries 1995), it should be emphasized that early intervention can significantly reduce the cost of weed management in the future (Chippendale 1991) (Figure 1).

As with any weed management activity, a cohesive, carefully designed plan will increase the chances of achieving management goals. Four key components are suggested for eradication programs: early detection and rapid response, efficacious control methods, careful monitoring, and education (DiTomaso 2000). In addition, adequate resources are needed to fund the program to its conclusion, and lines of communication must be clear to all invested individuals (Myers et al. 2000; Simberloff 2003). Eradication plans that contain these components have been successful because they were diligently implemented by many committed cooperators. For example, witchweed [*Striga asiatica* (L.) Kuntze] is a parasitic plant that attacks two important U.S. crops, corn (*Zea mays* L.) and sorghum (*Sorghum* spp.). First discovered in North Carolina in 1955, witchweed was aggressively surveyed and treated with herbicides, soil fumigants, cultural practices, and quarantine. After 50 yr, it has been contained to North and South Carolina, where an estimated 99% of the original infestations have been eradicated (APHIS 2000; Eplee 2001). Another example of success is California's aggressive eradication plan for hydrilla [*Hydrilla verticillata* (L.f.) Royle], a submerged, freshwater weed. Water surface and subsurface surveys, chemical and hand-removal treatment, and educating the public via brochures and signs at heavily used recreational sites has resulted in 60% of infestations being eradicated and no new infestations being reported since 1997 (CDFA 2003; O'Connell 1997).

The objective of this article is to provide an in-depth description and assessment of the Montana Dyer's Woad Cooperative Project, a program aimed at eradicating dyer's woad. We present and evaluate the progress to date on two decades of eradication efforts in Montana. This project can serve as an example for those faced with similar situations.

Montana's Dyer's Woad Cooperative Project: An Eradication Case Study

Dyer's woad, originally from southeastern Russia, was introduced to the eastern United States in the 17th century as a cultivated medicinal herb and textile dye crop (Varga and Evans 1978). It was accidentally spread to California and Utah as a crop-seed contaminant and as a horticultural and medicinal gardening plant; from which point, it spread throughout the West (Callihan 1990). Dyer's woad presents few management problems in the eastern United States, but it is considered invasive and noxious in western states. The rapid expansion of this plant may be because of its adaptation to alkaline soils and arid climates of the West (McConnell et al. 1999).

Dyer's woad is frequently found on dry, rocky-to-sandy soils in disturbed and undisturbed sites, including roadsides, railroad right-of-ways, forests, fields, pastures, and rangelands. Dyer's woad plants have an accelerated growth rate from the rosette to flowering stages, up to 10 cm in 1 wk, making it highly competitive and able to dominate plant communities (McConnell et al. 1999). In addition, dyer's woad is a prolific seed producer, producing an average of 383, but up to 10,000, seeds per plant, enabling it to rapidly invade disturbed or undisturbed sites (Farah et al. 1988; McConnell et al. 1999). For example, a dyer's woad infestation in Montana spread from 0.8 to 40.5 ha in 2 yr (Aspevig et al. 1985). The spread of dyer's woad is coupled with environmental and economic impacts. For example, on Bureau of Land Management lands in the Pacific Northwest, the annual spread rate of dyer's woad averaged 14%, which reduced grazing capacity by 38% (USDI 1985). Additionally, in 1981, dyer's woad was estimated to cost Utah $2 million in reduced crop and rangeland production (Evans and Chase 1981).

Early detection and rapid response is critical to eradicating new infestations of dyer's woad (McConnell et al. 1999). Dyer's woad was first found in Montana in 1934 (Hitchcock 1934). Since then, occurrences have been found and treated in

13 Montana counties. Most infestations are thought to have resulted from contaminated vehicles, railroad cars, or construction equipment (J. Eddie, P. Fay, and C. Williams, personal communication). Montana land managers recognized the potential for this species to become a detrimental invasive weed, particularly in areas with large amounts of rangeland and pasture because of its invasiveness in similar habitats in other western states. In response to concerns about dyer's woad, in the early 1980s former Montana State University (MSU) Extension Weed Specialist Dr. Pete Fay started researching effective management practices for dyer's woad and working with MSU students and personnel and county weed crews to pull dyer's woad and contain the infestations. With expanding dyer's woad populations in other states and because Montanans have seen other weeds like spotted knapweed (*Centaurea maculosa* Lam.) spread over millions of hectares, Montana developed an intensive and unified eradication effort for dyer's woad.

In 1984, the dyer's woad eradication program became a formal entity and was officially dubbed the Montana Dyer's Woad Cooperative Project. The Project is governed by an eight-member board comprising the Montana Dyer's Woad Task Force that provides clear lines of communication and authority necessary for others to take action. In particular, the Task Force sets and communicates a common statewide goal for dyer's woad among landowners, managers, scientists, and the general public and provides the basis for ongoing dialogue. The Task Force also hires and oversees a Project Coordinator (authors are current and past project coordinators, respectively) who manages a dyer's woad field crew. Funding for the Montana Dyer's Woad Cooperative Project is provided from the Montana Noxious Weed Trust Fund with matching funds from counties, the University of Montana, and Headwaters Resource Conservation and Development. With years of adequate funding, the Montana Dyer's Woad Cooperative Project has been a proactive management entity.

The Montana Dyer's Woad Cooperative Project's overall objective is to eradicate dyer's woad from Montana. Paralleling the essential components of an eradication plan that were mentioned in the Introduction, the eradication Project's four-part approach for obtaining the objective includes (1) early detecting of new infestations, including inventorying areas surrounding known infestations for potential spread of dyer's woad; (2) biweekly managing of known dyer's woad infestations with readily available treatment technologies throughout the growing season; (3) monitoring known infestations with a Global Positioning System (GPS) and recording data in the GPS data dictionary; and (4) educating the public and land managers on dyer's woad identification and management.

Sites. Dyer's woad has been found in the following Montana counties: Beaverhead, Cascade, Chouteau, Dawson, Gallatin, Judith Basin, Missoula, Musselshell, Park, Pondera, Silver Bow, Sweet Grass, and Yellowstone. Currently, only Beaverhead, Missoula, Park, and Silver Bow counties have existing infestations. All sites are semiarid, shrub–steppe or grassland plant communities. In general, these sites are along railroads, roads, trails, and creeks where dyer's woad is thought to have spread primarily through vehicle traffic and construction activities. In Missoula County, the infestation started when dyer's woad escaped a pharmaceutical garden at the University of Montana and began growing on an adjacent hillside (Hitchcock 1934).

Methods. The Project's early detection efforts are integrated with the Project's education component at state, local, and site levels. At the state level, dyer's woad is included in weed education and awareness campaigns. The Project educates land managers and owners across the state on dyer's woad identification. The "Bounty Program" provides an incentive to notify the Montana Dyer's Woad Cooperative Project about new infestations. A person finding dyer's woad more that 1 km from a known infestation is paid $50 by the Project.

At the local level, county weed coordinators teach weed crews and residents dyer's woad identification and what to do if they find an infestation. Early detection also occurs by inventorying or surveying potential spread routes of known infestations. This includes surveying roads, railroads, creeks, and suitable habitat for new infestations. The distance traveled on these routes varies from 3 to 20 km, depending on potential spread vector. For example, crew members currently survey a creek for 3 km before it enters a larger body of water and survey railroad tracks for 20 km between two known infestations.

At the site level, the dyer's woad field crew visits infestations every 2 wk from mid-May through October. Until 2003, sites were surveyed for dyer's woad by randomly walking through the known infestation. In 2004, the project started using a systematic inventory method to ensure all areas were inspected and increase dyer's woad detection probability. At a dyer's woad infestation site, crew members systematically inventory the site for new and existing populations by walking parallel transects over the entire area. The distance between surveyors is adjusted in the field based on the plant's growth stage, topography, and associated vegetative cover. To determine the distance between transects, crew members walk away from a dyer's woad plant until they are no longer confident they would see it. This is the determined distance between crew members. Fortunately, dyer's woad can reach 90 cm tall in the flowering stage and is easily located. Once a mature plant is found, the surrounding area is searched thoroughly for additional seedlings and rosettes.

When dyer's woad is found, inexpensive and effective treatment technologies are used to remove or kill the plant. This includes hand-pulling, digging, and spot-spraying with metsulfuron at 70 g ai/ha plus nonionic surfactant. County and University of Montana weed crews assist in spraying large or dense infestations where hand-pulling and spot-spraying are impractical. If the plant is flowering or producing seed, plants are removed from the site in double-lined, plastic bags. Bolting and rosette plants are pulled and left on site. A combination of cutting and removing the flowering- or seed-producing stem with spot-spraying of the remaining basal leaves has been the most effective treatment because it kills root fragments inadvertently left in the soil. Because sites are inventoried and plants treated biweekly throughout the growing season, few to no seeds are produced.

Dyer's woad infestations are monitored on an annual basis to evaluate changes in condition (size, density, and location) and progress toward meeting the Project objective. The location (Universal Transverse Mercator [UTM]) of an infestation is documented using a GPS unit. The size (hectares), shape, and dyer's woad canopy cover of the infestation are recorded in the GPS data dictionary. In addition, the number of plants pulled and sprayed is recorded.

Education is a vital component of the Montana Dyer's Woad Cooperative Project. The Project works to educate the public, landowners, and land managers throughout Montana about the threat of dyer's woad and its field identification. Project coordinators write and distribute regional newspaper articles, develop educational signs, post informational flyers, write Extension publications, and give presentations on dyer's woad and the eradication project. In addition, county weed-district personnel distribute dyer's woad information and discuss dyer's woad identification and management at weed pulls, field tours, and county fairs. The dyer's woad field crew also talks with people living near dyer's woad infestations and distributes weed identification flyers and books.

Evaluating the Success of Montana's Eradication Project

Most weed managers argue that eradication, or early detection and rapid response, is an essential and cost-effective part of a weed management program because it reduces the probability that a species becomes invasive by eliminating it before it becomes abundant, spreads, or evolves adaptations to increase its competitive ability (Allendorf and Lundquist 2003). However, measuring the benefits and costs of an eradication program is challenging (Myers et al. 2000) because it is difficult to predict various management measures and scenarios and because monetary benefits are hard to calculate on environmental resources with no defined market value (Simberloff 2003).

To evaluate the success of the Montana Dyer's Woad Cooperative Project, we used monitoring data to observe the change in the number of counties where dyer's woad is present, plotted the trend in population size over time, and evaluated change in area infested. We also used a more novel approach of predicting population spread based on numbers of plants treated and the demographic characteristics of dyer's woad.

Dyer's woad has been eradicated from 9 of 13 infested counties in Montana (Figure 2). An infestation is considered eradicated if no plants have been found on the site for 8 consecutive yr or if only one nonseed-producing plant was found and removed from a site and no additional plants have been present since. In the counties where dyer's woad is currently present, infestation size has declined dramatically (Table 1). The number of plants treated (pulled or sprayed) each year per county is presented in Figure 3. Detailed data before 1999 was unavailable; therefore, no data exist for some counties other than presence and absence data.

Sweet Grass, Gallatin, and Dawson counties have had individual dyer's woad plant occurrences in previous uncontaminated areas. These three occurrences speak to the effectiveness of the Project at early detection, rapid response,

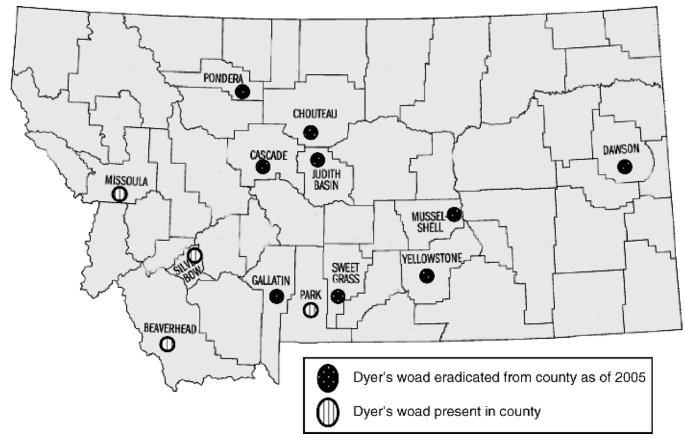

Figure 2. Current and eradicated dyer's woad locations in Montana.

and an effective education program. The identification and elimination of newly established populations was essential for eradication. By minimizing the time between dyer's woad introduction and detection, the plant was eliminated at the local scale and prevented from producing seed and becoming a widespread problem.

Dyer's woad population in Silver Bow county has declined from approximately 4 ha in 1989 to five plants in 2005 contained to approximately 0.01 ha (Mullin 1989) (Table 1; Figure 3). Even though no plants were found in this county in 2002, 2003, and 2004, biweekly inventories and annual monitoring ensure the seedbank is depleted and no additional seeds are produced.

In counties that had large infestations in 1985, a containment effort was needed in conjunction with repeated inventories and treatment applications to prevent spread while depleting the seedbank to the point where eradication is possible. Beaverhead, Missoula, and Park counties, the largest and oldest dyer's woad infestations in Montana, all had increases in the number of dyer's woad plants in 2004, and Missoula and Beaverhead counties had additional population increases in 2005 (Figure 3). The increase in plant numbers in recent years may reflect increased spring precipitation, which provided an improved germination environment, or the intensified inventory effort by the field crews in 2004 and 2005 in which previously undetected dyer's woad patches were located. In Park County, the increased inventory and

Table 1. Current and historic area covered by dyer's woad, per county in Montana, where it has not been considered eradicated. The total historic area was never measured with a Global Positioning System (GPS); therefore, infestation area was based on the knowledge of the local county weed supervisor, herbarium specimen labels, and Montana Department of Agriculture records.

County	Current area infested (2005)[a]	Historic area infested (1985)	Current average canopy
	ha	ha	%
Beaverhead	1.3	85	Low (1–5)
Missoula	0.85	32	Low (1–5)
Park	0.45	73	Low (1–5)
Silver Bow	0.01	4	Trace (1–10 plants)

[a] Current area infested is the sum of the area of isolated weed points scattered over multiple hectares; therefore, infestation area is not contiguous.

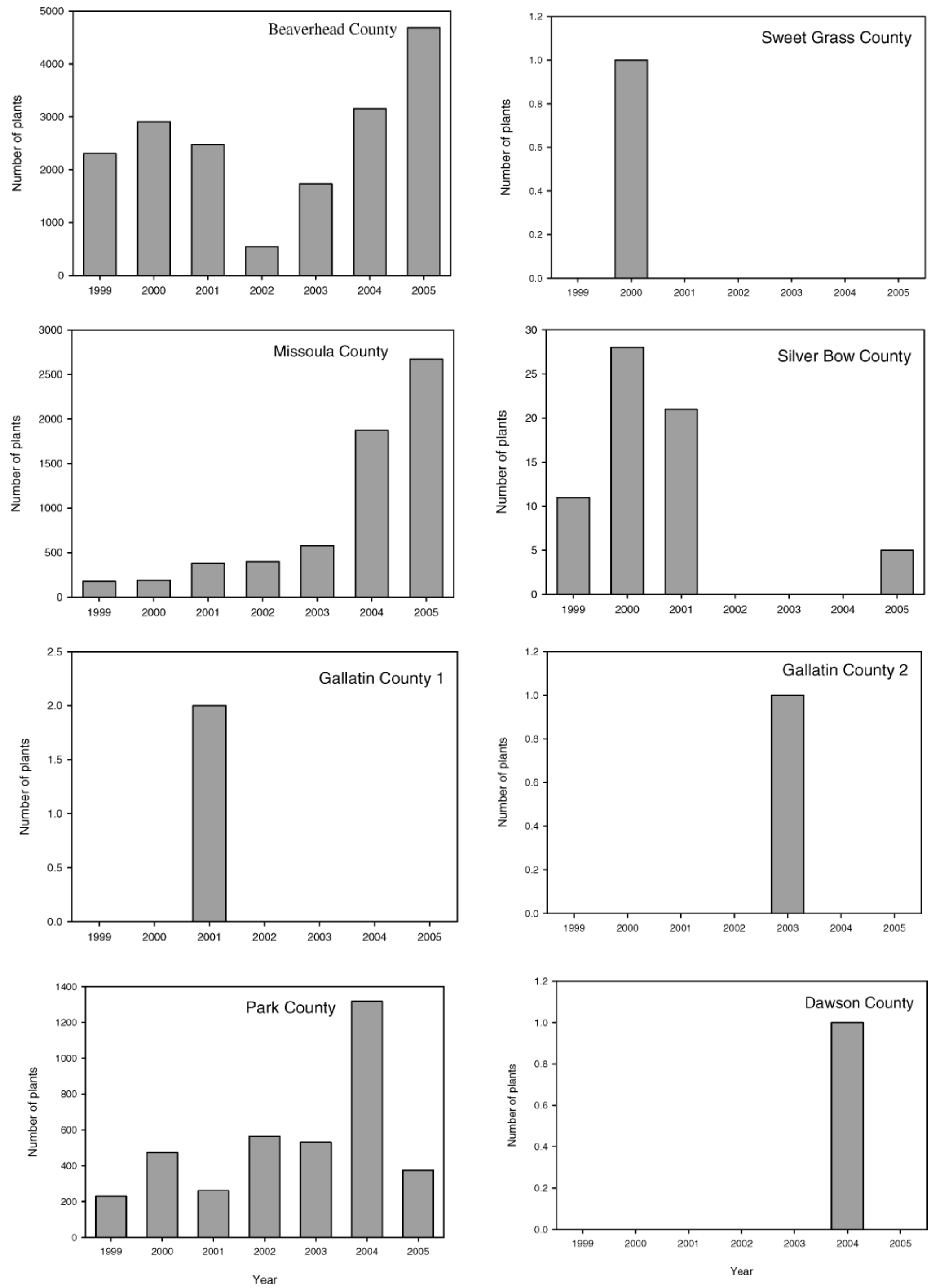

Figure 3. Number of dyer's woad plants treated for eight Montana counties from 1999 to 2005. Values on the y-axis vary per graph. Gallatin County is separated into two graphs because the infestations are 145 km apart. All infestations, except Gallatin County 2 and Dawson County existed before 1999.

treatment efforts resulted in a decline in dyer's woad numbers in 2005. Overall, from 1984 to 2005, the infestation has also declined in Park County from approximately 73 ha to 0.45 ha and from more than 100,000 plants to 374 plants, respectively (P. Fay and C. Williams, personal communication) (Table 1). Given that all flowering plants were removed in June 2005 and no plants were found in Park County from July through October 2005, we are optimistic that a downward trend will continue.

The 2004 and 2005 population size increase in Beaverhead and Missoula Counties reflects newly detected patches of seedlings, a possible result of more intensive inventories in these years. Both these counties have seen large declines in infestation area from 1985 to 2005 (Table 1). With

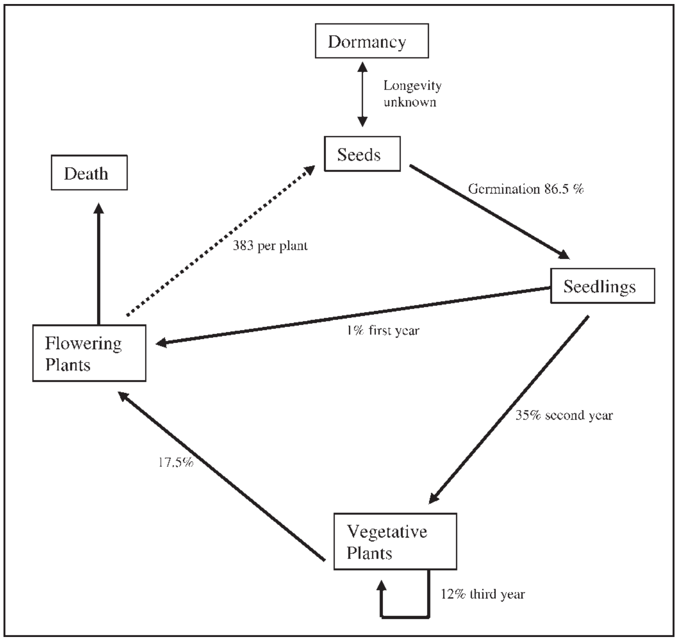

Figure 4. Phenological progression and average survival rate of dyer's woad in a field setting (Adapted from Farah et al. 1988).

Table 2. Projected potential dyer's woad growth rate in Montana without the Cooperative Dyer's Woad Project.

Year	Seedlings	Flowering plants	Vegetative plants	New seeds
		No.		
1999		2,725[a]		
2000	902,779[b]	9,028[c]	315,973[d]	3,457,643[e]
2001	2,990,861	76,176	1,046,801	29,175,420
2002	2.52×10^7	3.59×10^5	8.83×10^6	1.38×10^8
2003	1.19×10^8	2.38×10^6	4.17×10^7	9.10×10^8
2004	7.87×10^8	1.28×10^7	2.76×10^8	4.90×10^9
2005	4.24×10^9	7.78×10^7	1.48×10^9	2.98×10^{10}

[a] Total number of dyer's woad plants treated in 1999 was used to extrapolate the number of plants that would occur in 2005.

[b] The total number of plants treated in the previous year multiplied by the average number of seeds a dyer's woad plant produces (383) and assuming a 86.5% germination rate.

[c] Of the germinated seedlings, 1% will flower and produce seeds in the first year. Of the vegetative plants, from the previous year, 17.5% will flower and produce seed the second year. Vegetative plants were not included in the 2000 calculation because the number of vegetative plants in 1999 was unknown. Because dyer's woad is monocarpic, all plants that reach the flowering stage are subtracted from the population after they produce seed.

[d] Of the germinated seedlings, 35% will remain in the vegetative stage, and the rest will not survive.

[e] The total number of flowering plants multiplied by the average number of seeds a dyer's woad plant produces.

continued diligent eradication efforts, we hope to see major improvements in these counties in 2006 and beyond. In comparison to more than 100,000 dyer's woad plants pulled in Beaverhead county in both 1984 and 1988 (J. Eddie and P. Fay, personal communication), the 2005 population represents only 5% of the original infestation and reflects the Project's success to date. Continued intensive inventories, repeated treatments, and monitoring are needed to decrease the Beaverhead and Missoula County's dyer's woad infestations in the future so that eradication can be achieved. (The 2006 field season, completed after this article was written and submitted, located and treated 1,888 dyer's woad plants statewide compared to 7,735 dyer's woad plants treated in 2005. The largest declines in population size were in Beaverhead and Missoula Counties.)

By predicting population spread at the infested sites, we can begin to understand the environmental and economic value of an eradication program. One of the unique features of the Montana Dyer's Woad Cooperative Project is that for the past 7 yr, we have collected data on the number of dyer's woad plants treated. With these data and literature on the demographic characteristics of dyer's woad, we can predict the number of plants that may have resulted if the Project did not exist. Therefore, we can put a value on the Project, based on the potential spread, and compare the cost of the actual program with the cost of managing and containing dyer's woad across predicted infested areas.

To evaluate the environmental and economic value of the Montana Dyer's Woad Cooperative Project, we have calculated the potential population growth rate of dyer's woad, taking into account the average survival rate between phenological stages and average seed production per plant in a field setting (Figure 4). For the purposes of these calculations, we used total dyer's woad plants treated in 1999 to extrapolate the number of plants that would occur in 2005 if the eradication program did not exist and assuming little to no management of infestations at the local level. To estimate the number of new seedlings each year, we multiplied the total number of plants treated in the previous year by the average number of seeds a dyer's woad plant produces (383) and assumed 86.5% germination (Equation 1) (Farah et al. 1988; Young and Evans 1971). Based on the literature of dyer's woad phenological stages, we then calculated population growth until 2005. Of the germinated seedlings, 1% will flower and produce seeds in the first year, 35% will remain in the vegetative stage, and the rest will not survive. Of the vegetative plants, 17.5% will flower and produce seed the second year, and 12% will remain in the vegetative stage (Farah et al. 1988). Because dyer's woad is monocarpic, dying after flowering, all plants that reach the flowering stage are subtracted from the population after they produce seed (Equation 2). Table 2 and Figure 5 illustrate the potential exponential growth of dyer's woad population in Montana in the absence of the Montana Dyer's Woad Cooperative Project.

$$NS = 383 \times 0.865 \quad [1]$$

$$NF = [(VP \times 0.175) + (NS \times 0.01)] - MP \quad [2]$$

where *NS* is the number of new seedlings, *NF* is the number of new flowering plants, *VP* is the previous year's vegetative plants, and *MP* is the previous year's monocarpic plants.

Given that the average canopy cover of a dyer's woad rosette is 63 cm^2 in diameter (Farah et al. 1988) and mature plants average 0.5 m^2 in diameter (Krueger-Mangold and Pokorny, personal observation), we used an average plant canopy cover of 0.25 m^2 to extrapolate the area dyer's woad

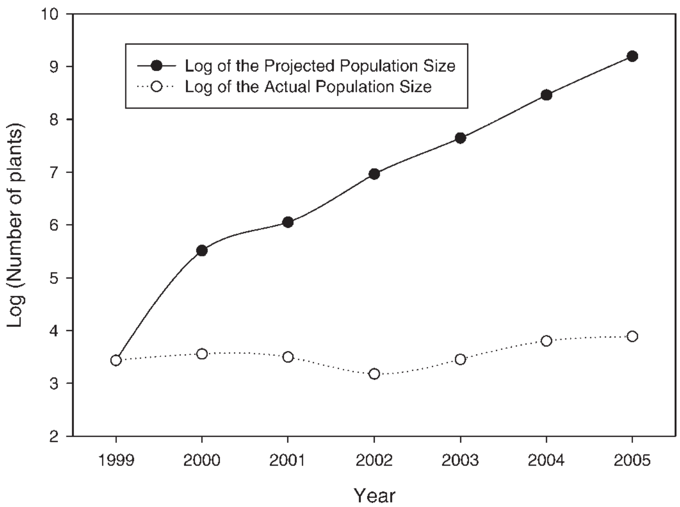

Figure 5. Projected dyer's woad population size (all plant life stages) in Montana calculated from the number of plants present in Montana in 1999 and actual statewide population from 1999 to 2005. Numbers are presented in the log scale.

may potentially cover if plants had not been treated from 1999 to 2005. We took the potential new plants produced since 1999 (calculated above) and multiplied by 0.25 m^2 to determine that 39,021 ha in Montana might have been covered with dyer's woad if they had not been treated in 1999. This number is probably an overestimation because it does not take into account self-thinning, dispersal distances, carrying capacity of the landscape, or proximity of suitable habitat surrounding current infestations. Given the area infested in the state is currently 2.6 ha, even a conservative estimate of the potential infestation size is much larger than actual area infested.

Another way to assess the value of an eradication program is to determine whether it is reducing economic impacts, particularly the cost of management. A simple way to evaluate the economic value of an eradication program is to use the calculated potential growth rate and potential area covered (calculated above) to compare the average management cost for Montana. From 1985 to 2005, the actual cost of the Montana Dyer's Woad Cooperative Project was $225,000, of which $142,000 was spent from 1999 to 2005. From 1999 to 2005, the average actual cost of the Project was $20,286/yr. However, if left unmanaged from 1999 and assuming $50/ha for a one-time application of herbicide, the most effective large-scale control method to date, it would cost Montanans $1,951,050 for 1 yr of dyer's woad management in 2005. Additional years of herbicide control would also be needed. This figure was calculated from the statewide population in 1999 of 2,725 plants and does not account for the thousands of plants that were treated before 1999.

Our calculations are admittedly simplified because they do not take into account spread factors such as habitat type compatibility for invasion, spread potential, dispersal patterns, number of introduction attempts, reinvasion, and the probability that invasion success increases with initial population size (Rejmánek 2000; Zamora and Thill 1999). We also do not account for costs associated with lost forage production, impacted native plant communities, and future management and restoration, making our calculations a conservative estimate. To improve our ability to assess the success of eradication programs, and improve cost–benefit analyses, scientists and managers need to develop simple and reliable ways to identify areas at risk to invasion (Dewey et al. 1991). An improved cost–benefit assessment may also provide justification for adequately funding additional eradication programs.

Summary

The Montana Cooperative Dyer's Woad Project has successfully eradicated dyer's woad from several counties, is decreasing infestation sizes in other counties, and is preventing new infestations in Montana. The success of the Project is largely accredited to the incorporation of the early detection and education efforts, repeated treatments (hand-pulling and spraying), and monitoring. In addition to these key components, adequate funding, including matching funds, was available, and the formation of a central organization, which created clear lines of communication and action plans, allowed for a successful project.

In Montana, the key to successful eradication of dyer's woad has been the early detection and rapid response to new infestations. In areas where a large seedbank existed, the eradication program has had to progress through a control-and-containment stage. Because our goal is to completely eliminate the species from the state, the work has taken persistence. By eliminating and containing dyer's woad infestations through the various components of the Montana Cooperative Dyer's Woad Project, the growth of millions of plants on thousands of hectares has probably been prevented.

Eradication is often seen as infeasible and expensive. However, many introduced plant populations have been eradicated at low costs, but few results have been published (Simberloff 2001). Westbrooks (2004) argues that early detection and rapid response is a cost-effective invasive plant–management approach because it addresses species that establish self-perpetuating populations and causes minimal or short-term impacts on the invaded plant community. Montana's small-scale dyer's woad eradication efforts did not require excessive resources to be successful. For counties that had large infestation sizes when the Project started in 1985, the eradication Project has also been a worthwhile investment because of the indirect positive effects on prevention, containment, and education efforts. If the eradication Project did not exist, dyer's woad may have cost Montana millions of dollars in control costs and may have negatively impacted natural resources.

Although the Project has been successful within Montana, it is imperative that other states with dyer's woad also effectively manage their populations and prevent spread. Successful, local-scale dyer's woad eradication projects exist in other states (Dorst et al. 1994; McAdoo and Carpenter 2002), but some eradication projects have not been completely successful because of the reintroduction of seed from surrounding infestations (Dorst et al. 1994). There is now a need for the formation of aggressive, regionwide dyer's woad eradication and prevention programs that will contribute to state efforts, particularly for reducing the probability of reintroduction.

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