Chapter 8. Invasive Plant Management: Options and Actions

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INTRODUCTION

Management of invasive species is a process, much like the invasion process, only in reverse (Chapter 3, fig. 3-2). It begins with identifying the problem and progresses through understanding the problem, developing solutions, applying solutions, monitoring the outcome, and re-evaluating the problem. Identifying and understanding the problem and developing solutions could be considered the lag phase where we do not expect much change in the invasive species population. We hope applying solutions will initiate a geometric reduction in the weed population, and ideally, if our soluions are sustainable, the monitoring and re-evaluation phase is synonymous with naturalization, only it is the management, not the weed, that is naturalized.

This conceptual process may seem idealized and unattainable when you consider naturalized infestations. However, management has achieved sustained reductions of weed populations in some pretty bad infestations. There have also been no reduction in weed populations after management, largely because management goals have resulted in actions that favor weed populations.

MANAGEMENT OPTIONS

Management options can be *organized* within the overall management picture using the framework outlined by Salafsky et al. (2002), *designed* using the conceptual framework of successional management (Sheley et al. 1996), and *applied* following Maxwell's and Rew's modified Nature Conservancy model introduced in Chapter 2.

Management options can be boiled down to, in order of priority (see Hobbs and Humphries 1995), prevention, eradication, containment, large-scale population reduction, and doing nothing.

Prevention can be applied only to invasive species that do not occur on the site. It requires identification of potential invaders, persistent and thorough ground survey, disturbance management, and immigration management. Examples of management actions can be found in Clark (2003).

Eradication is only practical on small-scale infestations, generally in the introduction phase (Rejmanek and Pitcairn 2002). Eradication actions must prevent survival and reproduction of the invasive species at all costs.

The objective of **containment** is to prevent large infestations of invasive species from spreading to weed-free areas. Moody and Mack (1988) argue that targeting small satellite infestations as opposed to attacking the front of the large infestation is most effective.

Effective management of large-scale, naturalized infestations is unlikely without massive resource inputs (Hobbs and Humphries 1995). However, invasive species population reductions and increases in desirable species can be achieved by applying management actions in a manner that takes advantage of natural processes (Sheley et al. 1996).

"Let go" is the last resort applied to weed populations that are of the lowest priority, to management areas of low value and high disturbance, and when the weed management budget is exhausted (Hobbs and Humphries 1995). Doing nothing still requires monitoring the weed population to evaluate changes in the weed population, risk to management objectives, and priorities.

Methods for control of invasive species can be physical, chemical, or biological. Hobbs and Humphries (1995) has a good description of each of these methods. They all have costs, benefits, and risks associated with their application that vary in magnitude with each individual invasive species and site. That is why prescriptions for weed management are not always practical, and managers are best off developing an understanding of their management system, the invasive species they are working with, and the effectiveness of each control method.

One of the greatest dilemmas facing managers with invasive species problems is how to set priorities for weed management action. The model in **Figure 8-1** illustrates how to assess management priorities based on the relative degree of site disturbance and value in terms of production or conservation. Areas of high value and low disturbance should be the first priority because the success rate will be highest, productive land will have an economic return that justifies management costs, and low-disturbance productive land is more likely to support competitive desirable plants that can prevent weed re-establishment. At the opposite end of the spectrum, low-value, high-disturbance areas have a high risk of weed control failure and little economic return. Monitoring is important to all management options and the type of monitoring, as discussed in Chapter 7, will depend on management objectives.

INTEGRATED PEST MANAGEMENT (IPM)

Scientists and managers generally accept integrated management as the system most likely to result in cost-effective and sustainable control of invasive species. Therefore, it should be helpful to review the fundamental principles of IPM.

The Principle of the Economic Threshold
There is an economic threshold of a pest density at which action must be taken to prevent an outbreak of the pest that causes economic injury. This can be illustrated with the population growth curve used in Chapter 3 to describe plant invasions (**Figure 8-2**).

This principle was developed in annual cropping systems to deal with insect pests that have tremendous economic impacts. The objectives are to reduce chemical pesticide impacts on the environment and to reduce the cost of pest management. It assumes that there is always

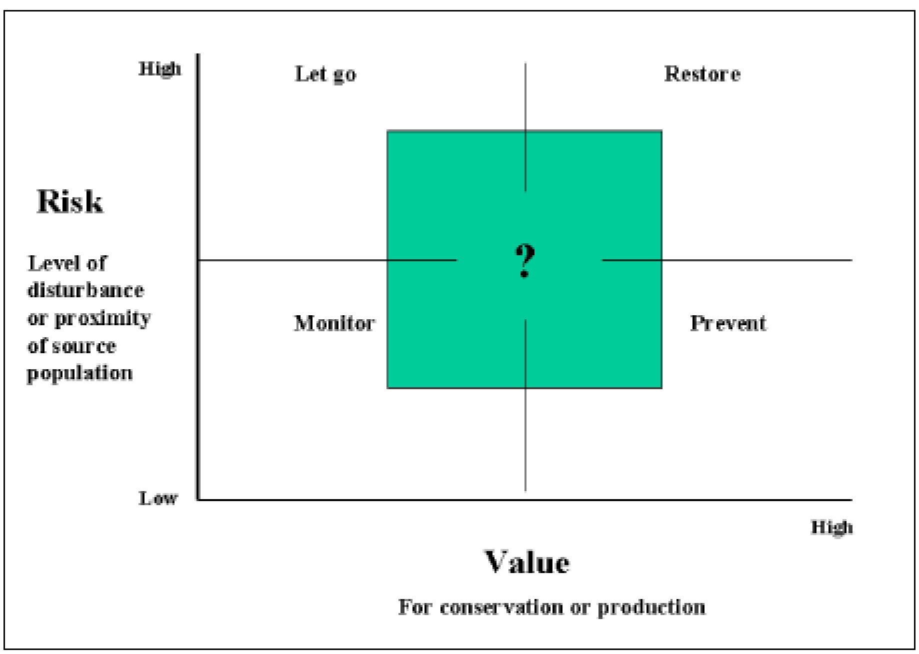


Figure 8-1. This figure illustrates a generalized way to assess management priorities based on the relative value of the land and its relative risk to being invaded, either because of distance or nearness to a source of colonizing invasive plants (adapted from Hobbs and Humphries 1995).

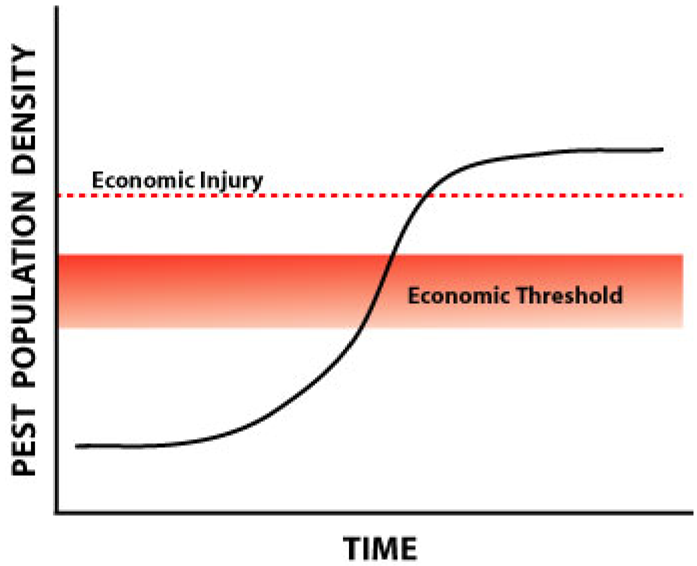


Figure 8-2. *This figure illustrates the principle of the economic threshold based on the population growth curve. As a pest's population increases (for our purposes the pest is an invasive species), there is a density (indicated by the shaded area) at which continued uncontrolled population growth will result in a pest density that causes economic injury (indicated by the dashed line).*

some level of pests in the system, that the level of the pest can be monitored, and that the change in the pest population can be predicted with some degree of accuracy.

IPM encourages non-chemical and sustainable management practices such as biological and cultural controls that maintain pests at low levels. This keeps pesticide use to a minimum by using them only in an outbreak situation.

The principle of the economic threshold implies that the cost of the action should be less than the loss that would have occurred if nothing had been done (Radosevich et al. 1997). It is easy to see how this may apply to annual cropping systems and productive pastures and hay meadows because there is economic value in the crop. The economics are not so obvious on rangeland and natural systems. Here is a rangeland example. Jacobs and Sheley (unpublished data) identified two thresholds of spotted knapweed cover on native grass rangeland grazed by cattle. The first threshold was at 40% spotted knapweed canopy (Daubenmire 1959). Tordon® would be recovered after five years of grazing. Lower levels of spotted knapweed cover did not reduce forage to the point where an herbicide application would pay off. The second threshold was at 60% spotted knapweed cover. At this level of infestation, native grass production did not recover enough to support profitable cattle production because cheatgrass (*Bromus tectorum*) became the predominant grass, which had limited use by cattle.

The 60% threshold in this example illustrates the importance of ecological thresholds in IPM. In this case, the native bunchgrasses were unable to sustain their populations under the pressure of cattle grazing and competition from spotted knapweed. This allowed the cheatgrass population to establish and increase because cattle did not graze it (due to timing of grazing), and because its life history characteristics allowed it to avoid competition with spotted knapweed, or it was at least reproductive under competition with spotted knapweed. When spotted knapweed was removed by the herbicide, cheatgrass, and not the native bunchgrasses, was available to fill niches opened by the treatment.

In natural systems, ecological thresholds are often more important than economic thresholds because management objectives are often not determined by profit. However, even in annual crop systems, economics are tightly linked to ecological factors, and ecological thresholds may determine the economic threshold. This should be strong incentive for monitoring. Only through monitoring can ecological and economic thresholds be identified.

How do thresholds help develop adaptive management? Let's dissect the example given above of the native bunchgrass community with naturalized populations of spotted knapweed and cheatgrass. The management objective is cattle production. Spotted knapweed is a threat to the objective because under cattle grazing management and competition from spotted knapweed, native bunchgrasses decrease. Research on similar sites indicates that when the spotted knapweed population ranges from 40 to 60% cover, an herbicide application will increase profitability. Cover below 40% does not impact forage production enough, and cover above 60% will decrease bunchgrass density beyond the point where it can naturally recover. In other words, revegetation will be needed, and revegetation increases the cost of management dramatically. A monitoring protocol is designed to estimate spotted knapweed cover and bunchgrass production. No herbicidal weed control action is taken if spotted knapweed cover remains below 40%.

This approach saves money and avoids environmental risks associated with herbicides. However, biological control insects and sheep (or goat) grazing can be used as alternatives to prevent spotted knapweed cover reaching 40%, or prolong the time it takes to reach that density. If sheep grazing is used, the risks and benefits also need to be monitored because sheep use grass and have value. If biological control insects are used, their costs must be factored into the economics. Monitoring bunchgrass production provides information to adjust stocking rates to prevent overgrazing and calculate economic benefits. When spotted knapweed cover reaches 40%, picloram is used to reduce the spotted knapweed population below the threshold.

SUCCESSIONAL THEORY AS A FRAMEWORK FOR DEVELOPING ACTIONS TO IMPLEMENT MANAGEMENT OPTIONS

Understanding ecological principles and concepts can help managers deal with the wide variety of weed species on a wide range of environmental types because they help add certainty to the dynamics of weed populations and the communities they invade. For example, Chapter 3 discusses how the population growth curve, a fundamental principle of population ecology, can be used to describe the invasion process. This same principle forms the basis of IPM. Concepts of niche, species interactions, community, biogeochemical cycles, and others are often used to explain invasions and impacts of weeds, and to develop management actions. The concept of succession is helpful in consolidating ecological principles within one framework (Sheley et al. 1996).

Invasive species management is complex and expensive. Applying management in concert with natural processes can reduce costs and increase success. Ecosystem development, or ecological succession, is one of the fundamental principles of ecology (Odum 1971). Succession can be defined as changes in species structure and community processes. It is believed to be community-driven (though the physical environment influences the pattern, rate, and limits of change), and it culminates in a stabilized ecosystem.

One of the premises of succession is that it is predictable; however, ecologists have been struggling to develop predictive models for a century. Earlier studies focused on describing changes and relating them to plant strategies and traits in order to develop the ability to predict succession (MacArthur 1962; Grime 2001). Connell and Slatyer (1977) proposed three models of succession based on facilitation; i.e., *relay floristics* (see Clements 1916), *tolerance*; e.g., Tillman's (1985) *resource ratio hypothesis*, and *inhibition* (see Grime 2001 for examples). More recently, the focus has been on understanding the mechanisms and processes directing plant community change to develop more accurate predictions (Luken 1990). Because changes associated with invasive species do not always fit neatly into successional models, understanding the mechanisms and processes of succession and how they interact may help managers predict how their actions will increase or decrease invasive species and help meet their management goals.

Pickett et al. (1987) developed a hierarchical model of succession that identifies three general causes of succession, controlling processes, and their modifying factors (**Table 8-1**). Luken (1990) suggested using the three general causes of succession—*site availability*, *species availability*, and *species performance*– as a management approach to direct plant community change. Managers can design disturbance to affect site availability, control colonization to affect species availability, and control species performance.

Sheley et al. (1996) proposed using Luken's model as a framework for designing integrated weed management programs (**Figure 8-3**). Understanding how plant communities change is appropriate for invasive species management because managers are either trying to prevent their plant communities from becoming weedy, or changing them from weedy to desirable plant communities after invasive species have naturalized. Successional theory is one way to organize integrated weed management and can be applied to all the management options listed above.

Table 8-1. *The causes of succession, controlling processes, and modifying factors (Pickett et al.1987).*

Causes of Succession	Processes	Modifying Factors
Site Availability	Disturbance	Size, severity, time intervals, patchiness, predisturbance history
Species Availability	Dispersal	Dispersal mechanisms and landscape features
	Propagules	Land use, disturbance interval, species life history
Species Performance	Resources	Soil, topography, climate, site history, microbes, litter retention
	Ecophysiology	Germination requirements, assimilation rates, growth rates, genetic differentiation
	Life History	Allocation, reproduction timing and degree
	Stress	Climate, site history, prior occupants, herbivory, natural enemies
	Interference	Competition, herbivory, allelopathy, resource availability, predators, other level interactions

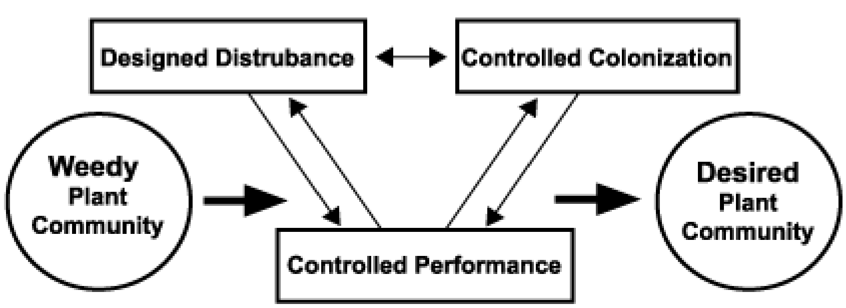


Figure 8-3*. Three general causes of succession have been proposed for invasive species management: disturbance, colonization, and species performance (Luken 1990).*

Three Causes of Succession

1. Designed disturbance (site availability)
The process of disturbance plays a central role in initiating and altering successional pathways, although a unified disturbance theory has not been developed (Pickett and White 1985). As we saw in Chapter 6, disturbance is important in invasion risk assessment, and it affects invasive population dynamics (Chapter 3). Natural and human-caused disturbances initiate, retard, or accelerate succession. The size, severity, frequency, patchiness, and pre-disturbance history influence the community organization and successional dynamics.

The size and severity of disturbance are two of the most important parameters that influence community change. They dictate the amount of physical space available for colonization and greatly influence the timing and patterns of resource availability. Light and soil moisture profiles, soil nutrient content, and factors that modify the use of these resources, such as air and soil temperature, are affected by the extent of vegetation damage or removal. Large disturbances often create environments with extreme fluctuations in resource levels and in temperature and wind that regulate resource use. Thus, the size and severity of disturbance are important management considerations.

Designed disturbance in weed management is any activity that creates or eliminates site availability and favors the establishment of desirable species and disfavors invasive species. Cultivation, burning, grazing, and herbicides are large and severe disturbances that have been used in invasive species management. However, small disturbances can also be effective, especially if they are specific to the invader under management and persistent over time (e.g., biological control that causes weed mortality). In successional management, disturbance is used in coordination with controlled colonization and controlled species performance to alter community composition to meet management goals and to minimize the need for continuous high-energy inputs.

2. Controlled colonization (species availability)
Controlled colonization is the intentional alteration of availability and establishment of invasive species and desirable species (Sheley et al. 1996). Management actions can influence seed production and propagule pools (including seed banks), and add seeds or propagules of desirable species. Biological control insects can reduce seed production of invasive species. *Urophora affinis* and *U. quadrifasciata* can reduce spotted knapweed (*Centaurea maculosa* Lam.) seed production by up to 80% (Harris 1980). Weed seed banks can be reduced by attrition if seed production is prevented. Olson et al. (1997) reduced spotted knapweed seeds in the soil after three years of sheep grazing. Griffith and Lacey (1991) found that using repeated application of the herbicide picloram to reduce the availability of spotted knapweed was cost-effective only on high value sites.

Highly degraded sites with naturalized populations of invasive species may require restoration or revegetation of desirable species, which is costly and has a high risk of failure. On an Idaho fescue (*Festuca idahoensis* Elmer.) rangeland site, Kedzie-Webb et al. (2002) found that application of picloram could restore Idaho fescue where spotted knapweed cover was less than 60%. When spotted knapweed cover was greater than 60%, a picloram application resulted in a plant community dominated by cheatgrass (*Bromus tectorum* L.). Where desirable species are not available to fill sites opened by weed management, Sheley et al. (2001) developed a “single entry” method to reduce the cost and increase the success of revegetating desirable grasses. In that study, bluebunch wheatgrass (*Pseudoroegneria spicata*) and pubescent wheatgrass (*Eletrigia intermedia* ssp. *trichophorum*) successfully established when picloram was applied and grasses were seeded in a simulated single application.

3. Controlled species performance
Controlled species performance is the manipulation of the growth, reproduction, and competitive ability of plant species to shift community dynamics in a desirable direction (Sheley et al. 1996). Biological control,

selective herbicides, selective grazing, altering resource availability, manual plant or plant part removal, or their combinations are management actions that affect species performance.

In western North Dakota, *Aphthona* spp. flea beetles were combined with multi-species grazing to manage leafy spurge (*Euphorbia esula* L.). On two 1-section pastures, approximately two million flea beetles were released, and 50 sheep and 20 cows grazed the pastures from May through September. Over five years, leafy spurge density was reduced from 71 stems/m^2 to 19 stems/m^2 (**Figure 8-4**) and grass cover increased from 38% to 65%. Leafy spurge was not eradicated from the sites but flea beetles and sheep grazing reduced its performance such that perennial grasses were allowed to re-establish dominance. Cattle grazing prevented buildup of grass litter, which helped maintain the performance of the grass.

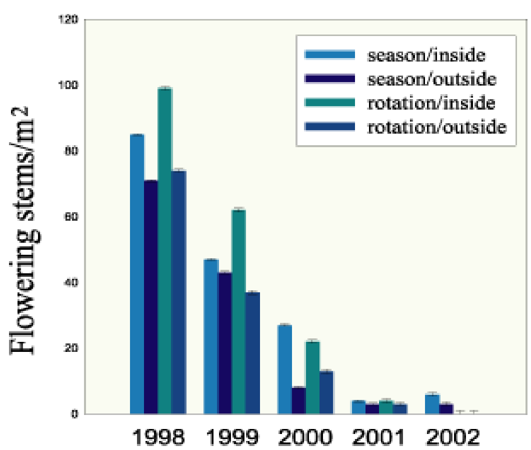


Figure 8-4. *The effect of Aphthona flea beetles and multi-species grazing on leafy spurge flowering stem density in western North Dakota.*

On two abandoned hay meadows in western Montana, 2,4-D was combined with repeated sheep grazing to restore perennial grasses to spotted knapweed infestations (Sheley et al. 2004). The herbicide was applied in late spring to reduce adult and seedling spotted knapweed plants. Sheep grazing began in May the following year to target spotted knapweed regenerating from the seed bank. The sheep were removed from the site after they utilized 90% of the spotted knapweed or 60% of the grass. Sheep grazing was repeated in June and July to prevent flower production when spotted knapweed reinitiated bolting. After four years, spotted knapweed biomass was about 15 g/m^2 where sheep grazing was combined with 2,4-D, compared to 45, 15, and 70 g/m^2 where 2,4-D, sheep grazing, or no management, respectively, were applied (**Figure 8-5**).

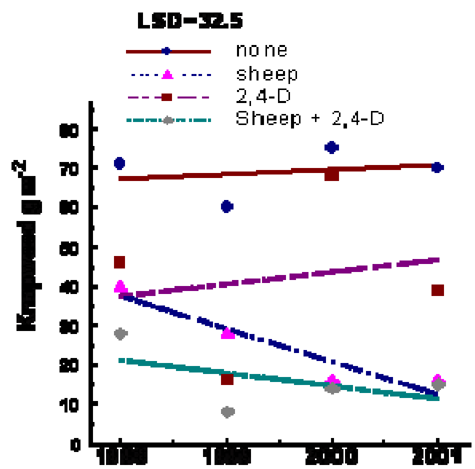


Figure 8-5. *The effect of 2,4-D and repeated sheep grazing on spotted knapweed biomass production in western Montana (Sheley et al. 2004).*

For an example of using three causes of succession in weed management, see the PowerPoint (Flash version) [Implementing Successional Theory in Weed Management: A Case Study.]

ADAPTIVE MANAGEMENT

Adaptive management has developed largely in the field of conservation biology to address two overlapping deficiencies that have parallels in invasive species management. The first is that research and management, at least until recently, have concentrated primarily on technical and biological/ecological development and application, with only token consideration given to the socioeconomic dynamics that are not completely controlled by management activities. There are social and economic pressures that affect management decisions, and there are social and economic ramifications of our management actions. The second consideration concerns the questions of how we manage and how we develop better understanding of managed system responses and potential in a world of great uncertainty, limited resources, and increasing societal pressure (Walters 1986).

Because invasions are complex and predicting the result of management is not always accurate, it may be helpful to treat management as an adaptive learning process where management activities themselves are viewed as the primary tools for experimentation. How can you know if something will work until you try it? Success will be more likely if you understand the system you are working in, understand the invasive species you are working with (Chapter 3), and understand the risks associated with the weed and the management action (Chapter 6). The only way you know if a management action did work is by monitoring change (Chapter 7).

The basic principle of adaptive management is that management action is determined by goals, measured risk that threatens goals, and measured progress toward reaching goals (Salafsky et al. 2002). In most cases, invasive species are not the only problems challenging managers. The general goal for the management area will direct the specific weed management goals.

Fundamental to adaptive management is to clearly define management goals. As Yogi Berra so ineloquently said, "Watch out if you don't know where you are going, because you might not get there." Overall site management goals are fundamental to risk assessment, action, and monitoring. Specific weed management goals should go beyond strictly killing weeds. A generalized objective might be to develop a community of healthy, desirable plants that meet general land use objectives like forage production, wildlife habitat, recreational land maintenance, or biodiversity (Sheley et al. 1996).

Identifying and prioritizing all threats and other factors that affect the general management goals and specific weed management goals are also critical. We can assume that all invasive species constitute a threat to management goals; however, weeds that are currently on the site or neighboring sites may constitute direct threats, and weeds that are adapted to the site but not present may constitute indirect threats. Vectors of weed spread and sources of disturbance may also be considered indirect threats. Management of invasive species should be considered in context with threats to management goals other than invasive species.

Management actions should be prioritized by the greatest risks that threaten management goals. Actions can be organized into the management options listed above. For example, what management actions can you take to prevent (prevention is the management option) weed invasion?

Practitioners that take action or cooperate in invasive species management are important resources. These resources can be individuals, organizations, or alliances and networks that directly or indirectly help with planning or management and can be considered a resource base.

Monitoring is an important action that will allow you to evaluate the success of management and develop future priorities. Indirect actions include education and awareness, policy and law, and changing incentives. Monitoring and evaluation of management action effectiveness is often overlooked in invasive species management. Monitoring can be time- and labor-intensive and does not have a direct impact on weed populations. However, the only way to determine where the weed population is in the invasion process, which is critical to determining what management action to take, is to measure how the population is changing over time. And the only way to determine the effectiveness of weed control action is to determine how the weed and desirable plant populations change over time.

As you know, the model we are using for adaptive management is adopted from The Nature Conservancy model (Chapter 2). However, a weed management plan should fit intothe overall management plan for the site or organization. Salafsky et al. 2002, provides a framework that should be helpful for incorporating weed management into an overall management program. This paper was written for the conservation biology audience, but it should be fairly easy to adapt to invasive species management. In fact, invasive species management can be considered a form of conservation.

Below is a management plan example that incorporates some of the ideas of Salafsky et al. (2002) and management actions based on successional concepts.

EXAMPLE MANAGEMENT PLAN

1. Site description, objectives and other resources

a. Site description

The management unit is an 80-acre native rangeland pasture in southwestern Montana that is part of a ranching operation on 980 deeded acres and 3,450 leased acres. It is on rolling foothills terrain on the west slope of the Absaroka mountain range, in the Yellowstone River Valley, within an Idaho fescue/bluebunch wheatgrass habitat type. The soils are coarse, bouldery, sandy loam; average annual precipitation is 14 inches; and the site averages 48 frost-free days each year. The pasture can be classified using Figure 8-1 or Figure 4 in Hobbs and Humphries (1995) as low productivity and moderate disturbance. The predominant grass species is Idaho fescue, the predominant native forb is fringed sage, and spotted knapweed infests about 85% of the pasture. Spotted knapweed is a highly invasive perennial weed that reduces forage production (Watson and Renney 1974).

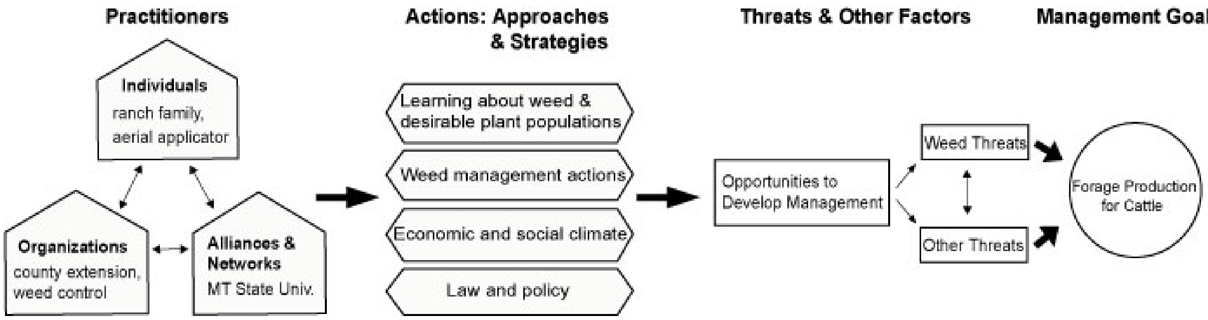
b. Objective

The ranch supports 150 cow/calf pairs, 20 yearling steers, 8 bulls, 60 ewes, and 15 horses. The management objective of the pasture is to provide dormant season pasture for the 150-cow/calf pairs and 20 yearling steers.

c. Other resources

The ranch has a gravity-powered irrigation system.

2. Simple conceptual model modified from Salafsky et al. (2002)



3. Description of conceptual model's components

a. Table of direct and indirect threats to forage production, and opportunities for dealing with them

Direct threats	Indirect threats	Opportunities
Spotted knapweed	Other invasive species	Establish insectary
Overgrazing		Develop integrated management
Elk grazing		
Drought		

b. Table of management approaches and strategies

Education	Weed management actions	Economic and social climate	Law and policy
On-site research	Herbicide	Cattle prices	Weed law
Extension Service	Sheep grazing	Herbicide prices	Neighbors
MT universities	Biological control	Land values	
	Monitoring	Land development	
	Irrigation		
	Fencing		
	No action		
	Revegetation		

c. Table of possible direct management actions for managing spotted knapweed

Disturbance	Colonization	Performance
Cattle grazing	Revegetation	Sheep grazing
Tordon	Biological control	Biological control

2,4-D	Sheep grazing	

4. Management plan narrative
The no action option was considered because the pasture was of low forage value. It was rejected for a number of reasons. First, the rancher was being pressured by the County Weed Coordinator to control the spotted knapweed, as a direct result of complaints from neighbors. Second, the pasture provided opportunities to develop integrated weed management using herbicides and sheep grazing, and a site to establish biological control insects, both of which could be used in other areas of the ranch. These opportunities were facilitated by a partnership with researchers at Montana State University that included funding, the third reason. Finally, the pasture bordered a high-value, knapweed-free alfalfa hay meadow, so controlling spotted knapweed on the pasture would help prevent weed spread onto the hay meadow.

Revegetation was rejected because there were sufficient desirable forage grasses available on the site to fill niches opened by weed control; the low-value site did not justify the expense of revegetation; and there was a high probability of failure because of soil type, climate, and landscape characteristics.

Application of the herbicide Tordon ® (picloram) on many sites is the most effective method for controlling spotted knapweed because it has soil residual activity that can suppress spotted knapweed regeneration from the seed bank for up to three years. Its use was rejected because it is more expensive that 2,4-D, and the residual would have a high probability of leaching rapidly through the porous soil and not providing much residual activity. In addition, it may have a greater impact than 2,4-D on non-target forbs that may be important competitors with spotted knapweed.

5. Management actions implementing three causes of succession

a. Designed disturbance
Using fixed-wing aircraft, 1 qt 2,4-D/acre was applied in early June after most of the spotted knapweed seeds germinated and before spotted knapweed adults initiated flowering. The aerial application was the least expensive method. The timing of application also minimized herbicide effects on early and late season forbs that may compete with spotted knapweed. Grazing cattle was deferred for one year to allow desirable plants to use resources released by knapweed control and occupy sites made available by the herbicide treatment.

b. Controlled colonization
Sheep grazing was applied in the fall after herbicide application, and repeated in the spring and fall in the years that followed. The sheep were used to target spotted knapweed regenerating from the seed bank and the plants missed by the herbicide application, and to reduce spotted knapweed flower production. The flowerhead-feeding weevil *Larinus minutus* and the root-feeding weevil *Cyphocleonus achates* were released two years after herbicide application to reduce spotted knapweed seed production. The 2,4-D application also reduced the availability of spotted knapweed on the site.

c. Controlled species performance
Sheep grazing and the two biological control weevils releases were management actions designed to reduce spotted knapweed competitiveness.

6. Monitoring
Six 2-m^2 grazing exclosures were constructed at random on the pasture. Cover, density, and biomass by species were measured in September each year from 0.2 x 0.5 m frames placed inside and outside each exclosure. Sweep net samples were taken to evaluate biological control establishment.

7. Evaluation
The 2,4-D application was effective in suppressing spotted knapweed for one year. Sheep grazing reduced spotted knapweed regeneration for three years; however, the sheep also used a significant amount of grass. Only the *Larinus minutus* was found in subsequent years after release. Temperatures may be too cold for *Cyphocleonus achates* to complete its life cycle. The deferred cattle grazing improved forage production.

8. Problems encountered

There were two related problems associated with the sheep grazing aspect of the weed management plan. The first was concentrating the sheep grazing in the areas of the pasture where spotted knapweed was the greatest. The sheep grazed grass and spotted knapweed evenly over the 80-acre pasture and did not have the expected impact on spotted knapweed. Second, there was considerable loss of sheep to predation, wolves in particular. Once the sheep had been attacked, it was difficult for the manager to keep the sheep on the site.

9. Changes in management

The pasture was first grazed by cattle and then by sheep. Using this method, there was more grass available to the cattle than when sheep grazed first, and the sheep utilized a greater proportion of spotted knapweed than grass. Predator-proof fencing was used to confine the sheep to areas where spotted knapweed was most productive, and the fencing prevented all but grizzly bear predation.

THE CONCEPT OF SCALE AND MANAGEMENT OF NONINDIGENOUS SPECIES

Scale is an integral part of the ecosystem concept, whereby all living organisms interact with each other and the physical environment they all share. These ecosystems can be small or very large, ranging geographically from sites up to regions, continents, or even the planet. The idea of scale was first introduced by O'Neil and his many associates (O'Neil et al. 1986) as a hierarchy of nested ecosystems where each species interacts with the others, but have different impacts depending on their place in the hierarchy.

In the diagram below, the temporal scale (in years) and spatial scale (in distance) reflect the sampling intervals required to observe environmental disturbance regimes, biotic responses, and vegetation patterns. The point here is to show how changes in scale influence the patterns or responses that we observe, which is important to consider when developing management strategies.

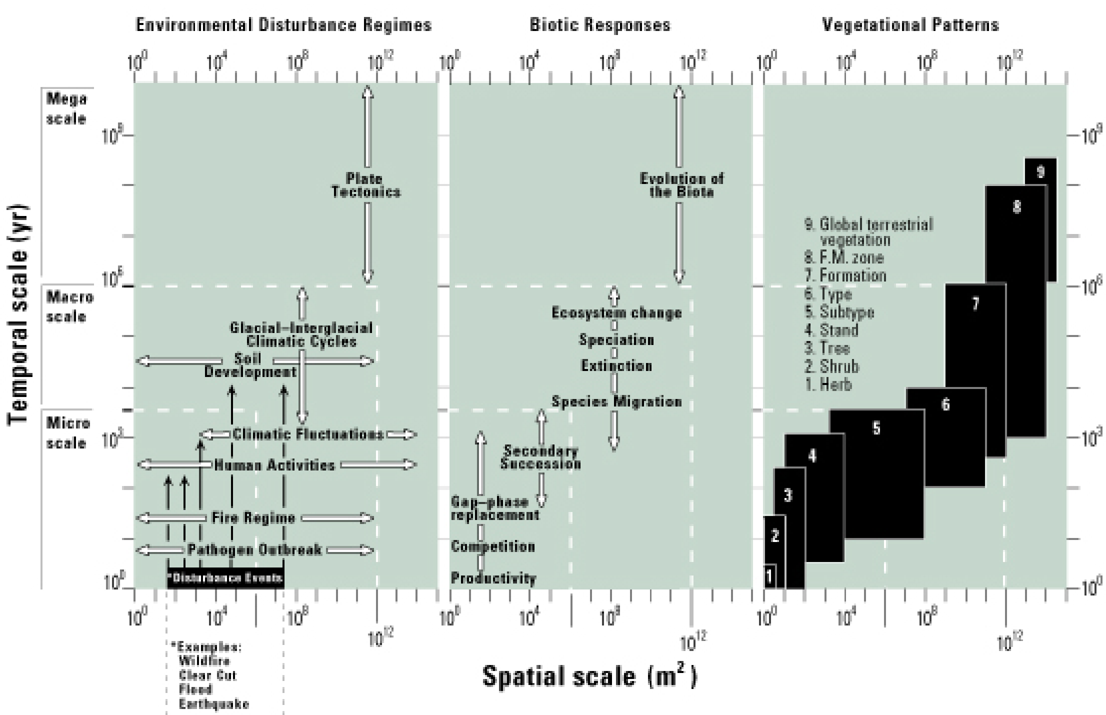


Diagram from Turner et al., *Landscape ecology in theory and practice: pattern and process*, 2001 (modified from Delcourt et al. 1983).

There are a few generalizations about scale that can be helpful. Generally, as scale increases from smaller to larger:

1) The complexity of the ecosystem increases with scale: thus species diversity increases at larger scales (e.g., regions) in contrast to smaller ones (e.g., watersheds or fields). This generalization is the thrust of the diversity/invasion debate..
2) Process rates slow; therefore change occurs more slowly over large scales than smaller ones.
3) Change that happens at a large scale has an almost immediate and irreversible impact on scales below. However, the reverse is not true; i.e., changes at small scales have almost no impact on scales above them, unless they accumulate over very large areas and for a very long time.
4) Emergent properties "happen"; that is, things that change over a larger area are usually different from and usually more significant than simply the additive effect of many little changes that occur on many small areas combined. A hierarchical perspective of biological invasions reveals three nested spatial scales that interact to determine the impact of invasions on plant communities (Pickett et al. 1987; Meiners and Cadenasso, in press). The coarsest scale is the **region**, which determines the pool of resident and invader species. This scale sets the potential range for species interactions. The intermediate scale is the **landscape** level, which determines the species within the larger regional pool that can colonize a particular habitat according to their ability to move around and to tolerate environmental stresses. The finest scale that is relevant to biological invasions is the **local plant community** or neighborhood.

This is the scale where invading species and residents interact, which leads to differential performance among the species and therefore the realized species composition of the neighborhood. A region-level program for prevention, control, or restoration after exotic plant introductions must necessarily focus on which species interact within the system and where, usually at either the community (habitat) or landscape levels of scale.

Communities (Habitats)

Many studies show that plant growth and invasive plant prevalence occur within certain ranges of habitats. For example, species are usually most productive within certain soil types. However, soil mapping units of extensive land management systems like forests or rangelands are generally too coarse to be of use for land management of invasive species. Climate also drives abiotic and biotic thresholds for plant growth in particular ecosystems. Here, edaphic characteristics such as topography and elevation modify climate, and therefore influence what plant species can grow at a given location. Weather also changes habitat suitability over short time scales through drought, seasonal frost, and flooding. Invasive plant species tend to adapt well to a variety of habitats but usually invade regions with climates similar to those of their native range first, then adapt to other climates later. Disturbance is another component of habitat suitability and is believed to have a strong influence on the presence of invasible sites within plant communities.

Landscapes

Across a region, a species may be detected in the late colonization/naturalization phase of the invasion process and thus be considered a stable population. However, this stable source population contributes to many subsequent local infestations through seed dispersal. These small satellite populations are migrants from the source and can become additional source populations themselves, markedly expanding the original infestation area. Rates of increase for satellite populations can be extremely high because satellite introductions have a much higher probability of success than initial introductions as a result of the constant seed flow that arises from source areas. Landscape features and connectivity relationships become important for predicting spread from source populations to new and as yet unoccupied locations for exotic plant species. Regions are composed of a mosaic of extensive natural resource areas (forests, rangelands, wetlands, etc.), intensively managed locations (farms, paddocks, holding areas for livestock, etc.), urban areas of various sizes (intensities), and the corridors (roads, rivers, etc.) that connect them all. Invasive plants can be present in each landscape feature, and transportation corridors increase the risk associated with species that spread as satellite populations.

Effects of Scale on Management Strategies and Actions: An Example

The effect of spatial scale on management strategies or options, and on management actions, can be illustrated by the ranch example given above. Recall that the management unit in this example was an 80-acre native rangeland pasture within a 980-acre ranch with the objective of raising cattle.

Complexity

First consider complexity. The 80-acre pasture is a relatively simple plant community that can be described as an Idaho fescue grassland. The ranch can be viewed as a landscape with a mosaic of habitats that include grassland, forest, and riparian areas. From these broad plant community descriptions it is obvious that there is a tremendous increase in potential plant and animal species that can interact when there is a small change in scale. There is also an increase in invader species. Spotted knapweed is the only invasive species on the 80-acre pasture, whereas invasive species on the ranch include Canada thistle (*Cirsium arvense*), yellow toadflax (*Linaria vulgaris*), houndstongue (*Cynoglossum officinale*), and common tansy (*Tanacetum vulgare*). By including surrounding lands, the invasive species list increases to include leafy spurge (*Euphorbia esula*), field bindweed (*Convolvulus arvensis*), sulfur cinquefoil (*Potentilla recta*), and Dyer's woad (*Isastis tinctoria*). Management complexity also increases at the ranch scale when corridors of weed spread such as roads, creeks, and irrigation ditches are considered. At the regional level, social and political considerations add to the ecological complexity; consider that the ranch is in the greater Yellowstone ecosystem.

Process Rates

Second, consider process rates. The rate of dispersal of a biological control insect may be fairly rapid and complete over the 80-acre pasture in a matter of a few years. However, because of physical barriers, it may take decades for the insect to disperse over the entire ranch. The same can be said of the plant invasion process. A population of spotted knapweed could be considered naturalized at the 80-acre pasture scale, but at the regional scale, spotted knapweed could be considered in the lag phase of invasion. That puts weed control in a totally different perspective with regard to management priorities. To the ranch manager, the low forage value pasture may be considered an area to be let go because the return from eradication efforts does not justify the cost of control. To the regional manager, the 80-acre infestation could be regarded as a high priority for eradication to prevent spread at the regional scale.

Impacts of Change at Different Scales

Third, consider the impacts of change at different scales. Plant species diversity may be reduced on the 80-acre pasture by the invasion of spotted knapweed; however, there may be no reduction of diversity on the ranch overall or in the region. The opposite also could be true. A naturalized population of an invader at the small scale could be measured as an increase in diversity at the large scale. On the other hand, reduced species diversity at the large scale is certain to be measured as reduced species diversity at the small scale, and in this situation, restoring species diversity at the small scale is unlikely to take place without high energy inputs.

The same can be said for ecosystem function. Changes in the energy flow at a small scale may have little impact on the large-scale energy flow. The spotted knapweed infestation may not reduce cattle production on the ranch if it is confined to the low-value 80-acre pasture, but the ranch may not support as many cattle if the infestation covers a large area of the ranch. From the perspective of weed management, intensive sheep grazing on a tenth-acre plot is likely to have a big impact on spotted knapweed performance within the plot, but an imperceptible effect on the spotted knapweed population of the entire ranch. This is reason to be careful in interpreting and applying results of plot studies to larger scales.

Emergent Properties

Fourth, consider emergent properties and the concept that "emergent properties happen" (haven't seen that bumper sticker yet). This, in a way, suggests the root of why invasive species become such a big mess. At the small scale, the immediate plant community, a patch of an invasive species may not measurably affect forage production, diversity, nutrient cycling, water cycling, or any other measure of value. In other words, it seems, and probably is, harmless. However, if the infestation is allowed to grow to a large scale, changes in properties emerge that may not have been predicted by monitoring changes at the small scale. Another aspect of this concept important to managers is how the application of weed management affects emergent properties. A large-scale broadcast herbicide application is more likely than spot spraying to affect ecosystem properties. Properties affected (disturbance) may be important factors in the invasion process. In other words, weed management has the potential to make an ecosystem more invasible. The concept of emergent properties supports the strategy of containment proposed by Moody and Mack (1988) and discussed above.

Temporal Scale

Temporal scale (scale relating to time) is also an important consideration when developing management strategies for invasive species. In weed management, temporal scale is most often referred to as short-term or long-term. The rate at which processes happen, such as the invasion process or an ecological process such as succession, is also an important management consideration. For example, if the time it takes for a population to become naturalized is measured in months in habitat A and is measured in a decade in habitat B, the population in habitat A is considered much more invasive, and therefore, may be considered a high priority for management.

Many invasive species are early seral and depend on disturbance to maintain population growth. In the short-term temporal scale, early seral invasive species may dominate an area and represent a management problem. However, over the long-term, early seral species may disappear from the area due to the natural processes of succession. An example of this can be seen in the clear cuts of coastal forests on the west coast. *Senecio jacobaea* (tansy ragwort), *Senecio vulgaris* (common groundsel), and *Hypochaeris radicata* (hairy catsear) appear soon after clear cutting, but drop out of the area after a few years. Another example that we know less about is *Buddleja davidii* (butterfly bush). This species is apparently an early invader of riparian areas, but seems to fall out of the system after a decade or so.

The effectiveness of management actions also is time scale-dependent. In the short-term, herbicidal control of weeds may be considered effective because there is a large reduction in the weed population over the few years of the herbicide's effectiveness. In the long-term, many weed populations recover to pre-treatment densities because the *causes* of weed invasion are not addressed in management.

For example, when the herbicide Picloram was applied to a spotted knapweed (*Centaurea maculosa*) population for three years, the knapweed became suppressed but cheatgrass (*Bromus tectorum*) flourished. Over time the spotted knapweed population regenerated from the seed bank and effectively suppressed the cheatgrass. The initial invasion by spotted knapweed was due to disturbance caused by cattle overgrazing, which suppressed the native perennial grasses and thus reduced competition.

SUMMARY

Options for management of invasive species include prevention, eradication, containment, large-scale population reduction, and when the money runs out, let go. Actions managers can take within each of these options include chemical, biological, and cultural.

The weed population growth curve that shows the change in population density over time can be used to prioritize management options. Prevention and eradication apply at the introductory phase of weed population growth. Containment and large-scale population reduction apply during the rapid population growth and naturalization phases. The weed population growth curve can also be used to identify economic or ecological thresholds to determine weed management actions. Biological and cultural management actions are applied to prevent invasions and to suppress weed population growth below a threshold. If weed population density reaches a threshold, chemical action is used to reduce the population density below the threshold.

Monitoring weed populations is key to determining thresholds and where the weed population is on the growth curve. Management that addresses site availability, species availability, and species performance under all management options will employ natural processes in weed population regulation, and the development of desirable plant communities. All management is determined by goals, measured risk to goals, and measured progress toward reaching goals.

In developing invasive plant management strategies, the scale of a management area will determine the complexity of the ecosystem, the rate of processes, the impact of change, and the significance of emergent properties. The impact of plant invasions and their management is different at the regional, landscape, or local plant community spatial scales and also is influenced by time.

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