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Implementing Strategic Weed Prevention Programs to Protect Rangeland Ecosystems

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Weed prevention is recognized as one of the most cost-effective management strategies for invasive plants. In the field of invasive plant management increasing emphasis is being directed toward proactive management. However, land managers are still somewhat reluctant to aggressively employ prevention programs. Part of this reluctance could be due to lack of understanding of what a comprehensive prevention program entails. The purpose of this paper is to improve strategic decision-making for site-specific prevention programs, such as those on ranches or in watersheds. Our interest is in advancing prevention planning for land managers—the people who are faced with the constant pressure of potential invasive species infestations on a day-to-day basis. To facilitate more widespread use of prevention programs we are proposing definitions for key terminology to standardize and facilitate communication about prevention programs. Additionally, we present a flow model with the steps necessary to successfully implement such programs. The model has three categories from which specific prevention planning occurs: (1) education, (2) early detection and eradication, and (3) interruption of movement. The flow model directs users through a series of interlinked steps. Finally, we provide a case study in which a ranch manager implemented a prevention program using this framework. By using this model, managers are poised to conduct more strategic planning. This model also has applications in outreach and education programs to assist land managers in prevention planning.

Key words: Containment zone, early detection, high-risk area, prevention framework, protection zone, weed awareness.

Rangelands provide natural resources from which significant economic and ecological goods and services are acquired. These lands capture and store water, provide wildlife habitat, cycle soil nutrients, and support in sustaining a $45 billion dollar livestock industry in the United States (Brunson and Huntsinger 2008; Havstad et al. 2007; Huntsinger et al. 2010; U.S. Economic Research Service 2011). Infestations of invasive plants negatively impact and continue to jeopardize these resources (Davies and Svejcar 2008; James et al. 2008; Kulmatiski et al. 2006; Sheley et al. 2011) and are one of the biggest threats to our western rangelands (Reeves and Mitchell 2012). A number of invasive plant species are considered major contributors to ecosystem degradation (Pimentel et al. 2005; Vitousek et al. 1997). Although restoration of land with invasive plant infestations may be possible, the process requires large investments in human and monetary resources and even then success rates are low (Carrick and Krüger 2007; Hemstrom et al. 2002; Vitousek et al. 1997).

In a 2004 survey, Duncan and Jachetta (2005) reported a total of 50 million hectares (2.47 acres per hectare) infested by 16 selected invasive plants in the 48 contiguous states. However, the true challenge for invasive plant management is more than accounting for land infested by these species but is in formulating sound prevention programs to limit further damage on ecosystems that provide critical goods and services (Pimentel et al. 2005). Implementing strategies to prevent establishment and spread of invasive plants makes logical scientific and economic sense. Prevention programs are recognized as being the most cost-effective and efficient method for reducing the costs associated with invasive plants (Cusack et al. 2009) and national directives are in place for invasive plant planning efforts that include developing prevention programs as a primary focus (National Invasive Species Council 2008). In our outreach with land managers we are increasingly recognizing the need to improve invasive plant prevention.

Hobbs and Humphries (1995) suggested developing ecosystem management methods to prevent weed invasion

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and a need for assigning prevention priorities based on ecosystem vulnerabilities. They contended weed management would be more successful if it shifted from a species-specific approach to an ecosystem approach. Considerable progress has been made in recent years. We are seeing a shift from prescription-based approaches with limited success to long-term weed management strategies (Sheley et al. 2010). Over the last several years, a successional management framework has been developed and tested as a decision-support tool for ecologically based invasive plant management (EBIPM) (Sheley et al. 2010). This model provides a stepwise approach providing managers with ecological principles linked to the best tools and strategies for amending ecological processes in disrepair. EBIPM is aimed primarily at existing plant infestations but prevention is a part of the model. Better defining a prevention program within this framework was the incentive for developing this paper. Although a focus on weed prevention is increasing, specific strategies are required to move prevention programs into mainstream weed management (Davies and Sheley 2007; Goodwin et al. 2012; Ransom and Whitesides 2012). Documented successes have been recorded where watershed-wide weed prevention areas (WPAs) protected rangelands from invasion. In Montana alone, over 2.2 million hectares have been enrolled in such WPA programs (Goodwin et al. 2012). A number of guidelines are available to assist managers in developing WPAs and implementing prevention practices (Cal-IPC 2012 Christensen et al. 2011; Goodwin and Jacobs 2007). We have also seen advances toward understanding the dispersal of invasive plants. Davies and Sheley (2007) described a framework to prevent dispersal of invasive plants where major dispersal vectors are linked to dispersal management strategies. This framework allows managers to prioritize efforts by ranking the dispersal vectors associated with their ability to disperse plant propagules (Davies and Sheley 2007). These strategies have advanced prevention as a crucial component of invasive plant management.

Many land managers work with limited financial resources and time constraints. Given the magnitude and complexity of invasive plant infestations, management strategies based on analyzing the cost vs. benefits allow managers to optimally allocate scarce resources (Sheley and Smith 2012). Using this rationale, it is sensible to systematically implement the least costly, most successful, and most beneficial strategies first (Davies and Johnson 2009; Sheley and Smith 2012). We used this rationale to develop a prioritized management action plan (Figure 1). The highest priority is to protect and prevent infestations from land without infestations; the second priority is to implement management on land that has at least 15% of desired remnant plants. Research has shown if infestations of invasive plants are controlled, the remaining desired plants may recover without additional restoration efforts (Davies and Sheley 2011). Finally, the lowest priority for management is areas with near-monoculture infestations where extensive restoration efforts are needed. This prioritization model provides a foundation from which our strategic planning prevention framework emerges. The need to solidify prevention programs as part of standard best management practices for invasive plants is substantial (Davies and Johnson 2011) as there are few tools to assist land managers with setting priorities for invasive species management (Lee 2001). Our objective is to provide a framework that improves strategic decision-making for prevention programs. In this paper we first propose definitions to begin standardizing terminology for weed prevention. Secondly, we propose a flow model as a framework to implement a prevention program. With a standardized terminology and a framework from which to base prevention plans, more widespread adoption and successful implementation of invasive plant prevention programs should ensue. Finally, we provide a ranch-scale case study where our framework and process was used to implement a prevention program for the invasive annual grass medusahead [*Taeniatherum caput-medusae* (L.) Nevski].

Key Terminology for Prevention Planning

Managers use a number of terms specific to managing invasive plants and sometimes these terms are used differently, which can cause mistakes in how management decisions are made (Rew and Pokorny 2006). Early detection and rapid response (EDRR) is one term that has gained widespread acceptance in weed management with national initiatives developed to detect and react quickly to prevent establishment of invasive populations (National Invasive Species Council 2008). Other terms in the literature aimed at prevention programs include "containment areas," "let-go areas," and "high-risk sites" (Goodwin et al. 2012; Hulme 2006; Jacobs 2007; Sheley et al. 1999). There are several terms where standardized definitions can benefit the field of invasive plant management. A set of standardized terms can facilitate more effective communication among groups planning prevention programs. Useful terms needing standard definitions include the following: protection zones, action zones, containment zones, and high-risk areas (Figure 2).

- Protection zones: Areas under management free from species of concern but at risk for future infestations due to high probability of newly arriving infestations. Within a protection zone the management goal is to keep land healthy and resistant to any invasive plant establishment.

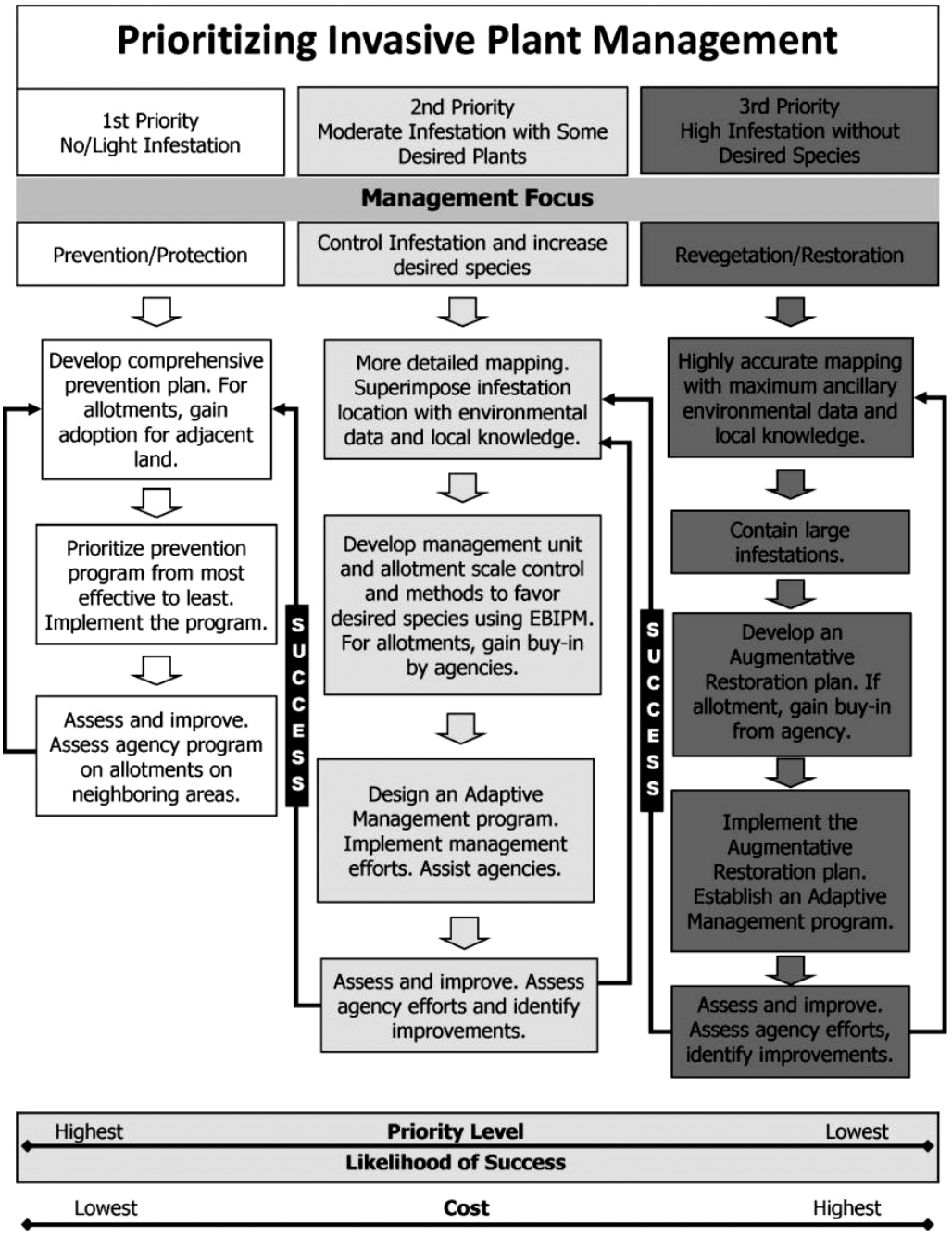

Figure 1. Prioritized management action plan for invasive plant management programs.

- Action zones: Areas bordering infestations where leading edges of infestations have been identified. An action zone lies between a protection zone and a containment. The management goal in action zones has an active survey program for EDRR and a plan for eradicating any detected invasive.
- Containment zones: Areas where larger (generally >1 ha) well-established invasive plant infestations occur. Within a containment zone the management goal is to reduce seed production. Revegetation to desirable plant communities is a long-term goal in a containment zone.
- High-risk areas: Pathways where seed dispersal may be occurring within and adjacent to action zones. They are often high-use areas or disturbed sites, such as roads, trails, waterways, recreation sites, and animal migration or livestock trails (Christensen et al. 2011; Rew and Pokorny 2006).Through dedicated regular surveying, finding small populations or even single plants will reduce the cycle of

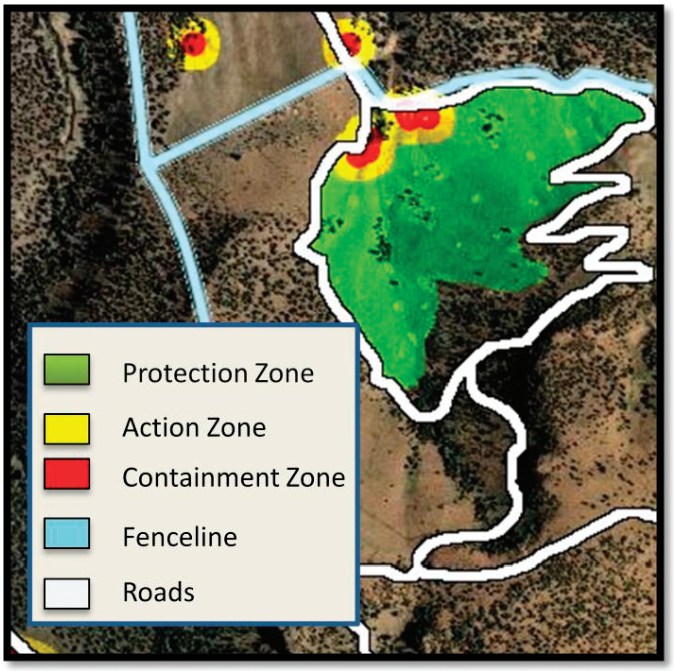

Figure 2. A map to illustrate the different zones for a weed prevention program.

expanding infestations (Moody and Mack 1988). Environmental and habitat characteristics may predispose a habitat to invasion by nonnative plants (Panetta and Mitchell 1991); for this reason high-risk areas should become part of weed prevention vocabulary.

Weed Prevention Decision Support Flow Model

Our intent with the prevention flow model framework is to provide a process that encourages managers in a prevention planning effort. It has been shown that a clear framework is useful in planning and decision-making processes and fosters learning and in knowledge transfer from one situation to another (Halle and Fattorini 2004). Our flow model begins with the overarching process of creating landscape goals (Figure 3). The next step is to develop a list of priority species and then create a general map for prevention planning. Once a map is generated the components of the model are developed under three subheadings: (1) education, (2) early detection and eradication, and (3) interruption of movement (spread). The flow model directs users through interlinked steps by a series of arrows. Arrows are looped to indicate when a process is repeated or is linked to other part of the model.

Creating Goals. Completing a goal-setting exercise is the key to initiating a focused program. Goal-setting involves all the people responsible for implementing a plan. A benefit of making goal-setting the first part in a planning process is to gain stakeholders' agreement on the value of prevention programs to improve weed management. A prevention goal can be broad, for example "stop any new invasive weeds from becoming established in the protection zone at the Cow Creek pasture" or a goal can be specific, such as "eradicate yellow starthistle from the action zone in the Old Homestead pasture." Goal-setting is not a one-time action; revisiting and updating on a regular basis is all part of a good planning process.

Developing a Priority List for Species for Prevention. The main purpose of priority weeds list is to focus on species of greatest concern. Depending on the area under management, a list can be as short as one species of special concern to a list of multiple species. Anticipating species with potential to infest and spread in given landscapes is an important aspect of a prevention program (Radosevich et al. 2007). If the priority list contains multiple species it will be useful to also rank them. We suggest species ranking include three categories: (1) EDRR: Species not currently found within the area being managed but known nearby with traits that can cause significant harm to the ecosystem. Species in this category receive highest priority because they have not yet established within an area and minimal resources are needed to prevent infestations. (2) Control: Species in this category includes aggressive plants established, but in localized patches where control or significant reduction in population could be accomplished. (3) Containment: Included in this category are species already well established within the management areas (Christensen et al. 2011).

Generating Maps of Known Infestations and Weed-Free Areas to Protect. A key point differentiating prevention programs from other weed management programs is the emphasis placed on protecting lands free or nearly free of invasive plants. Generating maps involves drawing known infestations within the management area. Initial mapping attempts are meant to be part of a long-term process. Land managers must recognize that effective maps require repeated surveying and remapping. Once known infestations and known weed-free areas are drawn, the next step is delineating protection zones, action zones, containment zones, and high-risk areas. Depending on the amount resources available, mapping can be as simple as hand-drawing areas in good condition and void of known infestations.

Enhancing Education and Awareness. Education and technology transfer are central to making prevention programs standard practices in weed management. In our model, to ensure education is a part of all prevention plans, we have made it a separate section. Although past studies suggest little awareness of invasive plants, public awareness regarding invasive plants and the potential ecological and

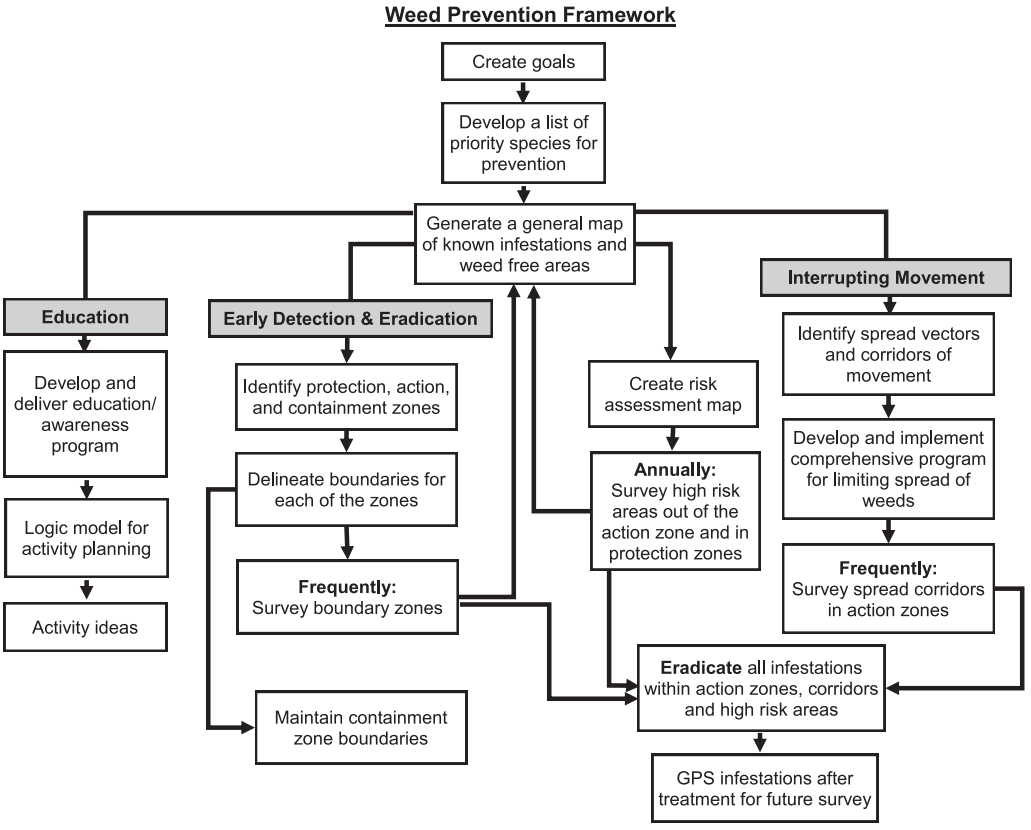

Figure 3. A flow model framework for developing and implementing weed prevention programs.

economic consequences is thought to be increasing (Daab and Flint 2010). For the general public to aid in managing invasive plants they need to be aware of the plants that are currently or potentially a problem (Daab and Flint 2010). This suggests that an educational component in prevention programs can change behaviors of the general public with regard to invasive plants. Education and awareness programs can take many forms depending on the area being managed and makes people more aware of the issue. Once they know more about an issue they can create a change in their behavior.

Designing education around specific outcomes can be achieved by creating a logic model (Table 1). When activities are linked to specific outcomes key education needs are targeted. For example, in Table 1, a logic model was created for lands experiencing many public visitors, such as a national or state park. The long-term outcome was to keep land without infestations free from invasive plants. To achieve this outcome, managers have a number of activities to implement. A private rancher would likely be interested in creating a more informal program, one involving family members and employees.

Examples of education programs include improving weed awareness and weed identification skills through different media such as brochures, posters, newspaper articles, Web sites, and educational events such as workshops, field tours, and bounty programs (Pokorny and Kreueger-Mangold 2007). Using well-placed signage at trailheads or along roadsides is generally low-cost yet effective in creating awareness. More in-depth programs could include holding field tours or workshops about specific invasive plant issues.

Initiating Early Detection and Eradication. EDRR is a well-recognized acronym in weed management today. There is minimal standardization for EDRR as most organizations have their own program and guidelines in place for implementing a program (Cal-IPC 2012; Rew and Pokorny 2006; Zimmerman et al. 2011). Important elements of a successful EDRR program include strategic inventorying and monitoring for satellite populations (Davies and Johnson 2011). We have proposed these types of activities in the prevention model so early detection and eradication is documented and repeatable. The first step to initiating early detection and eradication is to identify and mark protection, action, and containment zones on the map.

Once boundaries are delineated, a plan to survey the boundaries can be developed. There are numerous methods for conducting surveying, mapping, and collecting data. Reporting information should be kept to a manageable

level so as to remain efficient with labor resources. Collecting survey data allows managers to develop an adaptive management approach to prevention. The North American Invasive Species Management Association (NAISMA) has developed ''North American invasive plant mapping standards.'' (NAISMA 2014) Since we are advocating standardization in this paper as a way to encourage prevention programs, using the NAISMA standards is recommended. The following are general suggestions to improve information collected:

- Survey at predetermined times. Annual surveying of the high-risk areas within the action zone is a method for managers to strategically identify potential new infestations (Moody and Mack 1988).
- Survey for priority-list plants when phenology makes them most visible.
- With each survey, use the information gathered to update the general map. As the map is updated, eventually a risk assessment map can be developed.
- Concentrate surveying resources in the action zones. The probability of finding new patches or individual plants is highest in locations closest to established patches (Rew and Maxwell 2007).
- Create an action zone boundary minimum of 30.5 m (100 ft) in grassland areas, and even lower (15–23 m) in diverse vegetation areas (Figure 4).
- Consider using a systematic survey with belt transects to maximize the likelihood of finding target plants, such as used for Threatened and Endangered species. This may be a suitable method to employ in the action zones and high-risk areas when searching for invasive plants (U.S. Fish and Wildlife Service 2011). This method can be used when the occurrence of priority plants may be found anywhere in the action zone. For example, infestations of the invasive annual grass medusahead usually have diffuse boundaries and careful scrutiny will keep infestations from spreading (Davies 2008).

With boundaries set and surveyed, a plan for eradicating all infestations within action zones, corridor areas, and high-risk zones can be developed. Research has shown eradication efforts are practical for small-scale infestations of less than 1 ha (Rejmánek and Pitcairn 2002). Locations of any infestations should be marked with a global positioning system (GPS) so they can be found and checked in the next survey. The last action of the early detection and eradication section is to maintain containment zone boundaries. In a containment zone the goal is to prevent an infestation from spreading into uninfested portions of the management area (Hulme 2006). Methods for containment involve preventing reproduction and dispersal, treating the perimeter of a large infestation, eliminating satellite infestations, or any combination of these (Hulme 2006). Containment can be accomplished using different tools, including herbicides or livestock grazing to limit seed development. Containing the spread can also be accomplished with living barriers. Tall tussock perennial grasses planted as barriers around infestations have been shown to decrease the dispersal of the invasive annual grasses (Davies et al. 2010). A defensive ''hold-the-line'' approach will help ensure that infestations are not spreading.

Interrupting Movement. Pollination, seed production, and propagule dispersal play a fundamental role in intact natural communities but also in the potential invasion of nonnative plant species (Travest and Richardson 2006). Land managers can utilize this knowledge by managing the fate of invasive plant seeds, thereby interrupting invasive plant movement (Davies and Sheley 2007). Factors aiding dispersal of propagules include plant adaptations, locations where infestations are growing, and the type and frequency of vectors (Davies and Sheley 2007). In this section (Figure 3) the goal is to strategically interrupt invasive plant movement or spread. In a natural progression, vectors responsible for spreading propagules should be identified. Human and livestock travel corridors are known to serve as vectors of annual grass invasion (Davies et al. 2013; Gelbard and Belnap 2003). Once vectors and the corridors vectors travel are identified, a program can be designed around limiting seed dispersal. Management actions to reduce seed dispersal include closing trails, limiting travel through weed infestations during seed maturation, maintaining weed-free zones along trails, screening seeds out of waterways, creating living barriers, or some combination of these (Davies and Sheley 2007).

After zones have been established, eradicating infestations within the zones is the next step. All eradication efforts should be marked using a GPS unit so an area can be rechecked at a later date. Conducting control activities when a plant or satellite infestation is detected improves overall efficiency in a prevention program. Options for control are usually limited to mechanical removal or herbicides (DiTomaso 2000). While surveying, a shovel or a backpack sprayer with the appropriate herbicide offers the opportunity for responding immediately to small or single-plant infestations. In our flow model, all survey efforts lead to eradicating infestations in action zones, corridors, and high-risk areas. Satellite infestations detected early are treated with limited expense and treatment is usually efficacious (Porkorny and Krueger-Mangold 2007).

Case Study Using Prevention Flow Model Implemented on a Ranch Scale

To test this prevention flow model, in 2007 we collaborated with the owners of a 2,000-ha cow–calf ranching operation in central Oregon to implement

Table 1. Weed prevention plan logic model for education and awareness planning.

Inputs	Outputs		Outcomes -- Impact		
	Activities	*Participation*	*Short*	*Medium*	*Long*
• People committed to promoting prevention and implementing plans • Prevention plan • Maps with roads and trails marked • Any necessary funding to implement • Available data or information to identify protection, action and containment zones	• Create priority list of species of concern • Identify protection, action and containment zones on maps • Workshop or meetings of all interested parties • Create fact sheets with excellent pictures to identify species of concern. • Use online social media regularly to update Monument visitors. • Develop maps so visitors know areas the Monument is trying to protect. • Signage/ kiosks at trailheads with instructions on reporting infestations	• People involved in the day to day management of the prevention area • Adjacent private landowners • People using the area for production or recreation	• Plan endorsed by all participants • Programs in place for both staff and visitors for understanding the importance of preventing invasive plants in the Monument. • Brochures, maps, identification sheets developed. • Signage/ kiosks in place at trail heads to alert visitors to the threat of invasive plants and how to minimize dispersal. • Program established for visitors to report new patches of invasive plants.	• Increased awareness among staff about invasive species and the vector pathways. • Visitors are aware of invasive species of concern and they know practices to minimize dispersal. • Adjacent landowners partner to protect additional acreages. • Staff and visitors report new patches. • Surveying efforts detect new infestations. • Maps are updated after new surveys.	• Healthy, native landscapes (especially bluebunch perennial grass communities) in the Monument are protected from invasive plant invasions and infestations. • Plan implemented on other properties.

Assumptions: Resources are available to implement activities resulting in positive outcomes.

External Factors – Changes in personnel may create difficulty in continued implementation of plan.

a prevention program. The owners were concerned about the continued spread of the invasive annual grass medusahead on ranch property and onto surrounding properties. In addition to the goal of reducing medusahead infestations and revegetating heavily impacted areas, the owners were willing to test our flow model process for overall applicability.

This ranch encompasses a diverse mountainous landscape ranging from 1,000 to 1,200 m elevation. While many microclimates exist, the ranch is in a 30-cm (12-in) annual precipitation zone. On the rangelands, native grass species include bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) Á. Löve], Idaho fescue (*Festuca idahoensis* Elmer), Sandberg's bluegrass (*Poa secunda* J. Presl.), and

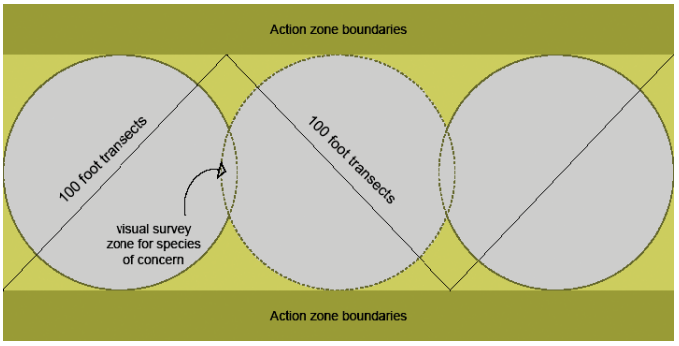

Figure 4. Survey strategy for action zone boundaries. (Color for this figure is available in the online version of this paper.)

Thurber's needlegrass [*Achnatherum thurberianum* (Piper) Barkworth]. Forbs include common yarrow (*Achillea millefolium* L.), lupine (*Lupinus* sp.), and phlox (*Phlox* sp.). Shrub species include Wyoming and mountain big sagebrush (*Artemisia tridentata* Nuttall subsp. *wyomingensis* Beetle and Young and subsp. *Vaseyana* (Rydb.) Beetle), and antelope bitterbrush [*Purshia tridentata* (Pursh) DC]. The dominant tree species on the ranch is western juniper (*Juniperus occidentalis* Hook) but ponderosa pine (*Pinus ponderosa* P. & C. Lawson) grows at the higher elevations.

We initiated the prevention planning process by creating goals: the owners were interested in continuing their cow–calf operation while decreasing outside hay purchases. To accomplish this, medusahead infestations needed to be contained and spread reduced. The plant priority list was relatively easy; medusahead was their highest management priority. Several other invasive plants known in the area were added to the list. If they were recorded in surveying they could be easily eradicated. According to the next step in the flow model, a map of the property was generated. Property lines, fence lines, roads and trails, watering areas, and areas where activity commonly occurs such as holding pens and corrals were all recorded (Figure 5).

Education. As this land was privately owned and most property boundaries were next to other private property, the education and awareness program was developed for employees, and invited hunters were made aware of the medusahead prevention program. This was a fairly informal program where the ranch owners and ranch magershowed individuals what medusahead looked like. They made requests for people to stay on roads and trails to limit dispersing seed into protection zones. The owners also changed the grazing patterns of the cattle. Cattle were moved into containment zones early in the season for heavy grazing to reduce overall medusahead seed production. Later in the growing season, once the desired perennial bunchgrasses had produced seed in protection zones, cattle were moved to graze in those pastures.

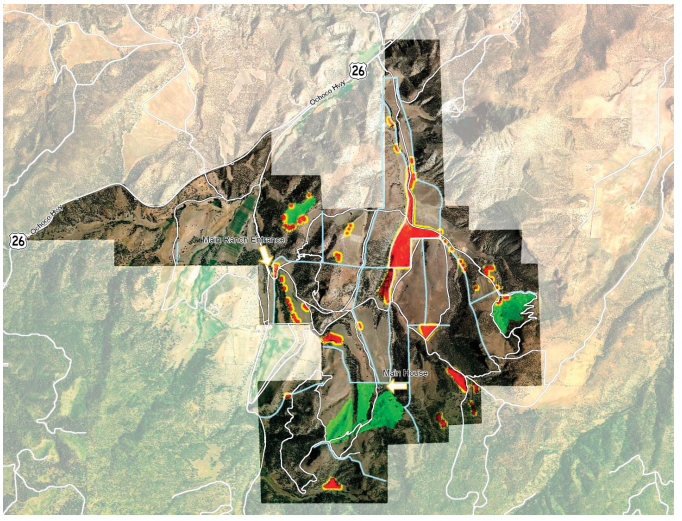

Figure 5. Map of Circle Bar Ranch with protection zones marked in green, action zones marked in yellow, and containment zones marked in red where infestations of medusahead are occurring. Fence lines are in blue and main ranch roads in white.

Early Detection and Eradication. The owners completed a limited survey to create initial boundaries for protection, action, and containment zones. As more detailed surveying was completed in subsequent seasons, boundaries were readjusted and high+risk zones were identified. We set up a color-coding system based on the level of medusahead infestation that corresponded with the zones we defined earlier (Figure 5). Leading edges of these infestations were located and action zone boundaries were surveyed regularly to make certain medusahead was not spreading from these areas. After initial mapping, land heavily impacted by medusahead was estimated to be at least 240 ha.

Interrupting Movement. Once initial surveying and boundary setting was completed, more detailed surveying was conducted and resources were dedicated toward a prevention program. A summer intern began systematic surveys of the property using a GPS unit and an all-terrain vehicle equipped with a herbicide spray system. By combining a surveying method and the ability to control satellite infestations, the intern was able to simultaneously implement early detection and eradication and interrupt seed production by spot-treating infestations along roads, trails, and gathering areas. All locations of medusahead were saved with the GPS system to begin building more accurate maps of infestations.

The prevention program at this ranch was a valuable component in managing an overall challenging medusahead infestation. The landowners were enthusiastic about the process. They helped us refine the model to be user-friendly and easily implementable. For example, it was their idea to hire a person in the summer to implement the

prevention program. Dedicating resources to the prevention program was the key to the overall management of the medusahead. In the ensuing years they have continued using the prevention framework for managing medusahead and other invasive plants. Additional education and awareness programs were initiated in the form of several field days. They wanted to show their success in reducing medusahead infestations and in restoring areas with heavy infestations. The owners estimated they committed resources amounting to about \$0.80 ha^{-1} yr^{-1} over a period of 5 yr. At this stage their program is on ''prevention maintenance.'' In their most recent survey (summer 2013) the landowners reported that the medusahead infestation was not advancing.

Concluding Remarks

Methods for managing ecosystems to prevent weed invasion should be developed using a priority-based system (Hobbs and Humphries 1995). The flow model we present in this manuscript provides one such method. The variable nature of plant invasions warrants a variety of strategies for prevention programs (Pimentel et al. 2005). Standardizing terminology and a flow model framework will advance invasive plant management, giving managers a clear pathway to implementable prevention plans. For prevention measures to be successful, much greater levels of awareness of these approaches using a priority-based system are needed (Hobbs and Humphries 1995). Systematic planning and implementation of prevention programs will transform invasive plant management from being primarily reactive to one of proactive management.

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Literature Cited

Brunson MW, Huntsinger, L (2008) Ranching as a conservation strategy: can old ranchers save the New West? Rangeland Ecol Manag 61:137–147

[Cal-IPC] California Invasive Plant Council (2012) Preventing the Spread of Invasive Plants: Best Management Practices for Land Managers. 3rd edn. Berkeley, CA: California Invasive Plant Council Publication 2012-03. 80 p. Available at http://www.cal-ipc.org. Accessed September 25, 2013

Carrick PJ, Krüger R (2007) Restoring degraded landscapes in lowland Namaqualand: lessons from the mining experience and from regional ecological dynamics. J Arid Environ 70:767–781

Christensen S, Ransom C, Sheley R, Smith B, Whitesides R (2011) Establishing a weed prevention area: a step by step user's guide. Burns, OR USA: U.S. Department of Agriculture–Agricultural Research Service. 40 p

Cusack C, Harte M, Chan S (2009) The economics of invasive species. Corvallis, OR: Oregon Sea Grant. 12 p

Daab MT Flint CG (2010) Public reaction to invasive plant species in a disturbed Colorado landscape. Invasive Plant Sci Manag 3:390–401

Davies KW (2008) Medusahead dispersal and establishment in sagebrush steppe plant communities. Rangeland Ecol Manag 61: 110–115

Davies KW, Johnson DD (2009) Prevention: a proactive approach to the control of invasive plants on wildlands. Pages 82–96 *in* Wilcox CP, Turpin RP, eds. Invasive Species: Detection, Impact and Control. Nova Science Publishers, Hauppauge, New York

Davies KW, Johnson DD (2011) Are we ''missing the boat'' on preventing the spread of invasive plants in rangelands? Invasive Plant Sci Manag 4:166–171

Davies KW, Nafus AM, Madsen MD (2013) Medusahead invasion along unimproved roads, animal trails, and random transects. West N Am Nat 73:54–59

Davies KW, Nafus AM, Sheley RL (2010) Non-native competitive perennial grass impedes the spread of an invasive annual grass. Biol Invasions 12:3187–3194

Davies KW, Sheley RL (2007) A conceptual framework for preventing the spatial dispersal of invasive plants. Weed Sci 55:178–184

Davies KW, Sheley RL (2011) Promoting native vegetation and diversity in exotic annual grass infestations. Restor Ecol 19:159–165

Davies KW, Svejcar TJ (2008) Comparison of medusahead-invaded and noninvaded Wyoming big sagebrush stepped in southeastern Oregon. Rangeland Ecol Manag 61:623–629

DiTomaso JM (2000) Invasive weeds in rangelands: species, impacts, and management. Weed Sci 48:255–265

Duncan CA, Jachetta JJ (2005) Introduction. Pages 1–7 *in* Duncan CL, Clark JK, eds. Invasive Plants of Range and Wildlands and Their Environmental, Economic, and Societal Impacts. Lawrence, KS: Weed Science Society of America

Gelbard JL, Belnap J (2003) Roads as conduits for exotic plant invasions in a semi-arid landscape. Conserv Biol 17:420–432

Goodwin K, Jacobs J (2007) Developing invasive weed prevention areas for rangeland ecosystems. U.S. Department of Agriculture Natural Resources Conservation Service, Bozeman MTInvasive Species Technical Note No. MT-15. 7 p

Goodwin K, Sheley R, Jacobs J, Wood S, Manoukian M, Schuldt M, Miller E, Sackman S (2012) Cooperative prevention systems to protect rangelands from the spread of invasive plants. Rangeland J 34: 26–31

Halle S, Fattorini M (2004) Advances in restoration ecology: insights from aquatic and terrestrial ecosystems. Pages 10–33 *in* Temperton VM, Hobbs RJ, Nuttle T, Halle S, eds. Assembly Rules and Restoration Ecology: Bridging the Gap between Theory and Practice. Washington, DC: Island Press

Havstad KM, Peters DPC, Skaggs R, Brown J, Bestelmeyer B, Fredrickson E, Herrick J, Wright J (2007) Ecological services to and from rangelands of the United States. Ecol Econ 64:261–268

Hemstrom MA, Wisdom MJ, Hann, Rowland MM, Wales BC, Gravenmier RA (2002) Sagebrush-steppe vegetation dynamics and restoration potential in the interior Columbia Basin, USA. Conserv Biol 16:1243–1255

Hobbs RJ, Humphries SE (1995) An integrated approach to the ecology and management of plant invasions. Conserv Biol 9:761–770

Hulme, PE (2006) Beyond control: wider implications for the management of invasions. J Appl Ecol 43:835–847

Huntsinger L, Johnson M, Stafford M, Fried J (2010) Hardwood rangeland landowners in California from 1985 to 2004: production,

ecosystem services and permanence. Rangeland Ecol Manag 63: 324–334
Jacobs J (2007) Invasive plant management: options and actions. Chapter 10 *in* Invasive Plant Management: CIPM Online Textbook Center for Invasive Plant Management. Bozeman, MT: Center for Invasive Plant Management. http://www.weedcenter.org/index.html. Accessed September 25, 2013
James JJ, Davies KW, Sheley RL, Aanderud ZT (2008) Linking nitrogen partitioning and species abundance to invasion resistance in the Great Basin. Oecologia 156:637–648
Kulmatiski A, Beard KH, StarkJM (2006) Exotic plant communities shift water-use timing in a shrub-steppe ecosystem. Plant Soil 288: 271–284
Lee M. (2001) Non-Native Plant Invasions in Rocky Mountain National Park: Linking Species Traits and Habitat Characteristics. Master's thesis. Fort Collins, CO: Colorado State University 218 p
Moody ME, Mack RN (1988) Controlling the spread of plant invasions: the importance of nascent foci. J Appl Ecol 25:1009–1021
National Invasive Species Council, (2008) 2008–2012 National Invasive Species Management Plan, accessed August 12, 2013, at http://www.doi.gov/invasivespecies/upload/2008-2012-National-Invasive-Species-Management-Plan.pdf. 35 p
Panetta FD, Mitchell ND (1991) Homocline analysis and the prediction of weediness. Weed Res 31:273–284
North American Invasive Species Management Association. 2014. North American invasive species mapping standards. http://www.naisma.org/images/NAISMA_Mapping_Standards2014_1.pdf. Accessed March 1, 2014
Pimentel D, Zuniga R, Morrison D (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. J Ecol Econ 52:273–288
Pokorny ML, Kreuger-Mangold JM (2007) Evaluating Montana's dyer's woad (*Isastis tinctoria*) cooperative eradication project. Weed Technol 21:262–269
Radosevich, SR, Holt JS, Ghersa CM (2007) Ecology of weeds and invasive plants: relationship to agriculture and natural resource management. 3rd edn. Hoboken, NJ: J. Wiley. 454 p
Ransom CV, Whitesides RE (2012) Proactive EBIPM—establishing weed prevention areas. Rangeland J 34:35–38
Reeves MC, Mitchell JE (2012) A Synoptic Review of U.S. rangelands: A Technical Document Supporting the Forest Service 2010 RPA Assessment. Fort Collins, CO: U.S. Department of Agriculture Forest Service Gen. Tech. Rep. RMRS-GTR-288. 128 p
Rejmánek M, Pitcairn MJ (2002) When is eradication of exotic pest plants a realistic goal? Pages 249–253 *in* Veitch CR, Clout MN, eds. Turning the Tide: The Eradication of Invasive Species. Gland, Switzerland: International Union for Conservation of Nature Species Survival Commission Invasive Species Specialist Group
Rew L, Maxwell B (2007) Monitoring non-native plant populations. Chapter 7 *in* Center for Invasive Plant Management, ed. Invasive Plant Management: CIPM Online Textbook Bozeman, MT: Center for Invasive Plant Management. http://www.weedcenter.org/textbook/index.html. Accessed August 12, 2013
Rew, LJ, Pokorny ML eds (2006) Inventory and Survey Methods for Nonindigenous Plant Species. Bozeman, MT: Montana State University Extension. Extension Service Bulletin EB 4503. 75 p
Sheley RL, James JJ, Rinella MJ, Blumenthal DM, DiTomaso JM (2011) Invasive plant management on anticipated conservation benefits: a scientific assessment. Pages 291–336 *in* Briske DD, ed. Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service
Sheley R, James J, Smith B, Vasquez E (2010) Applying ecologically based invasive plant management. Rangeland Ecol Manag 63:605–613
Sheley RL, Kedzie-Webb S, Maxwell BD (1999) Integrated weed management on rangeland. Pages 57–68 *in* Sheley RL, Petroff JK, eds. Biology and Management of Noxious Rangeland Weeds. Corvallis, OR: Oregon State University Press
Sheley RL, Smith BS (2012) Prioritizing invasive plant management strategies. Rangeland J 34(6):11–14
Travest A, Richardson DM (2006) Biological invasions as disruptors of plant reproductive mutualisms. Trends Ecol Evol 21:208–216
U.S. Economic Research Service 2011. Value of U.S. Cattle and Calf Production. http://www.ers.usda.gov/topics/animal-products/cattle-beef/statistics-information.aspx. Accessed September 12, 2013
US Fish and Wildlife Service 2011. Utah Field Office Guidelines for Conducting and Reporting Botanical Inventories and Monitoring of Federally Listed, Proposed and Candidate Plants. Utah Field Office, U.S. Fish and Wildlife Service, West Valley City, UT19 p
Vitousek PM, D'Antonio CM, Loupe LL, Rejmanek M, Westbrooks R (1997) Introduced species: a significant component of human-caused global change. N Z J Ecol 21:1–16
Zimmerman C, Jordan M, Sargis G, Smith H, Schwager K (2011) An Invasive Plant Management Decision Tool. Version 1.1. Arlington, VA: The Nature Conservancy. 43 p

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