Nevada Agricultural Experiment Station
University of Nevada, Reno

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Wyoming Big Sagebrush

State & Transition Model

And Management Key for Nevada

First Approximation

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INTRODUCTION

During the late twentieth century, public perception of Wyoming big sagebrush (*Artemisia tridentata ssp. wyomingensis*) [Beetle & A. Young] changed from being a 'weed' to a valuable resource in danger of extirpation in some landscapes. The two polar perspectives, perceiving it to be of no value and only competitive with grasses, or perceiving it to be so valuable and scarce that we must never control it, neither serve or benefit land managers or the wildlife that depend on this important habitat. During this period, a focus on rangeland condition has shifted to a focus on ecological thresholds and the information needed to allocate limited financial and other resources to those

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areas, times, and actions that are most important for maintaining rangeland health.

This publication focuses on ecological sites capable of supporting plant communities dominated by Wyoming big sagebrush. This shrub occurs at lower elevations on valley bottoms, alluvial slopes, foothills, and mountain side slopes. It typically inhabits areas too moist for salt desert shrub species and too dry for mountain big sagebrush. While this subspecies is somewhat palatable to sheep and mule deer, it is not as palatable as black sagebrush (*Artemisia nova* [Nelson]) nor is it palatable to cattle.

This state and transition model and management key describes vegetation change and management alternatives for the Natural Resources Conservation Service ecological sites listed in Table 1. However, some areas where these sites occur are better understood by disregarding their potential for transitioning to a tree state because they are logistically far from those sites that generally have juniper (*Juniperus sp*.) and/or pinyon pine (*Pinus monophylla* Torr. & Frem.) trees. In general, the potential for transitioning to the tree state is greater for Wyoming big sagebrush sites that have higher precipitation or elevation, have deeper soils, or are closer to sites with these characteristics. Similarly, the potential for transitioning to the tree state is greater for Wyoming big sagebrush areas that have closer proximity to trees.

Table 1. Ecological sites described by this model in Nevada (NRCS Ecological Site Descriptions, 2003).

Site number	Ecological site name	Site number	Ecological site name
023XY011NV	Dunes 8-10" P.Z.	026XY099NV	Coarse Loamy 8-10" P.Z.
023XY020NV	Loamy 10-12" P.Z.	026XY100NV	Stony Slope 10-12" P.Z.
023XY030NV	South Slope 8-12" P.Z.	026XY102NV	Gravelly Clay Loam 8-10" P.Z.
023XY033NV	Clayey 10-14" P.Z.	027XY007NV	Loamy Slope 8-10" P.Z.
023XY038NV	Droughty Loam 8-10" P.Z.	027XY008NV	Droughty Loam 8-10" P.Z.
023XY039NV	Loamy Slope 10-14" P.Z.	027XY029NV	Gravelly Fan 8-10" P.Z.

Table 1 Continued

Site number	Ecological site name	Site number	Ecological site name
023XY040NV	Granitic Fan 8-10" P.Z.	027XY045NV	Sandy 8-10" P.Z.
023XY049NV	Granitic South Slope 8-12" P.Z.	027XY051NV	South Slope 8-10" P.Z.
023XY051NV	Sandy 8-12" P.Z.	027XY054NV	Loamy Slope 10-12" P.Z.
023XY057NV	Granitic Loam 10-12" P.Z.	027XY058NV	Loamy 10-12" P.Z.
023XY063NV	Shallow Granitic Hill 10-14" P.Z.	027XY065NV	Granitic Slope 8-10" P.Z.
023XY068NV	Granitic Loam 8-10" P.Z.	027XY067NV	Granitic Loam 8-10" P.Z.
023XY071NV	Ashy Loam 10-12" P.Z.	027XY072NV	Granitic Slope 10-12" P.Z.
023XY072NV	Ashy Slope 10-12" P.Z.	027XY088NV	Granitic Loam 10-12” P.Z.
023XY077NV	Shallow Loam 10-14" P.Z.	027XY091NV	Loamy Fan 10-12” P.Z.
023XY082NV	Loamy Fan 10-12" P.Z.	027XY092NV	Granitic Fan 10-12” P.Z.
023XY088NV	Chalky Knoll	028AY005NV	Sandy 8-10" P.Z.
023XY096NV	Ashy Sandy Loam 10-12" P.Z.	028AY010NV	Coarse Gravelly Loam 10-12" P.Z.
023XY097NV	Loamy Fan 8-10" P.Z.	028AY015NV	Loamy 8-10" P.Z.
023XY099NV	Channery Hill 8-10" P.Z.	028AY017NV	Shallow Loam 8-10" P.Z.
023XY101NV	Stony Slope 8-10" P.Z.	028AY022NV	Gravelly Clay 8-10" P.Z.
023XY102NV	Gravelly Clay Slope 10-12" P.Z.	028AY028NV	Droughty Loam 8-10" P.Z.
024XY001NV	Dunes 6-10" P.Z.	028AY031NV	Loamy Fan 8-10" P.Z.
024XY005NV	Loamy 8-10" P.Z.	028AY040NV	Gravelly Loam 10-12" P.Z.
024XY006NV	Dry Floodplain	028AY050NV	Gravelly Clay 10-12" P.Z.
024XY013NV	Loamy 10-12" P.Z.	028AY054NV	Coarse Loamy Fan 8-10" P.Z.
024XY017NV	Sandy 8-10" P.Z.	028AY086NV	Coarse Loamy Fan 10-12" P.Z.
024XY020NV	Droughty Loam 8-10" P.Z.	028AY091NV	Loamy Fan 10-14" P.Z.
024XY026NV	Stony Slope 6-10" P.Z.	028AY095NV	Loamy 10-12" P.Z.
024XY028NV	South Slope 8-12" P.Z.	028AY121NV	Deep Loamy 8-10" P.Z.
024XY033NV	Steep North Slope 10-12" P.Z.	028AY124NV	Loamy Plain
024XY035NV	Shallow Loam 10-14" P.Z.	028BY005NV	Sandy 8-10" P.Z.
024XY045NV	Eroded Slope 6-10" P.Z.	028BY007NV	Loamy 10-12" P.Z.
024XY046NV	Gravelly North Slope	028BY010NV	Loamy 8-10" P.Z.
024XY047NV	Shallow Loam 8-10" P.Z.	028BY014NV	Loamy Plain 8-10" P.Z.
024XY058NV	Sandy Loam 8-10" P.Z.	028BY045NV	Loamy Fan 8-12" P.Z.
025XY013NV	Churning Clay 8-12" P.Z.	028BY052NV	Droughty Loam 8-10" P.Z.
025XY014NV	Loamy 10-12" P.Z.	028BY054NV	Silty Plain 8-10" P.Z.
025XY015NV	South Slope 8-12" P.Z.	028BY056NV	Silt Flat
025XY019NV	Loamy 8-10" P.Z.	028BY068NV	Dune 8-10" P.Z.
025XY021NV	Shallow Loam 8-12" P.Z.	028BY080NV	Shallow Loam 8-10" P.Z.
025XY027NV	Loamy 12-14" P.Z.	028BY082NV	Loamy Fan 12+" P.Z.
025XY045NV	Ashy Loam 8-10" P.Z.	028BY086NV	Gravelly Clay 10-12" P.Z.
025XY066NV	Ashy Loam 10-12" P.Z.	028BY094NV	Calcareous Loam 10-14" P.Z.
025XY070NV	Loamy Fan 8-10" P.Z.	029XY006NV	Loamy 8-10" P.Z.
026XY010NV	Loamy 10-12" P.Z.	029XY010NV	Loamy Slope 8-10" P.Z.
026XY011NV	South Slope 8-10" P.Z.	029XY029NV	Loamy 10-12" P.Z.
026XY015NV	Shallow Loam 10-12" P.Z.	029XY049NV	Sandy Loam 8-12" P.Z.
026XY016NV	Loamy 8-10" P.Z.	029XY057NV	Loamy Slope 12-14" P.Z.
026XY019NV	Churning Clay 10-12" P.Z.	029XY073NV	Bouldery Loam 8-12" P.Z.
026XY020NV	Sandy 8-10" P.Z.	029XY075NV	Loamy Slope 10-12" P.Z.
026XY022NV	Stony Slope 8-10" P.Z.	029XY105NV	Gravelly Clay 10-12" P.Z.
026XY024NV	Droughty Loam 8-10" P.Z.	029XY106NV	Gravelly Clay Slope 10-12" P.Z.
026XY026NV	Granitic Slope 10-12" P.Z.	029XY114NV	Loamy Fan 8-10" P.Z.
026XY029NV	Eroded Slope 8-12" P.Z.	029XY116NV	Loamy Plain
026XY051NV	Dune 8-10" P.Z.	029XY117NV	Silty Plain
026XY096NV	Sandy Plain	029XY119NV	Silt Flat
026XY098NV	Gravelly Loam 8-10" P.Z.	029XY158NV	Coarse Loamy 8-10" P.Z.

For the areas where this model and management key applies, we discuss two management situations: 1) areas where cheatgrass (*Bromus tectorum* L.) and other invasive weeds (annuals and perennials) are established and becoming, or are already an important management factor; and 2) areas where natives are the only ecologically important species established in the area or at least they still dominate ecological processes and management concerns.

1) MANAGEMENT WITH CHEATGRASS AND OTHER INVASIVE WEEDS

On these landscapes, the presence of exotic and/or noxious, invasive weeds threatens the natural resilience and utility of most if not all Wyoming sagebrush plant communities. These species compete very effectively with native plants. They can transition plant communities to new states (Fig.1) or dominate after certain disturbances without appropriate and timely management action. Their presence is always a hazardous situation. When common, their presence typically results in a transition to a new state because the exotic weeds, not the desired species, determine ecological processes.

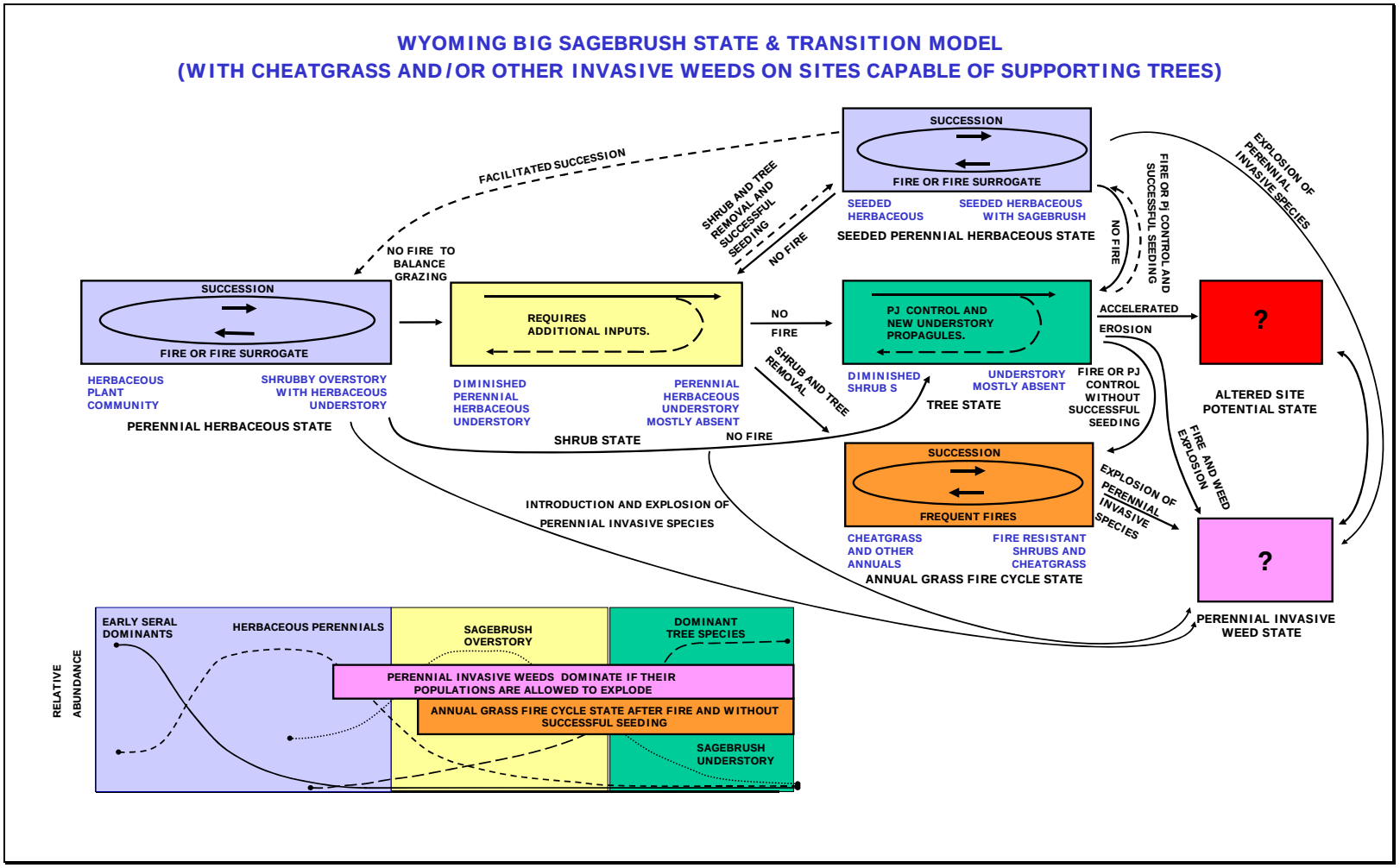

Fig. 1. Each box is shown as a different color to identify that it is a different state. The solid-line arrows between boxes are irreversible transitions across thresholds. Dashed-line arrows show active restoration of ecological processes. Inset box shows relative abundance of plant groups and relative sequence of transitions through succession without proactive management.

PERENNIAL HERBACEOUS STATE

Description: The plant community is dominated by deep-rooted perennial bunchgrasses, with perennial forbs and varying amounts of Wyoming big sagebrush and other shrubs. Sagebrush can dominate the plant community and juniper and/or pinyon pine trees may be present as seedlings, saplings, or sparse mature trees as long as the understory remains robust. If the perennial understory is dense and vigorous enough to recover quickly after being released from the competition of woody plants, the vegetation has not crossed a threshold to the shrub or tree state. Descriptions of the ecological sites listed in Table 1 provide relative species composition and production data for each ecological site in this perennial herbaceous state. Cheatgrass (or other non-native annual plants) is a minor component of the understory vegetation.

Successional trajectories: The perennial herbaceous state plant community is resilient or cyclic because secondary succession processes and disturbance regimes are functional. Periodic release of understory perennials from increasing competition from sagebrush is facilitated primarily by fire. However, other causes for widespread shrub die offs have been noted. Normal fire frequency is approximately 50-100 years (Wright and Bailey 1982). Without woody plant removal, the plant community transitions to the shrub state or if trees are present, to the tree state. On drier sites juniper may increase and on more mesic sites, pinyon may increase. As transition to shrubs or trees occurs, the proportion of cheatgrass in the herbaceous understory increases while perennial herbaceous species decline. Poor grazing management of large domestic and/or wild herbivores can diminish the vigor and expression of palatable perennial

herbaceous plants. Removal of deep-rooted species may leave only or primarily Sandberg bluegrass (Poa secunda [J.S. Presl.]) or cheatgrass. This makes summer moisture and other resources more available to non-palatable shrubs and/or trees and accelerates and increases the likelihood of transition to the shrub, tree, or annual grass fire cycle state.

Management strategies to maintain the state: Manage for vigor, density, and diversity of perennial herbaceous species. Include sagebrush and other woody species in management objectives as desired. However, manage for no more shrub and young tree canopy cover than is appropriate for the site in order to maintain a resilient understory. Management should not allow the plant community to transition across a threshold to the shrub or tree state. Research indicates that herbaceous biomass production begins to decline when sagebrush cover reaches 5-7% and density begins to decline when sagebrush cover reaches about 12-15%, depending upon site potential (Rasmussen and others 2001, Winward 1991). To increase the vigor and density of the native perennial herbaceous plants, intervene with mechanical control measures, prescription grazing, herbicides, or very judicious use of prescribed fire. Shrub and young tree control should be practiced as woody plant cover increases toward threshold levels. However, caution is advised because cheatgrass can erupt from a seed bank soon after control of woody plants opens niches that a sparse understory cannot rapidly fill. The winter-annual, cheatgrass, out competes perennial seedlings in most years on all but the sandiest soils. To minimize die off of perennial herbaceous plants and bare patches, woody plant management may

be needed more frequently than where only native perennial plants occur in the understory. Where soils are erodible, minimize soil surface disturbance. Wherever treatments disturb soil, ensure that adapted perennial plants or seeds are available to compete with cheatgrass given the specific treatment conditions, such as seedbed preparation, grazing regime, etc.

Grazing management should be designed to foster perennial herbaceous species in the community. Excessive, prolonged, or poorly timed grazing by animals with herbaceous diet preferences can increase shrubs. Shrubs can be decreased by relatively intense winter grazing by animals with shrub diet preferences. Supplemental feeding to concentrate cattle for mechanical damage controls sagebrush in small patches, especially when shrubs are dry or frozen and brittle. To limit bare ground after future disturbances, grazing and other land or vegetation management actions should not weaken the perennial herbaceous community. Where perennial herbaceous understory is weak and shrub cover is still well below maximum, consider using selective herbicides to manage cheatgrass and/or adjusting grazing management to restore vigor and density of desirable understory species several growing seasons prior to controlling shrubs. Bare ground is more susceptible to accelerated erosion, and invasive plants establish faster in open niches. Management to maintain the perennial herbaceous state (prescribed grazing and periodic control of woody plants) is much more cost effective than management to return to this state once a threshold has been crossed (control of woody plants, weed control, reseeding, and temporary rest from grazing).

SHRUB STATE

Description: Shrub cover has increased and perennial herbaceous understory cover has decreased across a threshold level. Deep-rooted, perennial bunchgrasses are rare to absent in the understory. The cheatgrass component varies from present to dominant in the herbaceous understory. This state is very susceptible to invasion by annual weeds before and especially after fire or other large scale disturbance. Wyoming big sagebrush and other shrubs dominate the plant community. Juniper and/or pinyon pine trees may be established on the site but do not yet dominate ecological processes.

Successional trajectories: Native herbaceous understory is diminished from perennial herbaceous state levels and may be absent or nearly so when sagebrush cover reaches its maximum for the site. The relative abundance of cheatgrass in the understory increases as perennial grasses decline. Eventually cheatgrass dominates the sparse understory but drives long-term community change for both shrubs and herbaceous species. Because a threshold has been crossed, removal of grazing pressure will not restore the native herbaceous component. This will coincidently require fire or other shrub control measures. However, burning or other woody plant control measures without reseeding will not return a mix of deep-rooted bunchgrasses and other plants characteristic of the perennial herbaceous state. Return to the perennial herbaceous state requires shrub control, cheatgrass control, reseeding, and possibly additional management, depending on site-specific conditions. Return to the perennial

herbaceous state requires facilitated succession beginning with transition to the seeded perennial herbaceous state.

Fire or other major disturbance will increase the abundance of cheatgrass and other annuals. A decline of big sagebrush in the overstory, coupled with an increase in cheatgrass density indicates a transitional pathway to the annual grass fire cycle state. With increasing cheatgrass fuel loads, the threat of wildfire increases due to better fuel continuity and much higher flammability of this fine-stemmed, often evenly distributed, early-growing and early-drying annual grass. This change in fuel characteristics indicates a transition to the annual grass fire cycle state that is completed by an inevitable fire. If trees are present, fire is delayed, and tree invasion is not controlled, the plant community will transition to the tree state. At the landscape scale, the rate of transition largely depends on the geographic extent of fires, and can be quite extensive (up to 100,000 ac or more).

Management strategies: To maintain the shrub state, or at least sagebrush, prevention of wildfire is critical. Strategies often include creation of green strips or other fuel breaks to keep wild fires small so that all sagebrush habitats are not lost at once. Prescribed grazing may be used to reduce fine and/or woody fuels.

To transition to the seeded perennial herbaceous state, apply shrub and weed control in conjunction with reseeding operations. Shrub control measures could include herbicide, mechanical, or shrub-consuming herbivore treatments, the judicious application of prescribed fire or wildfire. After wildfire or other shrub removal, reseeding becomes urgent. Seeding is absolutely required before or

within the first fall or early winter after shrub control. Thereafter, competition from a rapidly expanding cheatgrass population may prevent seeding success. Reseeding requires cheatgrass control unless a very hot fire removed all but 0-3 cheatgrass seeds per square foot. It also requires appropriate seedbed preparation, planting date, and follow-up management. Reseeding treatments could include native perennials, grasses, forbs and shrubs, and/or adapted non-native perennial species. Where soil stabilization following wildfire is a priority objective, seeding non-native perennial grasses with high seedling vigor may be the best option. Investigate the feasibility of facilitated succession, seeding initially with adapted non-native grasses and later inter-seeding with adapted native herbaceous and/or shrub species.

SEEDED PERENNIAL HERBACEOUS STATE

Description: The choice of species in the seed mix, species in the pre-existing seed bank, and the growing conditions in the first few years after the seeding largely determine the species composition of the seeding. On many Wyoming big sagebrush sites, few species will do predictably well. Even for crested wheatgrass (*Agropyron cristatum* L. Gaertner), the most commonly seeded and most dependable species, moisture following seedings is sometimes insufficient, especially on the driest sites with the greatest soil limitations. Because perennial bunchgrasses provide a clumped fuel composed of coarser stems that stay green longer than cheatgrass, they generally reduce fire spread rates, and the fire interval is generally long enough to allow sagebrush to become well established (unless seeding design or management precludes it). Although

functionally quite similar to the perennial herbaceous state, the seeded perennial herbaceous state is shown as a separate state because there is always an initial loss of genetic diversity once seeding is required.

Successional trajectories: Seedings often begin with expression of early seral species present in the seed bank such as annual forbs. As perennials and shrubs become better established, they typically exclude or severely diminish all but the most aggressive of these early seral species or limit them to small disturbed areas. If sagebrush was initially established by seeding or from seeds left in safe sites, it structurally dominates a seeding more quickly. If not, recruitment occurs from the edges or from unburned or untreated shrub islands. Other species colonization depends on the mechanisms of seed dispersal and their success in finding favorable microsites, or on treatments designed to facilitate succession through their establishment. Transition back to the perennial herbaceous state involves replacing the seeded species with native species and/or increasing species diversity including the addition of shrubs, especially sagebrush.

Management strategies: Seeding size, shape, or amount of edge and orientation with respect to prevailing winds, as well as fire management strategies to leave shrub islands or create a mosaic, can influence the process of sagebrush re-establishment. During and after seeding establishment, livestock grazing can be used to encourage niches for sagebrush and other species that may be present. Conversely, grazing can be discouraged or managed conservatively to favor only those species more palatable to livestock. Once the

seeding has been used to avoid the transition to an annual grass fire cycle state, management and additional seeding can be used to facilitate succession toward various species compositions. Natives can be interseeded but often do not compete well with established species unless steps like soil disturbance are used to open new niches. Often the focus for management is simply maintaining the seeding. This requires maintenance of ecological processes. Appropriate activities would include keeping the seeding from becoming so dominated by shrubs or weeds that the seeded understory is unable to survive a fire, or allowing sufficient grazing to maintain plant vigor and reduce wolf plants. Management strategies described for the perennial herbaceous state also apply to the seeded perennial herbaceous state. However, specifics of grazing management may differ according to the needs of the seeded and other desired species.

TREE STATE

Description: Juniper and/or pinyon pine has established on a site and has caused a decline in understory (herbaceous and shrub) cover and production due to extended fire return interval. Although trees generally establish under shrub canopies, they can invade the perennial herbaceous, seeded perennial herbaceous, and shrub states. Trees have assumed ecological dominance, driving future ecological processes. Understory (herbaceous and/or sagebrush) has decreased across a threshold level defined by its lack of resilience to a tree-removing disturbance. Tree biomass now dominates the plant community, with leaf and fuel biomass as much as seven to eleven times the levels of perennial

herbaceous or shrub states. However, tree cover is highly concentrated, often leaving large bare interspaces that are susceptible to rill erosion, especially on drier sites. Cheatgrass is present and often dominates the understory as trees mature. Although live cheatgrass density and vigor may be lower in the tree state than in other states, its seed bank is often extensive.

Successional trajectories: Herbaceous and/or shrub understory is diminished from previous state levels to almost absent where trees are mature and the site fully stocked. Shrub leaf biomass declines to approximately 20-25% of potential when tree leaf biomass approaches 50% of maximum potential for the site (Tausch and West 1995). During this process a 10 % increase in tree cover can result in a 50% decline in understory production. The degree of resilience of the understory is determined in part by the tree-removing disturbance. A very hot wildfire may remove remaining herbaceous species and their seed reserves (indicating the threshold to the tree state has been crossed) while a more gentle form of tree removal may release these species from the tree competition (indicating that the threshold had not yet been crossed). Once one or more thresholds have been crossed in getting to the tree state, return to the perennial herbaceous state requires transition to the seeded perennial herbaceous state first. This requires shrub and/or tree control, reseeding, and usually other management actions such as weed control. Cheatgrass is present and its proportion in the understory tends to increase as native understory species decline. If the native perennial understory is absent or sparse, fire or other tree control measures alone will not increase most herbaceous/shrub understory

species. Rather, the cheatgrass seed bank will increase cheatgrass abundance after the release from tree competition, and transition the site to the annual grass fire cycle state. Major soil erosion events after fire from severe wind, or from major precipitation events on moderate or steeper slopes, can trigger a transition to an altered site potential state. Mature tree stands may increase this risk by allowing rills to form in large bare interspaces.

Management strategies: To manage this state for continued tree production, protection from wildfire is essential. However, as trees grow, fuel accumulates and tree canopies grow closer to each other. This increases the likelihood of a catastrophic fire spreading across the landscape. Thinning a stand reduces fuel loads. However, larger bare interspaces increase erosion hazard. Continued net fuel production on this type often increases the risk of fires in neighboring woodland types including areas where trees are very old because fire was historically rare or involved only single trees. Management plans designed to break up the landscape scale continuity of fuels with firebreaks, greenstrips, or imposed differences in vegetation structure serve to reduce the risk of large fires that leave watersheds barren. Applying tree control and rehabilitation treatments in smaller patches increases the likelihood of fires creating a diverse mosaic of habitats. This reduces the cost of future fire fighting, increases the opportunity for fire use, and increases sustainability of ecological processes.

To transition to the seeded perennial herbaceous state, apply tree and weed control and seed adapted perennials. After successfully attaining the seeded perennial herbaceous state, facilitated succession can return the site to

the perennial herbaceous state. Tree control measures could include prescribed fire, mechanical, prescribed grazing, or herbicide treatments. Restoration requires the use of site-adapted grass, forb, and shrub species and methods. If site stabilization is a priority objective, non-native perennial herbaceous species may be the best option for revegetation. Rehabilitation is required in the fall or early winter immediately following tree removal.

ANNUAL GRASS FIRE CYCLE STATE

Description: Cheatgrass and/or other annual grasses and forbs (e.g., mustards) dominate the herbaceous community. Most perennial herbaceous species cannot compete with the dense population of cheatgrass and are absent or nearly so. Fire intervals often shorten to 2 to10 years. Sagebrush is generally unable to survive and reproduce with this fire frequency. Sprouting, fire-tolerant shrubs may form a shrub overstory where fires are too frequent for sagebrush but infrequent enough to support sprouting shrubs.

Successional trajectories: This plant community is functionally an annual grassland. Cheatgrass initially dominates the site following wildfire. Sprouting, fire-tolerant shrubs are the only woody plants, and these shrubs may eventually dominate structural aspects of the area if fires are not too frequent. Cheatgrass and annual forbs become the dominant vegetation after frequent, repeated fires. Poor grazing management can shift species composition toward less palatable species decreasing vegetative cover, while increasing erosion hazard. The level of risk has increased for the community to transition to a perennial invasive weed state. If perennial invasive species such as knapweeds (*Centaurea sp*.) are

introduced, the plant community could rapidly become dominated by these species, crossing a threshold to the perennial invasive weed state. This makes rehabilitation to a seeded perennial herbaceous state more difficult, even with extensive and intensive inputs. Fires export nitrogen and frequent fires may shift the plant community toward undesired species tolerant of low-nitrogen soils. Repeated fires expose soil to erosion more often, facilitating transition to the altered site potential state during severe hydrologic or wind events.

Management strategies: To manage this state for continual annual grass production, apply proper grazing for annual grassland. Leave sufficient biomass and time for seed production and soil protection while consuming sufficient fuel to reduce fire risk. This can be challenging due to highly variable production and timing of production among wet and dry years. In the wettest years, grazing may consume abundant forage in only some pastures or use areas or, with sheep herding, in fuel breaks. In the driest years forage may be essentially absent.

To transition to the perennial herbaceous state, cheatgrass control and reseeding operations are required. Mechanical, chemical, and grazing treatments can reduce cheatgrass seed production. If fire intolerant shrubs like sagebrush are included in the seed mix, a fuel management strategy must be employed to reduce fire danger to shrub seedlings. Prescription grazing and green stripping can be used across a landscape to reduce fuel loads, fire size, and frequency. Establishment of seeded perennial herbaceous species (such as bunchgrasses) will also reduce fuel continuity, potentially reducing the rate of fire spread and size.

PERENNIAL INVASIVE WEED STATE

Description: Although this state has yet to be identified in Nevada, one or more of the weeds listed on the Nevada noxious/invasive weed list, or a new invasive weed, could dominate the herbaceous vegetation, competitively excluding native perennial herbaceous dominants. Weeds may burn readily and typically exclude sagebrush and/or pinyon and juniper trees. Their competitive advantage, in an environment without diseases, or insects from their ancestral home allows them to displace most other plants to form virtual monocultures. Initial weeds may facilitate the establishment of even more competitive invasive weeds.

Successional trajectories: The risk of transitioning to the perennial invasive weed state increases after transition to the Shrub, Tree, Annual Grassland Fire Cycle, and the Altered Site Potential States. Risk increases as soon as invasive perennial plants, such as one of several knapweed species, begin to colonize an area unless they are eradicated immediately upon discovery. Otherwise, initial colonization generally expands toward a monoculture. Experience in other parts of the western United States demonstrates the highly competitive nature of some invasive weeds. However, which species will be most competitive on each ecological site, state, or phase is still unknown. As initial infestations change species composition and/or soil characteristics and site potential, other weeds will likely become more competitive, causing instability in species composition. Many invasive weeds are competitive, but do not effectively protect soil from erosion or they are highly flammable, leading to unprotected soils after fires, increasing the risk of crossing a threshold to the altered site potential state.

Management strategies: Invasive plant colonies should be eradicated immediately upon discovery. Once invasive weeds dominate a site, the expense of weed control, follow-up control, and revegetation treatments generally exceed on-site economic returns. However, these management strategies are justified to quarantine weeds in one area, reducing spread potentials. Herbicides, prescribed grazing (goats), and/or hand grubbing should be used to eradicate small populations. Where eradication is no longer possible, mechanical, chemical, and/or biological controls such as insects or prescribed grazing should be used to control or confine infestations. Weed control areas will require reseeding with the most competitive of adapted (native or non-native) desired species and careful post-seeding grazing management to reduce the risk and consequences of reinvasion. They may also require periodic treatment for residual weeds. For whole landscapes dominated by noxious weeds, there may be little option other than biological control. Yet biological controls are not available for many weed species.

To accomplish vegetation management objectives suggested for this state and transition model, care should be taken to avoid facilitating the spread of invasive weeds. Expansions to the road network and soil disturbances increase bare areas where invasive weeds can more easily establish. Virtually every invasive weed population is first a roadside weed before its population explodes. Many weed infestations begin in areas disturbed by machines, and some of these are for vegetation management purposes. To prevent weed infestations from spreading, it is important to routinely scout for new invasive weeds,

especially in areas likely to be initial colonization areas (roadsides, waters, riparian areas, turnout areas, corrals, utility corridors, borrow pits, treatment sites etc.). Managers may also, remove or alter stresses on native perennial species that can aid expansion from an affected area.

ALTERED SITE POTENTIAL STATE

Description: Accelerated erosion has resulted in loss of topsoil, altered hydrologic characteristics (i e. reduced infiltration and increased runoff), and lowered water and nutrient storage capacity. These changes to the growing environment have resulted in an altered ecological potential for the site. For example, a Wyoming big sagebrush site may become a shadscale (*Atriplex confertifolia* [Torr. & Frem.]), site. Lowered site potential means lowered vegetation production, less soil protection, and increased soil loss until a new equilibrium is reached.

Successional trajectories: The risk of transitioning to the altered site potential state increases after transitioning to the shrub, tree, annual grass fire cycle or perennial invasive weed states. The new site potential and the array of possible plant species and successional trajectories greatly depend on the soil remaining as the rate of soil erosion stabilizes. For very shallow soils, plants survive by tolerating extended periods without available soil moisture or by sending roots deep into rock fissures. Cheatgrass, a winter annual, survives drought as seeds that do not germinate in some years and by developing seed early. On sites where the topsoil has been eroded away, clayey subsoil often becomes exposed at the surface. Roots must penetrate the heavy clay and tolerate any shrinking

and swelling of the clayey soil during germination. Plants must then be able to persist with less soil moisture than available within an intact, non-eroded soil. Clayey sites are also susceptible to invasion by medusahead rye (*Taeniatherum caput-medusa* L. Nevski.).

Management strategies: Because topsoil or even subsoil has been lost, return of the native perennial herbs and shrubs characteristic of the perennial herbaceous state depends on soil forming processes that are slow under most conditions. The area should now be managed under the guidance provided by the state and transition model and ecological site description for the new ecological site if one is available that fits. It is expected that the species composition and limited productivity of the vegetation established on the altered site will have a low resiliency and minimal utility.

2) NATIVES ONLY

In these plant communities and landscapes, non-indigenous species are usually not present. Only plant species native to the Great Basin are important in ecological processes and management. If present, non-natives reflect a disturbance of vegetation that has left an open niche that can be easily filled through recovery of native vegetation. The general model (Figure 2.) may describe historic ecological processes and is still relevant in some areas.

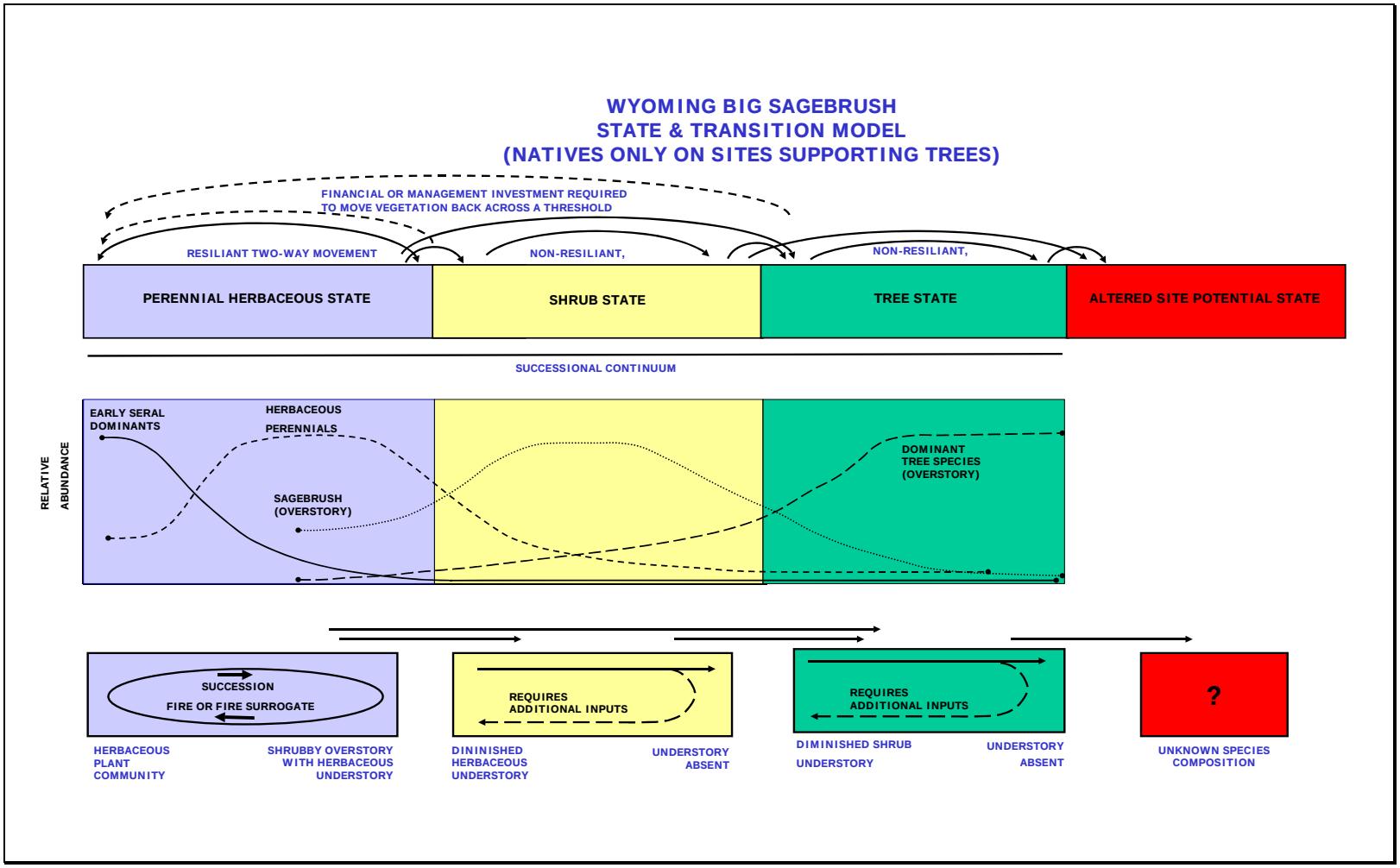

Figure 2. Each box is shown as a different color to identify that it is a different state. The solid-line arrows between boxes are irreversible transitions across thresholds. Dashed-line arrows show active restoration of ecological processes. Middle box shows relative abundance of plant groups and relative sequence of transitions through succession without proactive management.

PERENNIAL HERBACEOUS STATE

Description: The plant community is dominated by deep-rooted perennial bunchgrasses, perennial forbs, and varying amounts of Wyoming big sagebrush. Sagebrush can dominate the plant community and juniper and/or pinyon pine trees may be present as seedlings, saplings, or very sparse mature trees, as long as the understory remains robust. If the perennial understory is dense and vigorous enough to recover after being released from the competition of woody plants, the vegetation has not crossed a threshold to the shrub or tree state. Descriptions of the ecological sites listed in Table 1 provide relative species composition and production data for each ecological site in this perennial herbaceous state.

Successional trajectories: Plant community is resilient or cyclic because secondary succession processes and disturbance regimes are functional. Life-form dominance (species composition) is controlled primarily by fire, although Aroga moth or other phenomena can also thin or kill patches of Wyoming big sagebrush. Normal fire frequency is about 50-100 years (Wright and Bailey 1982). Without periodic woody plant removal, the plant community will transition toward the shrub state or if trees are adjacent to the site, to the tree state. On drier sites juniper may increase and on more mesic sites, pinyon may increase. Following wildfire, sprouting shrubs may dominate but will be gradually replaced by perennial bunchgrasses and sagebrush. If the area is devoid of big sagebrush, it could be restored through time with seeds from surrounding areas and could be re-established more quickly with seeding. Poor grazing management of large domestic and/or wild herbivores can diminish the vigor and

expression of deep-rooted perennial herbaceous plants leaving primarily Sandberg bluegrass. This makes soil moisture and other site resources more available to competitive shrubs and/or trees and accelerates and increases the likelihood of the transition to the shrub or tree state. If the perennial understory is too sparse or weak to recover quickly after being released by fire or other major disturbance, the vegetation has crossed a threshold to the shrub or tree state. Large fires that remove sagebrush leaving no islands and/or repeated fires that remove succeeding generations before reaching reproductive age (about 5 yrs) may create large landscape areas with few or no sagebrush plants for extended periods.

Management strategies: To maintain the perennial herbaceous state, limit development of shrub or tree cover to what is appropriate for a resilient herbaceous understory on the site. Research indicates that herbaceous biomass production begins to decline when sagebrush cover reaches 5-7% and density begins to decline when sagebrush cover reaches about 12-15%, depending upon site potential (Rasmussen and others 2001, Winward 1991). Intervene with prescribed fire, herbicide, mechanical control measures, and/or prescription grazing. Grazing can be managed to reduce stress to palatable species, especially during the growing season, slowing the advance of woody species. Grazing can also be used to accelerate the process of sagebrush recolonization after a fire. Shrub decrease can be fostered by relatively intense winter grazing by animals with shrub diet preferences. Concentration of livestock at feeding sites can reduce shrub density through mechanical damage to sagebrush, especially when shrubs are frozen or dry and brittle. Grazing prescriptions

should strive to maintain the vigor of the herbaceous community. Where the perennial herbaceous understory is weak and shrub cover is still well below maximum, investigate the feasibility of reseeding or adjusting grazing management to improve vigor and density of desirable species in the understory several growing seasons prior to controlling shrubs. Management to maintain the perennial herbaceous state is often much more cost effective than management to return to this state once a threshold has been crossed.

SHRUB STATE

Description: Herbaceous understory cover has decreased below a threshold level. Shrub cover has increased above a threshold level. Wyoming big sagebrush and/or sprouting shrubs dominate the plant community. Perennial understory vegetation, especially deep-rooted bunchgrass, is incapable of recovery after fire.

Successional trajectories: Native herbaceous understory declines substantially from perennial herbaceous state levels and trends toward absence when sagebrush cover approaches its maximum. If trees are present and not controlled, the plant community will transition to a tree state. Because a threshold has been crossed, transition to the seeded perennial herbaceous state requires fire or other shrub control measures, reseeding operations and follow-up management. Removal of grazing pressure alone will not restore the native herbaceous understory characteristic of the perennial herbaceous state or reduce shrub abundance. Burning or other shrub or tree control measures alone will not return the mix of deep-rooted bunchgrasses and other perennial herbaceous plants because the seed bank and seed source have been depleted.

Woody plant removal will release fire-adapted shrubs and create open areas for early-seral species and increase erosion potentials.

Management strategies: To maintain sagebrush stands, prevent wildfire but control junipers and/or pinyon pines as needed. To transition to the seeded perennial herbaceous state, apply shrub control measures in conjunction with reseeding. Shrub control measures could include prescribed fire, herbicide, mechanical, or grazing. Because one or more thresholds have been crossed, reseeding is essential after wildfire. Reseeding with appropriate seedbed preparation, planting date, and other methods should include a mix of adapted desired (native or non-native) grass, forb, and shrub species. Where perennial herbaceous understory is missing and shrub cover is still well below maximum, investigate the feasibility of reseeding several growing seasons prior to controlling shrubs. The goal of re-establishing a desired herbaceous component may require a multi-step approach through many years or decades.

TREE STATE

Description: Juniper and/or pinyon pine has established on the area due to extended fire return interval. Although trees generally establish under shrub canopies, they can invade both the perennial herbaceous and shrub states. The understory (herbaceous and shrub) has decreased below a threshold level because tree cover has increased above a threshold level. Trees dominate the plant community, with leaf biomass and fuel buildup often to seven to eleven times the level of the perennial herbaceous or shrub states. However, canopy cover is concentrated, often leaving large bare interspaces with erosion rills. The perennial understory can no longer respond to fire or other tree-removing

disturbances because seed banks, seed sources, and antecedent plants have been depleted.

Successional trajectories: The perennial herbaceous and/or shrub understory declines from previous state levels to almost absent as trees attain mature height at normal density. Shrub leaf biomass declines to about 20-25% of potential when tree leaf biomass approaches 50% of maximum potential for the site (Tausch and West 1995). Each 1% increase in tree cover can lead to about a 5% decline in understory production. Post fire vegetation is dominated by early seral species and the limited number of species that had survived tree dominance and fire or other tree removal. Because one or more thresholds have been crossed, transition to the seeded perennial herbaceous state requires reseeding and tree control. If native perennial understory is absent, fire or other tree control measures alone will not increase most herbaceous/shrub understory species to levels found in the perennial herbaceous state. Species from the surrounding landscape with wind-blown seeds will be favored. Removing trees will create open areas susceptible to invasive species, sagebrush, and fire-tolerant shrubs and/or accelerated erosion. After fire, major soil erosion from severe wind or major precipitation events on moderate or steeper slopes can trigger a transition to an altered site potential state. Accelerated soil erosion can also occur in large bare interspaces where rills can develop. This is more common on arid sites.

Management strategies: To manage this state for continued tree production, protection from wildfire is essential. However, as trees grow, fuel accumulates and tree canopies grow closer to each other increasing the likelihood of a hot

crown fire spreading across the landscape. Thinning to reduce crown cover, fuel load, and fuel continuity is critical to long-term maintenance of a woodland plant community. Continued net fuel production on this type often increases risk of fire in neighboring woodland types, including areas where trees are much older because fire was historically infrequent or lightening strikes caused only single-tree fires. Management plans should be designed to break up the landscape scale continuity of fuels with firebreaks, greenstrips, or imposed differences in vegetation structure.

To transition to the seeded perennial herbaceous state, apply tree control measures in conjunction with reseeding. Tree control measures could include prescribed fire, herbicide, or mechanical treatments. Reseeding should include adapted grass, forb, and shrub species and appropriate seedbed preparation, planting date, and follow-up grazing management and weed control where needed. Because one or more thresholds have been crossed, reseeding is essential after wildfire.

ALTERED SITE POTENTIAL STATE

Description: Accelerated erosion has thinned or eliminated topsoil, altered hydrologic characteristics, and lowered water and nutrient holding capacity. These changes alter the ecological potential of the site. Thereafter, reduced vegetation cover and infiltration rate increases erosion potentials reducing site potential until a new equilibrium is established.

Successional trajectories: New site potential, species composition of the revegetation seed mix, and subsequent successional trajectories greatly depend on characteristics of the remaining soil. For very shallow soils, plants survive by

tolerating extended periods without available soil moisture or by sending roots deep into rock fissures. On sites where clayey subsoil becomes exposed at the surface after topsoil has eroded away, plants must tolerate any shrink-swell characteristics of a clayey soil. Roots must be able to penetrate a heavy soil and they must be able to persist with less available soil moisture.

Management strategies: Because topsoil or even subsoil has been lost, return of native perennial herbs and shrubs characteristic of the perennial herbaceous state depends on soil forming processes that are very slow under most conditions. The area should now be managed under the guidance provided by the state and transition model and ecological site description most similar to the altered site. It is expected that the species composition and limited productivity of the vegetation established on the altered site will have low resilience and minimal utility.

CONCLUSION

This state and transition model and management key is designed to help managers recognize opportunities to influence Wyoming big sagebrush sites in a positive manner. It can be used for thinking at the site specific or the landscape scale. Management opportunities are identified by determining the state and successional trajectory by examining the vegetation. Pathways toward thresholds indicate a need for action to prevent a transition to an unwanted state. Thus, the model and management key helps set short-term and long-term management objectives. Usually these objectives call for restoring resilience to the perennial herbaceous state, protecting woody states from fire, focusing weed control on prevention of high impact invasive weed population explosions, and

reseeding immediately after a shrub or tree state burns. Management actions are less risky, less expensive, and more satisfying when and where important biological diversity remains and before difficult species, dangerous fuels, or accelerated soil erosion dominate ecological processes. That is, before crossing a threshold.

Across a landscape, the model helps focus attention on the highest priority areas where an important management action or change has become urgent. Across most landscapes, there are hot spots where site specific management is urgently needed. There are other areas where the vegetation will remain resilient into the future and areas where the threshold has been crossed. Crossing the threshold to another state, decreases resilience and increases vegetation treatment costs.

In general, the risk of losing the perennial herbaceous state is the highest priority. This state cycles among a variety of species compositions to which many wildlife and other species have adapted, including the many sagebrush-dependent species. In addition many other resource values are produced in one or more of the seral phases of this state. Its natural resistance to transitioning across a threshold due to its resilience following natural disturbances makes this state a low-cost management objective. However, after the introduction of exotic invasive weeds and a century of altered fire regimes, this state is often at risk where it still remains. Its increasing scarcity, and the presence of invasive weeds that can more easily dominate after transitioning to the shrub or tree state, elevates its value and its priority for management. Where it no longer remains, the seeded perennial herbaceous state is its closest alternative.

However, management does not equal preservation without disturbance. This state is maintained by periodic disturbance. Between fires, time, succession and growing season herbivory on the understory favors shrubs and trees. Fires are the way nature balances these stresses to favor the understory. The focus of land management in the Wyoming sagebrush type is to use management tools to simulate natural disturbances at the right times and with the right combination of other actions.

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