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Applying ecological principles to wildland weed management

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Recent advances in our understanding of plant succession will provide new conceptual tools for wildland weed managers. Some of the conceptual advances should allow better linkages between the general management of wildlands and weed management specifically. For example, in the future we should be more capable of evaluating the impact of a management action on the risk of weed invasion than we have been in the past. Much of the discussion in this paper focuses on soil resource availability as a primary ecological factor in wildland weed management. Much of the research upon which this premise is based is less than 15 yr old; thus, we are in the testing stages of applying these concepts. Wider application of ecological principles to wildland weed management will require a coordinated education program and effective interaction among researchers and managers.

Key words: Succession, soil resource availability.

Invasive species has earned the attention of a wide cross-section of society over the past several years. Examples of the degree of interest include (1) an Executive Order from the White House directing federal agencies to address the invasive species issue, (2) documents by both the Federal Interagency Committee on Management of Noxious and Exotic Weeds (FICMNEW) and the Council for Agricultural Science and Technology (CAST) outlining the need for action, and (3) numerous reports in newspapers and the popular press. The authors of the FICMNEW document point out that invasive plants infest over 40 million ha in the United States and the number increases by 8 to 20% annually. Federal agencies estimate that public natural areas are being invaded at a rate of about 700,000 ha yr^{-1}. There are studies documenting the effects of weed species on individual states or regions (e.g., Hirsch and Leitch 1996; Leistritz et al. 1992; Leitch et al. 1994;). The total direct and secondary economic effects of leafy spurge (*Euphorbia esula* L.) on the Upper Great Plains were estimated to be $129.5 million (Leitch et al. 1994).

Effects of invasive species on native ecosystems and economies are clear; unfortunately, the solution to the problem is unclear. There are two major limitations to solving invasive species problems on wildlands: (1) ecological–environmental effects of management measures, and (2) monetary costs. Concern over ecological and environmental effects are particularly acute regarding public lands, and in many western states, half or more of the land area is federally owned. On the public lands, the federal agencies must conduct environmental assessments and seek public input before proceeding with invasive plant management. Rare or threatened plants and animals must be considered in the environmental assessment, as well as effects on water quality, human health, etc. I would include in this category all the social constraints that must be considered in practicing weed management on wildlands. The second major constraint to weed control on wildlands is the relatively low economic return per unit of land area. Intensive agronomic approaches that have been successful with row crops are not economically feasible on many wildlands. Relatively expensive treatments such as herbicides or mechanical manipulations may be part of an integrated approach, but economics, lack of efficacy, and ecological concerns limit their routine use on any given parcel of land.

In this paper, I present an approach that allows a bridge between wildland management and weed management, such that management actions in general can be considered in terms of their effect on the potential of a site to be invaded. To accomplish this task I present some of the ecological concepts that hold promise for decision-making, provide some specific examples, and suggest opportunities to improve wildland weed management.

Ecological Principles

The use of successional principles for managing rangeland weed populations was proposed by Sheley et al. (1996) and elaborated on by Sheley and Krueger-Mangold (2003). They suggested that the three basic causes of succession proposed by Pickett et al. (1987) (site availability, species availability, and species performance) must all be considered in designing rangeland weed-management strategies. The planning process involves designed disturbance, controlled colonization, and controlled species performance to address the three causes of succession with the goal of establishing productive, weed-resistant communities. Further discussion of this topic can be found in Luken's (1990) excellent book *Directing Ecological Succession.*

The obvious question is, How do we design weed-resistant communities? We could simply suggest that mixtures of plants with different rooting depths or root morphologies should compete well with any invader for soil resources. That might be a good first approximation, but it is not mechanistic in approach. A key to understanding competitive ability may lie in the ability of a species to lower critical soil resources to the point where they are unavailable to other species. Tilman and Wedin (1991) found that the outcome of competition on low-nitrogen (N) soils was predicted by the ability of individual species growing in monocultures to reduce extractable soil N. In other words, a species that is able to reduce soil N to relatively low levels displaced other species over time. They suggested that high root biomass is indicative of nutrient competitive ability. Early successional species may be inferior N competitors but have faster growth rates and better colonization abilities than later successional species (Tilman and Cowan 1989). Tilman and coworkers conducted their research on a relatively mesic prairie site in Minnesota. However, soil N also had a major effect on successional dynamics in northwestern Colorado (McLendon and Redente 1992). This study involved reducing N (by adding sucrose) or adding N to a disturbed sagebrush steppe site. Succession proceeded most rapidly on the low-N sites and slowest on the high-N sites.

There is mounting evidence that site invasion, as well as succession, is influenced by soil resource availability. During secondary succession there is an initial increase in N availability after disturbance, followed by a decline during the later stages of succession (Vitousek et al. 1989). A number of studies have shown that soil disturbance increases N mineralization (Binkley and Hart 1989; Stenger et al. 1995). The work of Tilman and coworkers suggests that succession is driven by the ability of later successional species to reduce soil N. Frederick and Klein (1994) worked with a more arid group of species (compared with the work of Tilman and coworkers in Minnesota) and also found that later-successional species devote more resources to roots (compared with early-successional species) and release more recalcitrant substrates into the rhizosphere, slowing decomposition and increasing N immobilization. McLendon and Redente (1991) showed that added N slowed succession and increased the period of dominance by annual species. Vinton and Burke (1995) studied shortgrass prairie plots that had received a factorial arrangement of water and N additions from 1970 to 1974. Twenty years later they found that only the plots that received additions of water and N contained an abundance of the annual species kochia [*Kochia scoparia* (L.) Schrad.]. Unfortunately, there has been limited research on the link between N availability and spread of invasive species. Stohlgren et al. (1999) studied exotic species abundance in nine vegetation types in the Colorado Rockies and Central Grasslands and concluded that (1) sites high in herbaceous foliage cover and soil fertility are subject to invasion in many landscapes, and (2) this pattern may be related to soil resource availability and is independent of species richness. Davis et al. (2000) presented a formal theory to explain site invasion on the basis of fluctuating soil resources. They list two primary means by which resource availability can increase: (1) use of resources by the existing vegetation declines, and (2) resource supply increases in excess of vegetative uptake.

If we assume that the available N influences the potential for site invasion, then we have a relatively large body of knowledge that can be drawn upon to evaluate management decisions. For example, more N is generally available in grassland soil the year after a drought because uptake by plants is reduced by the drought, whereas microbial activity continues at low soil moisture (Risser 1988, West 1991). Conversely, during wet years, the combination of mineralization and nitrification may not be able to keep up with plant demand, and N becomes limiting to plant growth (Seagle and McNaughton 1993). The period immediately following a drought may be critical for keeping invasive species from spreading. We also know that N availability can increase immediately following fire (Hobbs and Schimel 1984), although that may not always be the case (Blank et al. 1994).

A Link between Wildland Management and Weed Management

A critical point for land managers and researchers is that soil resources and the ability of species to extract those resources can control succession. To develop successful strategies for containing and reducing invasive species on wildlands, a two-pronged strategy is needed: (1) using successional management approaches to reduce existing infestations, and (2) developing land management approaches that reduce the likelihood of future infestations (Figure 1). The first part of this strategy has been addressed elsewhere (Sheley et al. 1996), but the second part has implications for the manner in which we apply treatments to wildlands and the areas we prioritize for weed control. This point can probably best be made by providing several real or hypothetical examples.

The first example pertains to management of western juniper (*Juniperus occidentalis* Hook.). This native species has expanded dramatically in the past 100 yr and can have negative effects on sagebrush (*Artemisia* spp.) steppe plant communities (Bates et al. 2000; Miller et al. 2000). On the site studied by Bates et al. (2000), western juniper had caused a severe reduction in cover and productivity of the understory community. To evaluate the effects of juniper dominance, all junipers were cut with a chainsaw on half of a 1.6-ha plot. The first year after cutting, the residual community responded, but standing biomass was only 46 kg ha^{-1} in the cut plots compared with 21 kg ha^{-1} in the uncut controls. There was also a large increase in KC1-extractable N on the cut site compared with the uncut sites (Bates 1996). By the end of the second growing season, standing biomass was 329 kg ha^{-1} on the cut site and 38 kg ha^{-1} on the uncut site, and soil N was similar between sites. The second growing season was very wet and probably speeded recovery of the native herbaceous species. The recovery of the herbaceous species filled the gap in N uptake created when the junipers were cut. What does this have to do with weed management and invasive species? As mentioned previously, high soil resource availability greatly increases the risks of weed invasion. In the planning process, it would be useful to identify potential invasive species in the area and the predicted length of time the site might require for recovery. If a stand of invasive species exists in the area, it would be prudent to control that stand before cutting juniper. If the understory community has been severely depleted, it may be necessary to seed the site with a mix of competitive species. The main point is that we must begin to think about how management influences site invasion potential.

The second example is more hypothetical in nature and involves musk thistle (*Cardus nutans* L.). This species has moved into southeastern Oregon along a major highway, expanding into adjacent rangeland. Many landowners have stated they did not have musk thistle until they applied sagebrush control treatments to their land. I am not aware of specific research on sagebrush–musk thistle interactions,

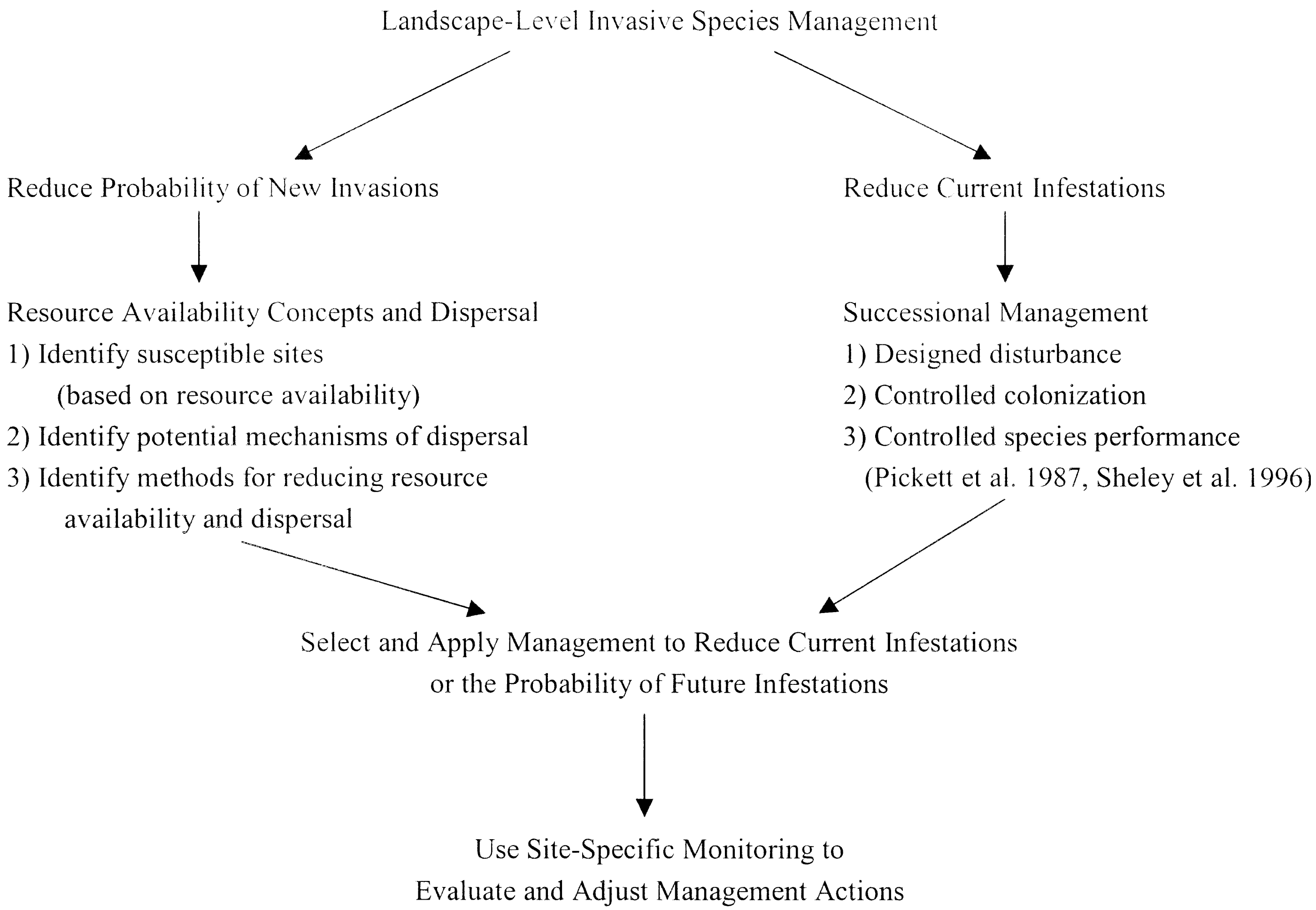

FIGURE 1. Effective management of wildland weeds will require a focus on both reducing current infestations and on reducing the probability of future infestations.

but it is logical to assume that the tap-rooted big sagebrush (*Artemisia tridentata* Nutt.) would compete effectively with the tap-rooted musk thistle. For this hypothetical example, we will assume that removing big sagebrush increases the invasive potential for musk thistle and that natural grassland communities are more susceptible to invasion by musk thistle than are shrub steppe communities.

To emphasize the decision-making process, I have developed a map (Figure 2) and a list of issues that ought to be considered: (1) the brush on roadsides is often cut to increase the visibility of deer, which are a threat to motorists. The nonsprouting big sagebrush is removed by this process, which will encourage expansion of musk thistle. Are there low-growing or resprouting shrubs that might be planted along the roadway to compete with musk thistle? Or alternatively, are there deep-rooted species of grass that might be appropriate as part of a seeding mixture? The advantage of a grass is that it will survive spraying with broadleaf herbicides, thus allowing for thistle control while maintaining desirable plant cover. (2) The highway is the primary source of propagules that spread into adjacent rangeland. Therefore, management of private and public pasture and rangeland along the highway corridor is critical in arresting the spread of musk thistle. In these areas shrub control and grazing management should receive special attention. Shrub control could be avoided for some distance out from the corridor, and grazing management should be focused on short periods of grazing followed by no grazing to keep the vegetation actively growing. Although I should stress that a good deal more research is needed on the interaction between grazing management and weed populations. (3) Wildfires are not unusual in this area, and ignition can be from lightning or humans. Many human-induced wildfires start on the roadside and radiate away from the road. Burning removes sagebrush and provides a pulse of soil N (Hobbs and Schimel 1984) that increases the risk of weed expansion. Burned areas would require careful monitoring and spot control for at least several years following fire. A major disadvantage of a fire that begins at the roadside is that it can easily allow expansion of musk thistle from the highway corridor into adjacent rangeland. (4) If the grassland areas were considered to be at risk of invasion but not yet invaded, then the segment of highway corridor to the west of the sagebrush control areas should be a priority for monitoring and control. In this example the prevailing wind direction is from the west, which should help limit the westward flow of propagules. In this example I have assumed that the sagebrush control area represents the furthest westward expansion of musk thistle.

The third example is expansion of spotted knapweed

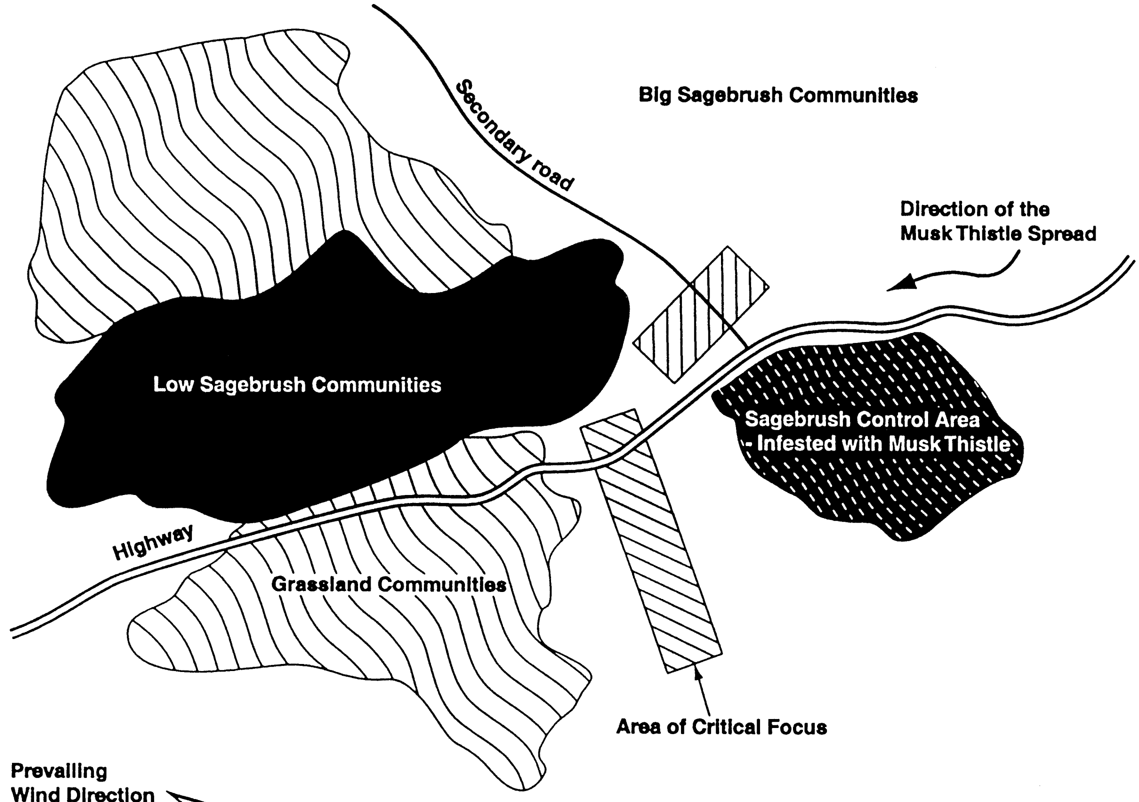

FIGURE 2. Hypothetical example of musk thistle (*Cardus nutans* L.) spreading from east to west along an eastern Oregon highway. Illustration by Rodney McPhail.

(*Centaurea maculosa* Lam.) into the fescue (*Festuca* spp.) grasslands of Glacier National Park (Montana). In their study, Tyser and Key (1988) found that spotted knapweed spread from the disturbed roadsides into adjacent grasslands. The authors suggested that several factors intrinsic to the grasslands contributed to the invasion of knapweed: (1) frequent breaks in plant cover, (2) disturbances by small burrowing animals, and (3) overgrazing by native ungulates that at the time of the study were at historically high population levels. I believe that yearly climatic variability is another factor to consider. Risser (1988) suggested N accumulation is common during drought because microbial mineralization exceeds uptake of N. Thus, invasion of a site is highest during the period immediately after a drought. Research in the U.K. has shown that drought increases the risk of weed invasion into healthy native communities (J.P. Grime, personal communication). In the Glacier National Park example, the priority should be to develop strategies for removing invasive species from the roadsides. Drought and other disturbances are inherent to the area, so minimizing propagule availability may be the most effective strategy.

Opportunities

Application of the concepts presented in this paper is unlikely without a shift in our view of land management from a descriptive to a functional approach. To this point (at least in rangeland management), we have largely been descriptive, using some form of species composition to evaluate land condition and the effect of management. The approach I have described requires that we take the additional step of evaluating the influence of climatic variation, natural disturbance, and management on resource availability. I do not mean to suggest that managers need to measure N availability, but rather that researchers should summarize what is currently known about resource availability in a way that is useful to managers. It is not necessary to precisely define soil resource levels for every management action, but we can begin to make general rules for managers to apply. Range sites (or ecological sites) could be viewed in terms of resource availability, as suggested by Svejcar and Sheley (1995). Such an approach would be an important step in identifying sites with a high potential for weed invasion (e.g., Stohlgren et al. 1999). Managers should be encouraged to conduct "on-site" research to obtain information specific to their situation. There is also a need to develop research–education–implementation teams to test the usefulness of management strategies based on resource availability.

Many of the ideas presented in this paper have not been widely applied or even discussed by those currently responsible for managing weeds or wildlands. A well-organized primary and continuing education program is critical for blending the newer ecological principles into weed management. There must be a common understanding of concepts and terminology if communication among the various disciplines is to improve. Responses to management decisions must be viewed from a longer time scale (succession can be slow) and a larger spatial scale than what is comfortable for many of us.

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