Shrub Management

Handbook for Utah Rangelands

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Preface

Welcome, Friends! Utah contains a variety of shrub species adapted to its unique environmental conditions ranging from salt-deserts at lower elevations to woodlands at higher elevation mountain foothills and plateaus. Decades of management experience and research have led to a greater understanding of the complex relationships among vegetation, soil and climate, and how shrublands provide a multitude of ecological services to both humans and wildlife. We integrated this extensive information to guide you in developing realistic project plans and implementing appropriate management strategies. Whether your management goals are to increase livestock forage, improve wildlife habitat, or something different altogether, we hope this handbook enhances your understanding of basic shrub biology, ecological concepts, and management principles, and that you can use these components to choose the most appropriate technical tools for your project site.

How This Handbook Is Organized

Shrubs are an essential part of plant communities and purposeful manipulation of their abundance can yield desired ecosystem services. Given the critical ecological role of shrubs, the primary objective of this handbook is to assist land owners, managers, habitat specialists, conservationists, and producers in achieving the best possible plant community composition to meet their specific goals, as well as an adequate balance of shrubs and herbaceous plants to maintain health of the site. The handbook contains four main sections that can be viewed alone or as a systematic, step-by-step framework to customize your learning needs—The Authors.

1. Know your site – Site characterization is the first step in determining how your project area responds to disturbance and management. Ecological sites are a way to classify and describe soils and vegetation. This section introduces Ecological Site Descriptions (ESDs), which are reports written by experts to communicate specific information about site characteristics, plant communities, management alternatives, and supplementary site information.

2. Develop a management plan – Shrub management is open-ended and often leads to unexpected outcomes. This section advocates a 7-step shrub management cycle that promotes adaptive learning—a practical way to refine your project objectives after management strategies are implemented and assessed. This cycle will stimulate an understanding of ecological systems and help document your progress toward obtaining your project goals.

3. Understand target shrubs – The unique biology of shrub species determines their adaptations to specific sites and disturbance regimes. In addition to knowing your site, understanding target shrub biology will reinforce your grasp of ecological principles and the limiting factors to achieve your project goals. This section reviews four different shrub species and presents case studies illustrating potential management outcomes in Utah.

4. Learn technology to manipulate shrub abundance – Because shrubs are a key component of vegetation, altering their abundance will undoubtedly influence other vegetation components and site properties including ground cover, environmental conditions, and energy flow of the ecosystem. This section discusses modern technologies to manipulate shrub abundance, including mechanical tools, herbicides, burning, seeding, and post-treatment grazing.

5. Glossary and list of online resources – Many terms within this document are defined in the glossary. Links to online resources are provided so you can reference and continue learning about key shrub management topics.

Note: an online version of this handbook will be accessible at
https://extension.usu.edu/rangelands/pages/utah-shrubland-management-project

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Section 1 – Know your site

Understanding your project site is tantamount to initiating a shrub management project, but we often don't have the necessary pieces of information at hand. This section introduces the concept of Ecological Site—a classification system for describing landscapes based on vegetation, soils, and other physical properties. Information associated with Ecological Sites is succinctly summarized within Ecological Site Descriptions (ESDs), which are documents written by experts and accessible online. ESDs can be used to determine the suitability of your site for various uses and its capability to respond to different management and disturbances, including manipulating shrub abundance. With this knowledge, you can build a greater understanding of the ecological principles and limiting factors that affect your project objectives.

To identify ecological sites, first access Web Soil Survey (WSS) and navigate to your project area using the interactive map tools (Appendix 1). Once you have determined the Ecological Sites associated with your area, you can access the associated ESDs through the Ecological Site Information System (ESIS; Appendix 1). This ESIS website is an extensive online resource that describes Ecological Sites and that classifies them by regions (Major Land Resource Areas) within states (e.g., Utah). ESDs are a launching pad for understanding the ecology of your project site and obtaining critical information to interpret how the site will respond to management.

What can ESDs tell you? Your project site has the potential to provide a wide range of ecological services including livestock production, wildlife and plant habitat, water and carbon sequestration, recreation, and resource extraction. ESDs reveal how ecological sites are defined by physical properties (Box 1). The association between soils and vegetation is a prominent feature of ecological sites and ESDs help interpret key differences between sites (Figure 1). We also emphasize that across a landscape, soils can gradually change from one soil type into another, creating intermediate conditions. Consequently, there may be more than one ecological site present across your project area, so be sure to study a few ESDs in order to properly classify your site(s).

- **Climate patterns**
  Characterized by temperature (e.g., seasonal fluctuations, yearly averages), precipitation (e.g., form – rain vs. snow, amount, seasonal fluctuations), humidity, and wind (speed, direction).

- **Hydrologic patterns**
  Characterized by how water moves across or off of a site (horizontally or vertically through the soil), how quickly water moves over or down through the soil, how much water is lost due to evaporation.

- **Soil properties**
  Key features include soil depth, texture, bulk density, pH, organic matter content, and nutrient availability.

- **Topographic position**
  Land features including elevation, slope, aspect, and complexity of the landscape (e.g., hummocky vs. a flat plain).

Box 1. Physical properties that define Ecological Sites.

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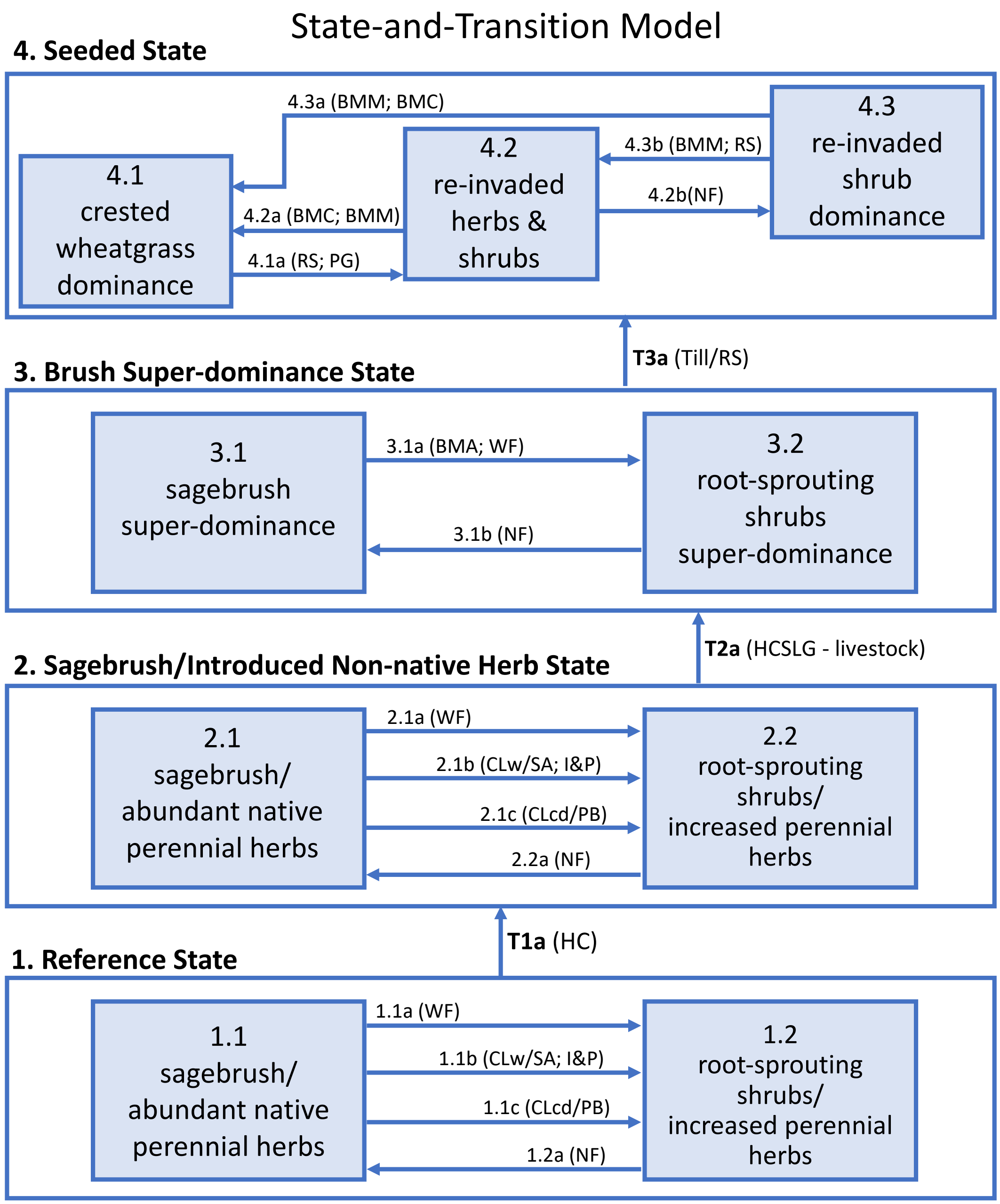
This Semi-desert Alkali Loam ecological site in northwestern Utah is characterized by low annual precipitation (8-12") and silty to fine sandy loam soils with high sodium content. Soils support codominance of greasewood (*Sarcobatus vermiculatus*) and Wyoming big sagebrush.

This Upland Shallow Hardpan ecological site in central Utah exists on gravelly loam soils with 13-18" annual precipitation. This site is typically dominated by Wyoming big sagebrush and Utah juniper, but recent fire has promoted dominance of the sub-shrub snakeweed (*Gutierrezia sarothrae*).

Figure 1. Contrasting ecological sites in Utah where variable annual precipitation, soil properties, and disturbance regimes result in distinct vegetation communities.

ESDs also contain detailed descriptions of vegetation dynamics within a site. Recognizing vegetation dynamics is critical because vegetation can exist in alternative stable states. These distinct states are constrained by a variety of underlying factors, including physical and chemical soil properties, disturbance, and current management practices. However, vegetation is dynamic among and within states. State-and-Transition Models (STMs) use boxes to depict vegetation states and plant community phases, and arrows to represent the processes governing transitions (Figure 2). Studying an STM will help identify the variety of states that may be present on your site and provide knowledge of how management can influence transitions. Pay close attention to transitions that cross a threshold, signifying a change in site characteristics that cannot be reversed without considerable effort. In contrast, some transitions between plant community phases are reversible given time, the right environmental conditions, or the appropriate management inputs. For example, transitions between plant community phases in the reference state of Figure 2 are controlled by disturbances such as fire (or lack of) because big sagebrush is fire sensitive and rubber rabbitbrush can re-sprout from roots after fire. In addition, Figure 2 illustrates that options to reduce shrub abundance (i.e., brush management via all methods combined [BMA], chemical only [BMC], or mechanical only [BMM]) emerge in States 3 and 4 as site conditions become increasingly different from those in the reference state.



BMA	Brush Management (All)	NF	No Fire
BMC	Brush Management (Chemical)	PB	Parch Blight
BMM	Brush Management (Mechanical)	PG	Prescribed Grazing
CLcd	Climate (unusually cold and dry)	RS	Re-Seed
CLw	Climate (unusually wet)	SA	Soil Anoxia
HC	Historic Change	Till	Tillage
HCSLG	Heavy Continuous Season Long Grazing	WF	Wildfire
I&P	Insects & (other) Pathogens		

Figure 2. State and Transition Model (STM) for Upland Loam (Basin Big Sagebrush); Ecological Site Number R047AY308UT. This STM model depicts four distinct vegetation states (1: Co-dominated by native shrub and herb species, 2: Native herbs in shrub understory have been replaced with introduced, non-native herbs, 3: High shrub density and severely depleted herbaceous understory, and 4: Abundant shrubs have been removed and forage grasses have been seeded). Major changes among states are depicted by transitions (T1-T3). Within a state, vegetation shifts between plant communities (shaded boxes) are depicted with (arrows).

How do ESDs promote an understanding of ecological principles and limiting factors?

Ecological principles are basic assumptions about how ecosystems function. They are shaped by our experiences and can be enhanced by knowing more about a project site. Enhanced knowledge helps identify limitations of a site and promotes your ability to develop realistic project goals, choose the right tools and management strategies, and execute your plan with confidence.

ESDs provide a description of the unique physiographic features and landforms of your site, including information about elevation, slope, and flooding potential. Knowing physiographic features will reveal suitable and unsuitable locations to execute management actions. In a similar vein, knowing climatic features of the site will inform you about seasonal trends in precipitation and temperature and indicate ideal time frames to conduct activities that coincide with the developmental stages of key plant species and the best times to apply herbicides or avoid unintended damage to sensitive plant species or fragile soils.

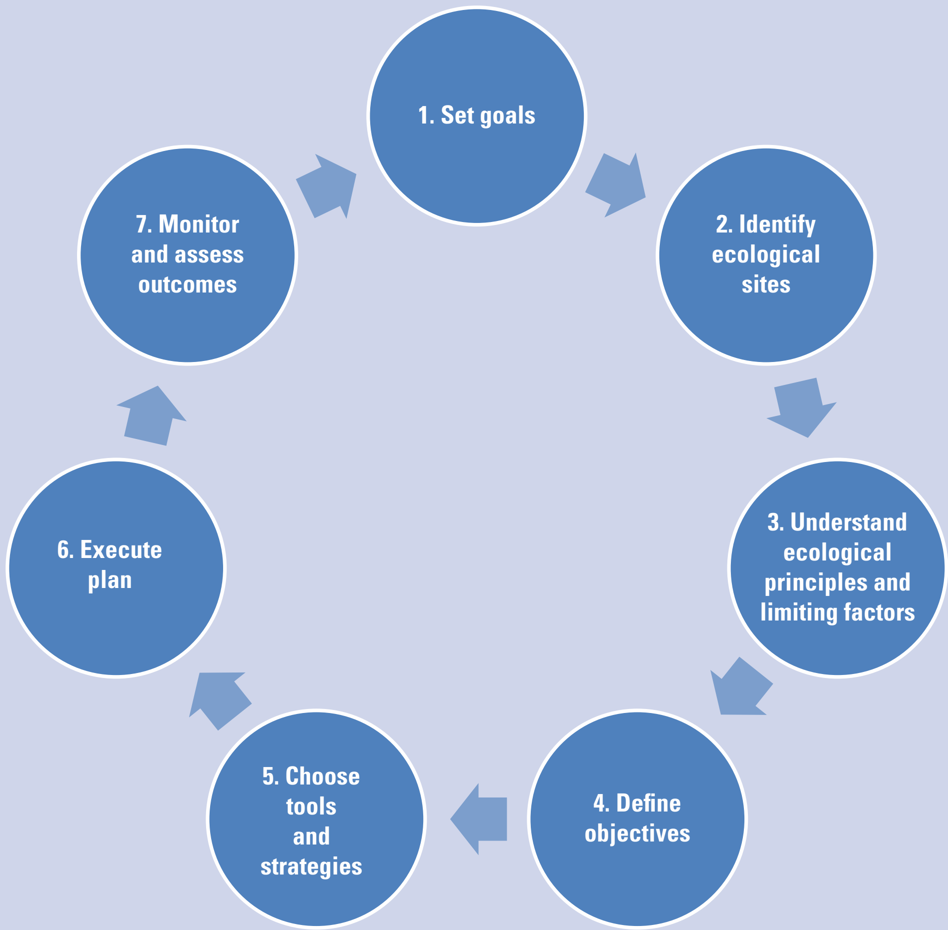
Plant communities are typically described in considerable detail within ESDs to inform you about expected cover percentages and annual production. It is better to know the limitations of your site before undertaking a management plan that your site simply can't produce due to its ecological potential. Management goals that disregard defined abiotic (e.g., soil compaction, salinity) and biotic (e.g., invasive species) thresholds reflect inadequate knowledge about ecological principles and limiting factors. Lastly, ESDs contain detailed site interpretations of animal communities, hydrology, recreational uses, and wood products. Knowing this information will improve your understanding of how the ecological system functions. Site visits will also be more productive as you seek answers to key questions, such as:

- Which plant communities are represented in the current vegetation state?
- Do current vegetation and soils exhibit qualities associated with the reference state or with an alternative state that has been impacted by human activity?
- Are there plant communities at risk of crossing an ecological threshold to a less desirable state?
- What are the abundance and distribution of desired plants and invasive plants?
- How prevalent is bare ground? Does it exceed expectations for a particular ESD?
- Which factors or processes, such as steep slopes or low potential plant cover, increase the risk of erosion?
- Does vegetation provide a diverse and productive habitat for wildlife or livestock use?

Section 2 — Develop a shrub management plan

Managing vegetation is a complicated process. Viewing your project plan as a sequence of steps will simplify this process, help you understand your ecological system, and document your progress with an effective monitoring protocol. Because every management area has unique ecological properties and limitations that should influence your choice of actions and outcomes, this section introduces a 7-step process that will guide you in developing an adaptive shrub management plan. Following these steps creates a cycle of effective management that encourages adjusting your plan as unexpected situations arise or management goals change (Box 2).

Box 2. Shrub management cycle.



Adaptive management promotes "learning while doing," instead of trial and error. New knowledge about your project area can be used in a variety of ways to adjust your overall management plan. For example, let's imagine you set goals to improve wildlife habitat for mule deer on two ecological sites differing in annual precipitation and plant productivity. By incorporating your knowledge of ecological principles and site limitations you define objectives that include two strategies: 1) reduce shrubs by 15% in a mosaic (patchy) pattern across both sites using a mechanical tool and 2) seed with native grasses and forbs. After you execute this plan and monitor vegetation and wildlife features for 2 years, the management cycle will create numerous information feedbacks. For example, if assessments in Step 7 reveal rapid recovery of shrub seedlings on the more productive ecological site and undesirable annual weeds on the less productive site, this information can be used to refine your knowledge in Steps 2 and 3 so that you can tailor necessary adjustments to Steps 4 and 5 to the different ecological sites. For example, you will need to develop separate strategies to address the rapid recovery of shrubs on the more productive site and the increase of annual weeds on the less productive site.

Step 1: Set Goals.

Just as your management area will have distinct physical boundaries, setting clear and realistic management goals will provide a standard to measure your progress. Most importantly, setting clear goals requires identifying which ecosystem services you wish to address, who will be essential stakeholders, and how money will be expended (Figure 3).

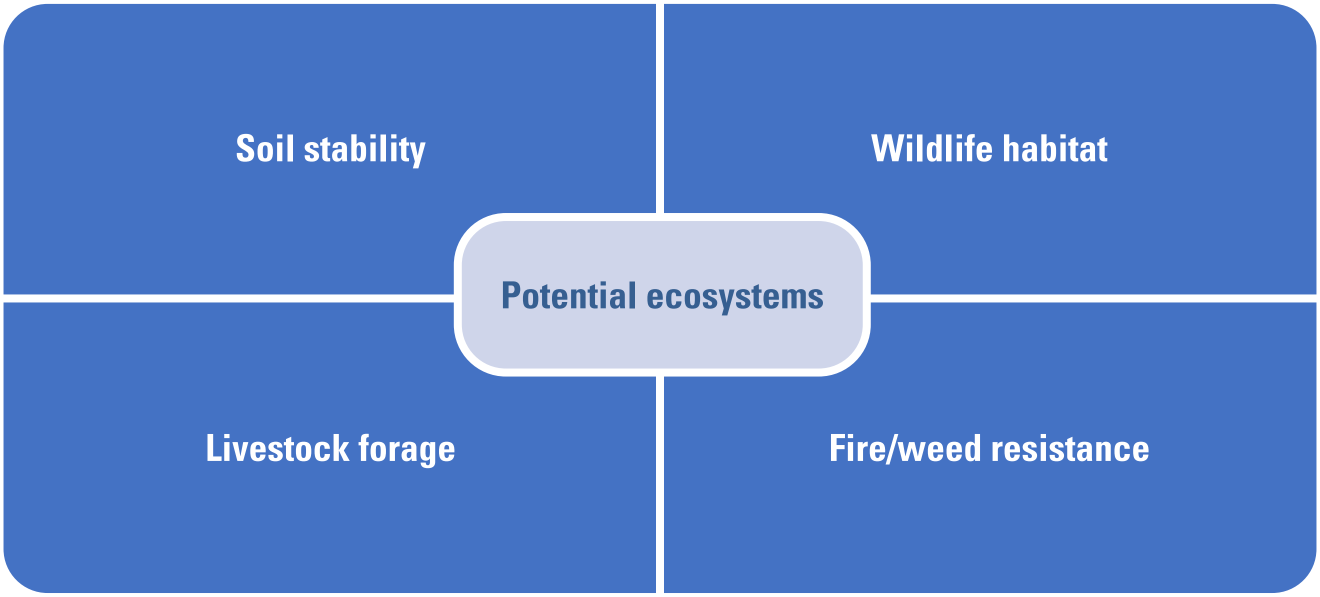


Figure 3. Which ecosystem services are most important?

Step 2: Identify ecological sites

Classifying your study area and its current condition are essential for shrub management. Ecological site classifications define how your project site represents a distinct unit that supports a particular suite of native plant species. These classifications also describe your site's association with a specific range of soil and climatic properties.

Remember, ecological sites exist as alternative stable vegetation states depending on land condition. In other words, site attributes define the condition of your land relative to an ecological potential. For example, site degradation resulting from low perennial vegetation cover, excessive soil erosion, high amounts of bare ground, and low water infiltration will collectively determine which alternative states are present and whether they have departed from their potential (Table 1). Most vegetation states indicate departure from their full potential and therefore their ability to provide important ecosystem services. Consequently, your management plan should specifically address the unique conditions that exist within each vegetation state.

	Alternative stable state			
	State 1: Shrub/ herbaceous co-dominant (reference)	**State 2: Shrub dominant, degraded herbaceous**	**State 3: Invasive annual dominant**	**State 4: Seeded: non-native perennial grass dominant**
Departure from site potential	None to slight	Moderate	Extreme	Extreme
	Capacity to provide ecosystem services (low = √, moderate = √√, high = √√√)			
Soil stability	√√√	√√	√	√√
Wildlife habitat	√√√	√√	√	√
Livestock forage	√√	√	√	√√√
Fire/weed resistance	√√	√	√	√√

Table 1. Generic description of four vegetation states within a hypothetical ecological site illustrating how departure from reference site potential influences the capacity of vegetation states to provide a number of important ecosystem services. Note: higher levels of departure from site potential in States 2 and 3 reduce the capacity to provide a given ecosystem service.

Step 3: Understand ecological principles and factors that limit achievement of shrub management goals.

In this step, you will become aware of the ecological principles that influence how your site responds to management. This step will also assist in setting realistic management objectives (Step 4) and provide you with an understanding of how certain management actions may be more appropriate than others (Step 5).

Ecological principles define how species interact with each other and how they behave in different environments; these principles represent the best cumulative understanding we have obtained over the last 60 years. When ecological principles are the basis for shaping objectives and selecting actions, unnecessary risks and unintended results can be avoided.

Examples of ecological principles:

1. Thresholds exist between vegetation states that limit the capacity of management to influence persistent changes in vegetation (e.g., ecosystems can reorganize into new states following disturbances, and these changes may be irreversible).
2. Frequent disturbances (e.g., vegetation removal, soil agitation) favor fast-growing annual weed species. Infrequent disturbance favors slower-growing species (e.g., long-lived bunchgrasses and/or large-statured shrubs/trees).
3. Productivity of vegetation is limited by soil resource availability, which is typically patchy on rangelands and changes from year to year, depending on factors such as annual precipitation, soil type, and landscape position.
4. Species diversity (e.g., the number of different species and functional types; grasses, forbs, shrubs) and vegetation heterogeneity (e.g., variation in plant structures over time and across the landscape) can improve many ecosystem services.
5. Water infiltration can decrease and erosion can increase due to loss of vegetation and biological soil crust cover.

Step 4: Define objectives.

Defining project objectives allows you make a prediction of what will be accomplished by your management plan. Objectives should be specific, measurable, and realistic for your ecological site conditions. Objectives should also define target values for site conditions and include time-specific expectations, so you can track your management goals. Objectives should also be linked to specific ecosystem services (Table 2) and be reexamined or revised throughout the management process. For example, information feedbacks created in the shrub management cycle (Box 2) will inevitably lead to adjusting objectives to remedy site limitations, clarify uncertain ecological outcomes, and correct unexpected consequences of prior applications of tools and strategies.

Example Objective	Ecosystem Service
Decrease the proportion of bare ground between plants to 15% within 2 years.	Soil stability.
Increase native forb cover to 5% within 2 years	Wildlife habitat.
Increase production of herbaceous species by 50% within 2 years.	Livestock forage.
Create fuel breaks along property boundaries with bare ground exceeding 80 inches between plants.	Fire/weed resistance.

Table 2. Linking objectives to specific ecosystem services.

Step 5: Choose tools and strategies.

The four previous steps will dictate your choice of tools and strategies for managing shrubs. Your choice of tools and management strategies also depend on developing a clear understanding of shrub biology (Section 3) and the existing technology to reduce shrubs abundance (Section 4). Combined, all these factors must be considered in the context of precision, cost, and risk.

A few thoughts to consider:

1. The effectiveness of tools and strategies will vary depending on site type and condition.
2. Your understanding of ecological processes and principles will be key to choosing the most appropriate tools and strategies for your management area.
3. Your choice of tools and strategies must match your available funding resources and time commitments.
4. Beware of unintended consequences such as damaging fragile soils, biological soil crusts, and sensitive plant species. Minimize disturbances that favor weed invasion.
5. When you apply treatments is equally important as where you apply treatments. Time your applications to maximize opportunities for native species recovery. Many desired outcomes take considerable amounts of time, sometimes as much as 10 years or longer.
6. Because so many factors are impacted by year-to-year variation in environmental conditions, many treatments may need to be re-applied.

Step 6: Execute plan.

With so many factors involved in executing your management plan, the outcome of shrub management cannot be predicted perfectly. While this uncertainty is expected, you can adapt your plan by making appropriate adjustments as you track your progress. This approach, referred to as "adaptive management," is often discussed, but rarely practiced. Your plan will be more adaptive if you set aside untreated areas to serve as comparative controls for treated areas and apply more than one tool/strategy for a given site. Now, that's executing a plan like a scientist!

Step 7: Monitor and assess outcomes.

The way to know if you are making progress is through monitoring site and vegetation attributes. Monitoring is crucial for adaptive learning. Many resources are available to help you design an effective and affordable monitoring protocol to sample specific indicators of desired ecosystem services (Appendix 2). In brief, the best monitoring protocols to track your progress over time will include 1) sampling before and after treatments, 2) sampling both untreated and treated areas, and 3) sampling reference areas that represent your "target values" for desired ecosystem services (Figure 4). Assessing outcomes should go hand in hand with re-evaluating prior steps and adjusting your tools and strategies. Adjustments are necessary when target values are not met.

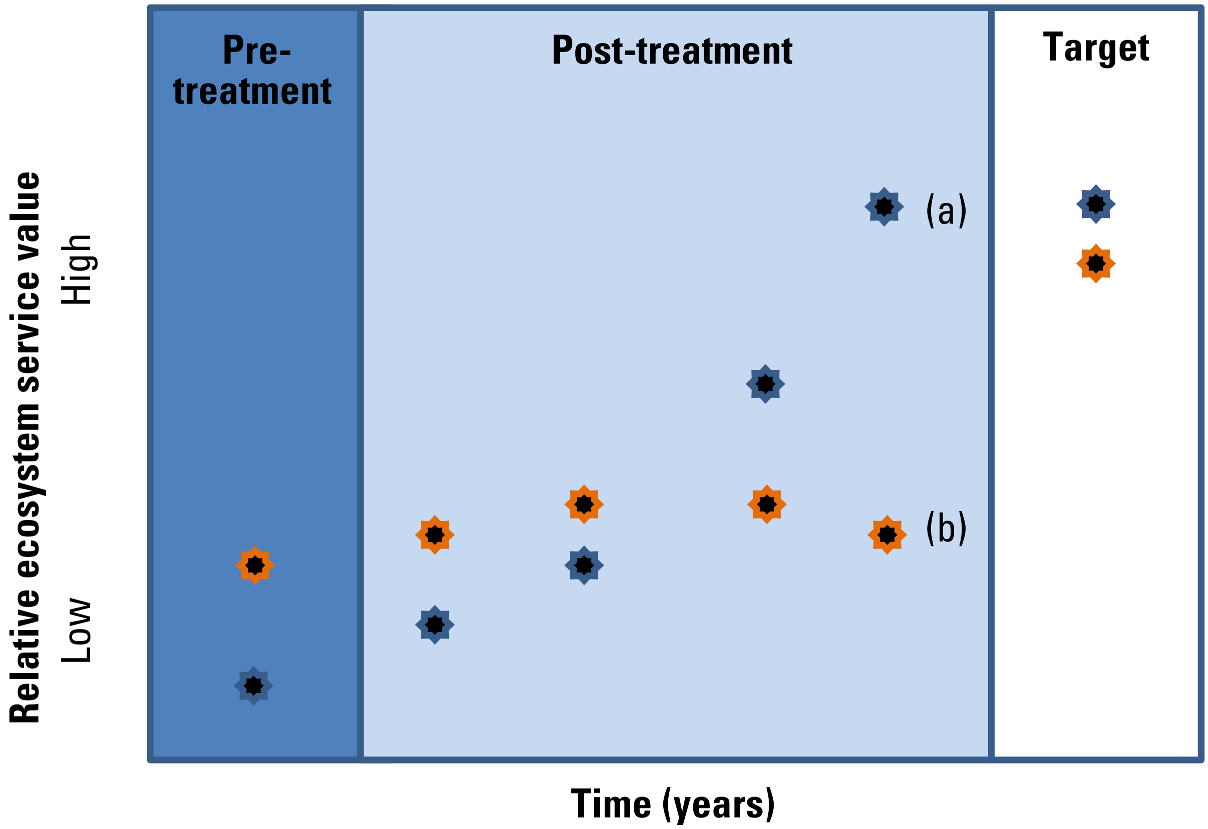


Figure 4. Schematic showing how monitoring can track ecosystem services (blue and orange symbols) over time to determine whether target values are met (a) or not met (b).

Section 3 — Understand target shrubs

Shrubs are possibly the most diverse plant growth form. Thus, improving your understanding of shrub biology will improve land management skills, interpretation of ecological principles, and management decisions. Shrub diversity is illustrated by immense variety in leaf structure, leaf longevity, leaf chemistry, palatability, drought and salinity tolerance, browsing tolerance, and sprouting potential (Box 3). All these properties shape how shrub species respond to, and interact with, the environmental conditions of your project site and help explain the amazing range of adaptations that allow shrubs to expand and contract their cover. In this section, we present biological descriptions for four shrubs species that represent a wide range of variation in growth form and response to disturbance. Following these descriptions, we provide case studies summarizing management outcomes for each shrub species. Online plant identification tools, fact sheets, and plant guides for all shrub species can also be obtained at http://plants.usda.gov.

Box 3. The diverse shrub growth form.

By definition, shrubs are plants with multiple, persistent, and woody stems. However, shrubs display a broad diversity of these growth form characteristics that determines their competitive ability with herbaceous species, response to disturbance, and relative abundance during plant community development. At one end of the spectrum, shrubs that develop annual stems that die back to woody bases are commonly referred to as "sub-shrubs." At the other end of the spectrum, shrubs generate woody stems that persist, and bear leaves for more than a year. The broad middle ground of this spectrum includes shrubs with varying levels of woody bases and herbaceous branch ends. Shrubs are also distinguished by regrowth associated with the type of buds (i.e., an embryonic, undeveloped stem) they develop and where they are located, such as on stem tips (apical bud) or on stem base or roots (adventitious bud). Bud types and their location on stems influence how a shrub species will respond to stress and disturbance. A third feature of shrubs includes leaf longevity and nutritive quality. In general, shorter-lived leaves are more nutritious and grow more quickly compared to longer-lived leaves that are less nutritious and may be more protected with rougher or waxy surfaces to withstand stressful environments and defoliation by insects and animals. Furthermore, shrubs manifest distinctive differences in mechanical and chemical defenses that influence their value to wildlife and livestock. Lastly, shrubs rely on the longevity of the seeds they produce (seed banks) as a mechanism to perpetuate populations. Understanding these regenerative processes in shrubs will help you incorporate sound ecological principles into your project planning and avoid surprises.

Example 1. Black greasewood, *Sarcobatus vermiculatus* (Hook.) Torr.

Photographs of black greasewood illustrating the fleshy leaves, light-colored stems, and stiff spines **(left);** it is often found in valley bottoms with salt-affected soils and poor drainage **(right).**

Distribution — Black greasewood is widespread in western deserts of North America, usually in valley bottoms, floodplains, and dry washes. In Utah, it frequently occurs in salt deserts of the Great Basin, but also in upland mountain and high plateau valleys that experience a seasonally high-water table. It thrives on fine-textured soils such as silts, clays and fine sandy loams that often are saline, sodic, and/or alkaline.

Growth form and habit — To survive in salt desert habitats, plants develop deep taproots that can reach reliable groundwater. In addition, its shallow roots contain adventitious buds that yield new stems when the aboveground shrub is damaged or when competing vegetation is removed, allowing it to replace neighboring shrubs after disturbances such as tillage, burning, grazing herbaceous understory vegetation, and extended drought. Newly emerged stems and young growth are often flexible and deep green in color, but stems become dark, spiny and brittle as they age. Leaves are fleshy and succulent and contain high salt concentrations that can bring salts to the soil surface through litter accumulation.

Management challenges and considerations — Black greasewood is a long-lived and disturbance-adapted species that thrives in semiarid saline or alkaline soils with high pH and poor drainage. On one hand black greasewood offers site stability and important wildlife habitat under harsh conditions where past disturbance may have damaged biological soil crusts, increased wind and soil erosion, and allowed annual weed species to establish and flourish. On the other hand, when it replaces other desirable species, it limits the potential of ecological sites to provide some ecosystem services.

We advocate determining ecological site status to understand how soils and climate govern the abundance of black greasewood and carefully considering how prevailing management pressures regulate its abundance. If it is a component of historical vegetation at your project site and provides favorable habitat and forage values, you may want to leave it alone or manage livestock disturbances to minimize its expansion—especially since salt desert communities are often fragile. Alternatively, if it has expanded and displaced other desirable vegetation and threatens the potential of a site to provide desired ecosystem services, reducing its abundance is likely necessary. Treatments applied to reduce black greasewood and achieve desired outcomes will likely need to be repeated and will require continual management to maintain a desired level of shrub cover given its regeneration potential. Combining your management tools to minimize regrowth and increase the amount of perennial herbaceous vegetation is advised.

Reduction strategies —

1. Burning is not a good management option because it favors re-sprouting and may increase annual weeds.
2. Herbicide effectiveness varies depending on the specific herbicide, but is generally improved when applied in the spring when plants are actively growing and translocation of harmful chemicals to below-ground portions of plants is most effective.
3. Mechanical treatments are only as effective as their ability to prevent re-sprouting. Thus, mechanical methods, including soil tillage, should be repeated in the same season and then followed by herbicide to further stress re-sprouting stems.
4. Regardless of the tools used, black greasewood treatments should always be followed by seeding to reestablish species adapted to the ecological site conditions.

Example 2. Broom snakeweed, *Gutierrezia sarothrae* (Pursh) Britton & Rusby

Photographs of broom snakeweed illustrating its fine stems, small linear leaves, and bright yellow flowers **(left);** it often dominates heavily disturbed areas on coarse, shallow soils **(right).**

Distribution — Broom snakeweed is broadly distributed in western and central North America and is prevalent in the Intermountain West and throughout Utah. It is adapted to a wide range of arid conditions and soil types from clayey loams with low drainage to sandy well-drained soils, and to shallow gravelly conditions. This species generally thrives best on limestone soils and is less common on saline or alkaline soils.

Growth form and habit — Broom snakeweed is a sub-shrub with stems that arise from woody bases each growing season. A main stem is usually present, and plants develop a taproot and extensive lateral roots. Broom snakeweed can re-sprout after aboveground portions are removed but only if some portions of the lower stems are left intact and they contain buds. Its ability to persist on sites is due to production of high amounts of seed that enable it to spread into disturbed areas and compete with developing seedlings of perennial grasses and forbs. These qualities allow it to stabilize soils and provide valuable cover to wildlife species. The lifespan of plants is shorter (i.e., <20 years) than shrubs like big sagebrush with which it often grows.

Management challenges and considerations — Many wildlife species such as pronghorn and black–tailed jackrabbits eat broom snakeweed. However, its ability to increase on grazed lands is due to toxic compounds and high concentrations of crude resins that make it unpalatable to livestock. The deterioration of perennial grasses due to grazing, drought, and fire typically enhances the spread of broom snakeweed and its dominance on grazed lands.

Due to its prolific seed production, broom snakeweed plays an important role in plant communities because it can recover following disturbances that degrade herbaceous vegetation and create bare soil. Year-to-year fluctuations in annual precipitation strongly affect its population density, suggesting that stresses such as insect infestations and drought will create oscillations between low and high densities. The cyclic nature of broom snakeweed populations requires paying close attention to when management efforts are scheduled for your project site (Box 2). Its tendency to rapidly increase when drought conditions subside suggests that reducing seed production during wetter years will reduce its ability to recover from seed banks and outcompete herbaceous species. In addition, the coincidence of a minor broom snakeweed infestation on degraded sites with low perennial grass cover may indicate it could quickly expand. In addition to characterizing ecological site conditions, we advocate thinking about how seed bank density of broom snakeweed and the past precipitation conditions at your site might influence your future population dynamics and the choice of reduction strategies.

Reduction strategies —

1. Burning generally kills plants and consumes seeds that remain on branches. However, burning will not greatly reduce seeds located on the soil surface if fires are cool and lack fine fuels that tend to increase fire temperature and duration for a given spot. If possible, burning should be conducted at the end of the dry season to maximize fire temperature and consume seed before new seedlings emerge.

2. A broad range of herbicides are available to reduce broom snakeweed. Keep in mind, your focus for herbicide applications should be on curtailing new seed production and preventing new seedling emergence. Choose herbicides that can address these factors and apply them at the most effective time, taking into consideration how herbicide chemistry interacts with soil and environmental conditions.

3. Mechanical treatments are not generally used because top-killing plants is not as effective as tools that prevent broom snakeweed recovery from seed banks. However, mechanical treatments that cultivate the soil, bury seeds, and prepare suitable conditions for seedings of desirable plants should be considered if they do not compromise existing, desirable vegetation.

4. Seeding is critical to provide adequate competition for emerging snakeweed seedlings. Reestablishing perennial grasses is essential because their growth and development coincide with broom snakeweed. Maintaining high perennial grass cover is essential to minimizing snakeweed spread and preventing its ability to recover after herbicide applications.

Example 3. Rubber rabbitbrush, *Ericameria naseosa* (Pall. Ex Pursh) G.L. Nesom & Baird

Photographs of rubber rabbitbrush plants with waxy leaves and upright, flexible stems that are usually light-colored **(left);** it rapidly re-sprouts after being disturbed and produces bright yellow flowers in late fall **(right).**

Distribution — Rubber rabbitbrush is widely distributed in the western U.S. In Utah, it primarily occurs in pinyon-juniper woodlands, sagebrush-steppe, shrublands, and salt desert plant communities, but can also be a component of riparian and forested mountain areas. Rubber rabbitbrush has numerous subspecies and varieties, which show distinct adaptations to soil type, climate, and landform throughout Utah. Subspecies can also be defined by stem color; namely, gray and green forms. It typically grows in sunny, open areas on plains, valley bottoms, foothills and mountains, and floodplains on a broad range of soils from coarse to fine-textured. Rubber rabbitbrush can tolerate both upland (cool and moist) and semidesert (hot and dry) habitats but is more common in the latter.

Growth form and habit — Rubber rabbitbrush plants are typically between 1 and 4 feet tall and have numerous branches arising from the base, with an overall rounded form. Root systems include a deep taproot and dense fibrous roots. Stems are upright, very flexible, and covered in dense, fine hairs that result in a wide range of colors. Stems have woody bases that and can re-sprout very quickly and reestablish canopies faster than any other native shrub. Re-sprouting occurs from buds located on stem bases and roots. Similar to

stems, leaves take on a wide range of colors and sizes and provide a basis to identify the plant to subspecies. Leaves are covered in fine hairs and have waxy cuticles that increase drought tolerance but reduce palatability for livestock.

Management challenges and considerations — Due to physical and chemical properties of its leaves, rubber rabbitbrush is marginal for livestock grazing, but it provides important food and shelter for numerous wildlife species. Late flowering makes it valuable for numerous insects including pollinating bees and butterflies. Rubber rabbitbrush also plays an important role in most plant communities due to rapid growth and regeneration potential after disturbances such as soil cultivation, prior shrub reduction, and fire. Rapid regeneration provides a mechanism for rubber rabbitbrush to replace slower-growing shrub species that can take many decades to recover. It also reproduces through seed dispersal in late fall and functions as an early colonizer of plant community phases (Section 1). Any disturbances could "reset" plant communities to an early developmental stage and favor rubber rabbitbrush dominance. In contrast, plant communities in later stages of development are not dominated by rubber rabbitbrush indicating that the lack of disturbance favors slower-growing, longer-lived, non-re-sprouting shrub species. These ecological principles should be the basis for determining management objectives and help you understand how disturbance history and regeneration traits shape current vegetation conditions and the relative abundance of rubber rabbitbrush within plant communities. Lastly, rabbitbrush dominance is difficult to reduce over a short time span (i.e., 1-4 years), but options do exist to shift plant community composition over longer time frames using a combination of reduction strategies.

Reduction strategies —

1. Burning can injure plants and provide short-term reductions in rubber rabbitbrush. Fire should be avoided if non-sprouting native shrubs such as sagebrush (*Artemisia spp.*) or antelope bitterbrush (*Purshia tridentata* [Pursh] DC.) risk being killed or injured.

2. Herbicides are an essential component of reducing rubber rabbitbrush because they can be selectively applied to individual plants and present little risk of disturbing soils. However, herbicide applications are notoriously challenging due to the thick hairs and waxy surfaces of rabbitbrush, which reduce absorption of herbicides on stems and leaves. Chemical formulations and application rates are available to increase absorption, but cutting or mowing stems will increase chemical absorption. Herbicides should be applied in late spring during rapid growth, so injury can be maximized. However, if late spring coincides with low soil moisture due to drought, applications should be delayed until conditions improve. Pre-emergence herbicides should also be considered to reduce seedling emergence from seed banks. However, injury of non-target plants should be expected with this strategy, and care must to taken to minimize this risk.

3. Mechanical treatments that merely injure above-ground portions of plants are not advised, especially on deep, loamy soils at low elevation sites where regeneration is rapid. Instead, whole plants should be removed from the soil and plants allowed to dehydrate. Mechanical treatments are most likely to succeed if they are applied to individual plants or in areas where plants have already been killed by herbicide. Soil cultivation associated with disking or root planing (see Section 4) will favor annual weeds and rubber rabbitbrush emergence from seed banks; thus, below ground tools must be followed with seeding to enhance species diversity, stabilize soils, and provide a source of competition to emerging seedlings.

4. Seeding is crucial on most project sites, especially if mechanical tools are being used and if sites contain areas with no perennial herbaceous vegetation. Many species are available for seeding, but they should be capable of rapidly establishing, persisting, and competing with rubber rabbitbrush seedlings.

Example 4. Big sagebrush, *Artemisia tridentata* Nutt.

Photographs of big sagebrush showing thick, woody stems and silvery small leaves **(left);** although it is fire-intolerant it often occurs from valley bottoms to upland mountain meadows **(right).**

Distribution — Big sagebrush is a diverse species-group composed of three subspecies that commonly hybridize and occupy a broad range of habitats in the Intermountain West. While subspecies often exist in distinct habitats, they can also co-exist and hybridize on the same site. Subspecies can be differentiated by their genetics, morphology, and ecological attributes and include the following: 1) basin big sagebrush (*Artemisia tridentata* Nutt. *ssp. tridentata*) at lower elevation sites and deeper soils (1,900-6,900 feet), 2) mountain big sagebrush (*Artemisia tridentata* Nutt. *ssp. vaseyana* [Rydb.] Beetle) at higher elevation (2,600 feet-10,000 feet), wetter sites, and 3) Wyoming big sagebrush (*Artemisia tridentata* Nutt. *ssp. wyomingensis* Beetle & Young) at lower elevation (2,600-7,200), drier sites and shallower soils. Given its broad distribution and adaptation to a wide range of climatic conditions, big sagebrush often becomes the dominant or co-dominant shrub species in later stages of plant community development. Big sagebrush provides a critical foundation to species diversity and wildlife habitat, and is essential to the structure of shrub-steppe and shrubland ecosystems due to its role in regulating site hydrology and nutrient cycling and providing a refuge for understory native species. Many wildlife species require suitable big sagebrush stands that provide food, cover, and breeding areas.

Growth form and habit — Big sagebrush develops persistent woody stems that do not re-sprout from buds after plant canopies are damaged or removed by disturbances. Reproduction and recolonization are primarily from seed, which leads to variable regeneration and plant community resilience across ecological sites. In general, resilience to environmental stress and disturbance is lower in warm/dry sites compared to cool/moist sites where soils are more favorable and environmental conditions are more suitable for big sagebrush recovery. Subspecies also differ in leaf chemistry, palatability and stress tolerance, which impact wildlife and livestock use and variation in growth and seed production from year to year.

Management challenges and considerations — Big sagebrush ecological sites are commonly imperiled by drastic reductions in perennial herbaceous vegetation, annual grass invasion, and conifer tree encroachment, which present challenges to achieving the highest possible native species diversity and recovery of numerous ecosystems services through land management. Consequently, a long-term (>10-20 year) perspective must be considered when managing big sagebrush sites given its regeneration mechanisms and the pervasive threats to site resilience. Weed invasion coupled with altered disturbance regimes create alternative stable states wherein degraded abiotic conditions increase the amount of active restoration required to achieve desired conditions.

Degraded conditions require increased attention to established ecological principles to understand site limitations and determine the most appropriate management strategy. Under some circumstances, big sagebrush sites can be managed passively by altering livestock grazing, seeding, or transplanting understory

species. However, when crossing biotic thresholds such as extreme loss of understory vegetation and invasive grass dominance leads to crossing abiotic thresholds such as frequent wildfires, soil erosion and altered nutrient and water cycles, reduction strategies can help reduce degradation and instigate site recovery toward desired conditions.

Reduction strategies —

1. Burning large areas or complete removal of big sagebrush should be avoided; rather, creating patches of intact shrub stands interspersed with open areas will support a broader range of ecosystem services. Depending on fire intensity and frequency, burning often results in high mortality of big sagebrush and is therefore most appropriate for smaller patches to create a mosaic pattern. Frequent fires prevent adult plants from dispersing seed into disturbed areas, lead to slow natural recovery, and promote dominance by weedy annuals and fire-tolerant shrubs. Additionally, if understory herbaceous vegetation is devoid of perennial grasses, annual weeds will quickly colonize burned areas and slow plant community development toward desired, stable vegetation states.

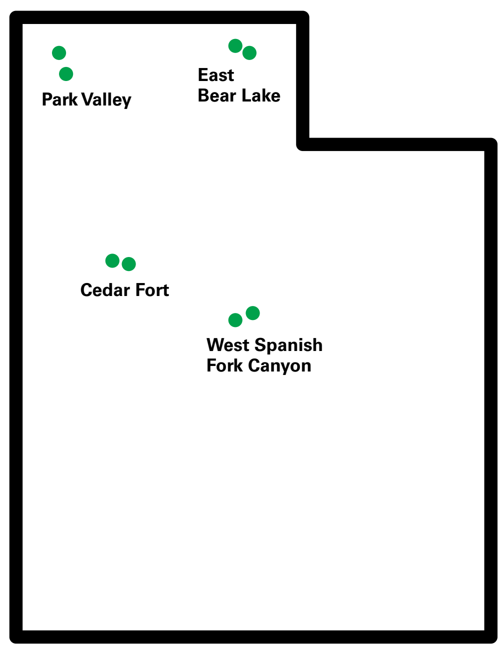
2. Many herbicides can thin big sagebrush stands, create small open areas, and increase understory herbaceous species cover. However, these herbicides run the risk of injuring perennial forbs, so care is needed when considering season and rate of application.

3. Mechanical treatments for big sagebrush typically target older/larger plants to stimulate growth of younger plants and understory herbaceous species. Mechanical treatments that disturb soils or biological soil crusts should be avoided unless it is required to create a seed bed for subsequent seedings. Expect weedy species to increase after any soil disturbance.

4. Seeding or transplanting is essential to expedite understory herbaceous recovery on sites that were degraded prior to big sagebrush reduction. Site-specific soil and environmental conditions of a project site should dictate your choice of herbaceous species to plant.

Utah shrub management case studies

Between 2013 and 2017, four cooperative research/demonstration areas were established on private lands in Utah at eight ecological sites (right). Utah State University, U.S. Department of Agriculture (Agricultural Research Service & Natural Resources Conservation Service), and Utah Department of Agriculture and Food (Grazing Improvement Program) initiated studies with the following goals: 1) reduce over-abundance of shrubs through herbicide treatment and 2) increase cover and density of herbaceous vegetation to improve site suitability for livestock grazing and wildlife habitat.



8 Utah Ecological Sites

Vegetation was monitored for 5 years in herbicide-treated and control (untreated) areas within two ecological sites at each demonstration area. Shrub reduction focused on specific shrub species at each demonstration area, including black greasewood, broom snakeweed, rubber rabbitbrush and big sagebrush (Table 3). A description of each area, along with unique challenges, results, and considerations for studies are presented below. Further information about demonstration areas, ecological sites, and target shrub species can be obtained online at https://extension.usu.edu/rangelands/pages/utah-shrubland-management-project

Table 3. List of target shrubs, ecological sites, herbicide details, and locations of four demonstration areas in Utah.

Target shrub	Ecological Site-landscape position	Herbicide/Season/Rate	Location
Black greasewood	1. Semidesert Loam (Wyoming Big Sagebrush) 2. Semidesert Alkali Loam (Black Greasewood)	**Escort® XP/Spring/2.0 oz·acre^{-1}	Park Valley
Broom snakeweed	1. Upland Stony Loam (Mountain Big Sagebrush) 2. Upland Shallow Hardpan (Mountain Big Sagebrush)	**Cimarron® Max/Spring/3.2 oz·acre^{-1}	Cedar Fort
Rubber rabbitbrush	1. Upland Loam (Basin Big Sagebrush) Ecological Site – bench top 2. Upland Loam (Basin Big Sagebrush) Ecological Site - swale	*Picloram +D/Spring/7.4 pints·acre^{-1}	West Spanish Fork Canyon
Big sagebrush	1. Upland Stony Loam (Black Sagebrush) 2. Upland Loam (Wyoming big sagebrush)	*Tebuthiuron 20P/Fall/2.5 lbs·acre^{-1}	East Bear Lake

*Alligare, 13 N. 8th Street, Opelika, AL 36801
**Bayer Environmental Science, a Division of Bayer CropScience LP 2 T. W. Alexander Drive Research Triangle Park, NC 27709

Black greasewood

Left: post-treatment photograph showing persistence of large-statured black greasewood plants.

Shrub reduction — Herbicide treatment resulted in substantial decreases in greasewood cover at Ecological Site 2, but no reductions were observed at Ecological Site 1. Large plants were more abundant at Ecological Site 1 and were not impacted by herbicide; however, density of smaller greasewood plants was consistently reduced at both sites. Within treatment areas, unintentional mortality was nearly 100% for the native shrub green molly (*Bassia americana* [S. Watson] A.J. Scott). **Forbs —** Perennial forbs were generally not present at both sites. Compared to control areas, annual forbs, consisting mostly of weeds, were greatly reduced within treated areas at Ecological Site 2. **Perennial grasses —** Cover and biomass in treated areas were 2-fold compared to control areas at Ecological Site 2, but no increases were observed for Ecological Site 1, indicating that successful shrub reduction stimulated grass recover at Ecological Site 2. **Important factors —** Small-statured plants of greasewood and green molly were primarily injured by the herbicide treatment.

Broom snakeweed

Left: pre-treatment vegetation showing density of snakeweed and few perennial grasses.

Shrub reduction — Snakeweed cover and density were effectively reduced after 4 years at both ecological sites, but reductions were most striking at the drier Ecological Site 2, that had not experienced historical cultivation disturbances. **Herbaceous vegetation —** Herbicide application more effectively reduced biomass production of weedy annual forbs and increased perennial grasses at Ecological Site 2. In contrast, cheatgrass (*Bromus tectorum* L.) greatly increased at Ecological Site 1. Seeding did not increase perennial grasses at either site. **Important factors —** Historical disturbances, such as mechanical removal of sagebrush, soil cultivation, and wheat production that occurred on Ecological Site 1, can lead to undesirable increases in weedy species following snakeweed control. In addition, even though we found drastic reductions in snakeweed and conducted follow-up seedings across both sites, further measures are needed to increase perennial herbaceous vegetation to prevent snakeweed reinvasion.

Rubber rabbitbrush

Left: post-treatment photograph showing control area (left) and treated area with plants injured by picloram +D (right).

Shrub reduction — Rubber rabbitbrush cover and density were reduced at both ecological sites. In addition, snakeweed and sagebrush were also greatly reduced at Ecological Site 2. **Herbaceous vegetation —** Density and cover of perennial grasses and forbs were not modified by herbicide treatment. **Important factors —** Year-round continuous livestock grazing during the first 3 years of the study negated our ability to detect increases in herbaceous vegetation. Lighter grazing pressure is recommended to allow existing perennial vegetation to achieve higher recovery.

Big sagebrush

Left: post-treatment conditions showing dense sagebrush plants injured by tebuthiuron.

Shrub reduction — Tebuthiuron treatment reduced sagebrush cover by at least 50% after 3 years for both sites, yet it increased substantially by the fifth year at Ecological Site 2, which had previously experienced mechanical shrub removal, cultivation and wheat production over 70 years ago. **Perennial forbs —** Cover was reduced in tebuthiuron-treated areas at Ecological Site 1 over 5 years whereas it increased during the first 2 years at Ecological Site 2. **Perennial grasses —** Tebuthiuron treatment increased perennial grass cover only at Ecological Site 1 in year 5. Livestock grazing occurred in the fall and spring in all years, and the landowner noted general improvements in forage production and animal performance. **Important factors —** Although tebuthiuron effectively reduced sagebrush cover within 18 months, coarse-textured soils at Ecological Site 1 allowed deeper percolation of tebuthiuron, leading to increased exposure of perennial forbs and sagebrush to the herbicide. Finer soils at Ecological Site 2 reduced overall percolation of herbicide. Thus, sagebrush and perennial forb mortality were less.

Section 4 — Learn technology to manipulate shrub abundance

Properly managed land can support wildlife habitat and livestock grazing, improve water quality, maintain landscapes for recreationists, and conserve areas to protect endangered/threatened species. Shrub management entails manipulating shrub abundance in a cost-effective manner to enhance the capacity of a site to provide these ecological services. As opposed to complete eradication, most situations will entail creating patches of treated and untreated areas. Accordingly, we first recommend using maps of your project site to formulate a pattern for shrub manipulation (Figure 5).

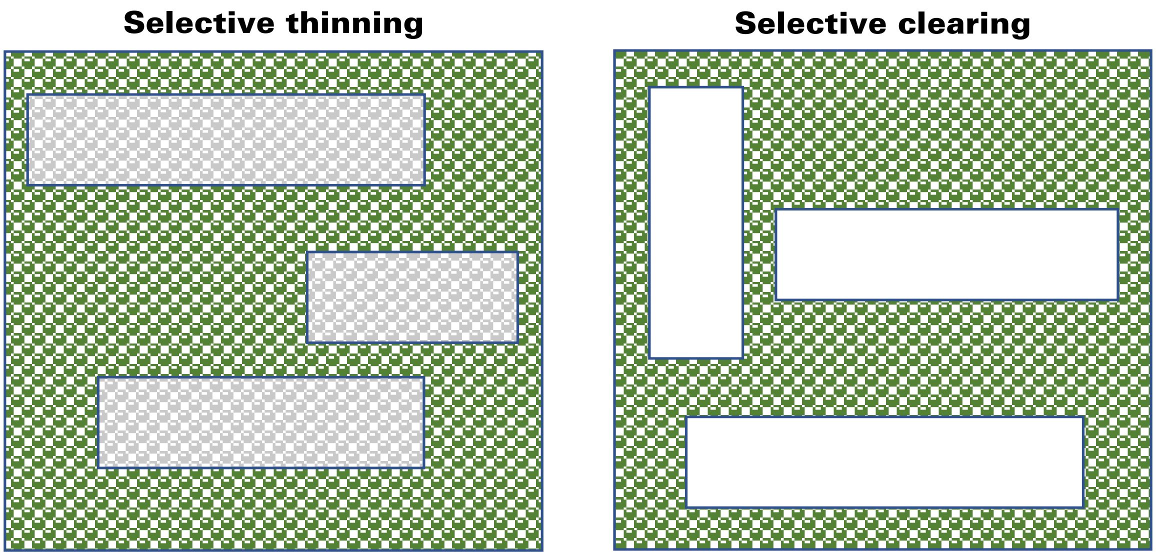


Figure 5. Schematic illustrating alternative patterns of shrub manipulation to create mosaics by selective thinning and clearing.

Second, learn about current technology and choose manipulation tools that are most suitable to achieve your project goals and objectives. Technology and associated tools to manipulate shrub abundance come in many forms and will differ in precision, cost, and risk. Some tools are highly selective in injuring or removing plants of a specific size, but lack the precision to target specific species. Other tools are generally non-selective, but inexpensive. Some may effectively injure target shrubs but incur undesirable impacts on non-target plant species and biological soil crusts or create soil disturbances. Lastly, some tools are best-suited to injure individual plants and avoid undesirable impacts, while others can only be applied at larger scales, making them more cost-effective than tools designed for smaller treatment areas. When ecological principles and limiting factors are understood for your target shrub and project site (Box 2), you can effectively determine which tool or combination of tools is most appropriate when executing your shrub management plan. Below is a summary of commonly applied tools and technology.

Prescribed Burning

Fire naturally occurs on Utah shrublands and prescribed burning has long been an effective tool to reduce shrub abundance, increase herbaceous production, enhance habitat for both livestock and wildlife, and reduce accumulated litter and woody fuels. While wildfires typically occur in dry years and can magnify drought stress, prescribed burns are usually conducted under safer, wetter conditions, which improve the likelihood for desired herbaceous species to respond favorably to reduced shrub abundance.

Before conducting a prescribed burn, carefully examine the state laws and environmental quality rules that regulate when, where, and how to burn vegetation on private property. In addition, burn and air quality permits must be obtained through the Utah Division of Forestry, Fire & State Lands prior to conducting a prescribed burn (https://ffsl.utah.gov/).

Burning is a cost-effective tool to reduce shrub abundance because it immediately damages most shrub species, leading to increases in nutrients that support positive responses in herbaceous vegetation. However, shrub recovery and the duration of these positive responses of herbaceous vegetation varies widely by species. Although some shrub species are killed by fire (e.g., broom snakeweed, big sagebrush, antelope bitterbrush [*Purshia tridentata* [Pursh] DC.]), other species (e.g., black greasewood, rubber rabbitbrush, spineless horsebrush [*Tetrademia canescens* DC.]) are only top-killed and re-sprouting enables them to recover within a few years. Consequently, it is critical to understand the biology of your target shrub species (Section 3) as well as know the effects of fire on important species at your project site. Fire ecology, including the immediate fire effects on more than 1,000 species and their potential post-fire recovery are available on the Fire Effects Information System website (https://www.feis-crs.org/feis/). Achieving desired management objectives through burning will require a firm grasp of how plant biology interacts with fire characteristics (Table 4).

Table 4. Key factors* influencing the effectiveness of burning to reduce shrub abundance.

Plant biology	Fire characteristics
• Life form and plant size • Bud location and protection • Seed persistence and dispersal	• Timing of burn • Size of burn and fuel patchiness • Intensity and severity of burn • Fuel density, volume, and moisture

*See Pyke, D.A., Brooks, M.L., & D'Antonio, C., 2010. Fire as a restoration tool: a decision framework for predicting the control or enhancement of plants using fire. *Restoration Ecology* 18, 274-284.

Prescribed burning is primarily done in the fall to minimize damage to cool season perennial plants and possibly enhance desirable forbs. In general, rhizomatous grasses suffer less mortality from fall burning compared to bunchgrasses, whose susceptibility to fire increases with the density of basal stems. In contrast to fall burns, summer burns are more likely to kill or injure native perennial grasses and increase annual grasses that disperse their seeds in early summer and rarely are consumed entirely in fast-moving summer fires.

Herbicide

Herbicide application offers a highly flexible tool to manipulate shrub abundance and create a desired balance between woody and herbaceous plants. Complete elimination of a shrub species is not advised and will negatively impact ecosystem health. In addition, herbicides should not be applied if initial cover of perennial grasses and forbs is low because your site could quickly transition to a weedy plant community unless sites are successfully seeded. Forbs and non-target shrubs are also particularly sensitive to herbicides, and injuring them will diminish ecosystem services. Keep in mind that herbicide applications will be most effective when existing herbaceous vegetation can quickly benefit from the excess soil resources (water, nutrients) made available by reduced shrub abundance.

The effectiveness of herbicide application will depend on many factors that interact with one another. These include site factors such as soil type, terrain, and climate (Section 2), biology of target shrubs (Section 3), and herbicide activity (see below). It is important to weigh the benefits and challenges of applying herbicides (Table 5), identify and understand key safety considerations, and properly apply herbicides to achieve your project goals and objectives.

Table 5. Benefits and challenges of using herbicides to manipulate shrub abundance.

Benefits	Challenges
• Specific shrub species are targeted • Can be applied to individual plants • Large areas can be treated quickly • Avoids damaging fragile soils • Can be applied on difficult terrain • Can be applied aerially • Integrates well with other treatment methods	• Non-target injury may occur • Applicators must be adequately trained and licensed • Application is limited to specific times coinciding with shrub physiology and climate • Equipment must be carefully calibrated • Products and application are costly • Repetitive applications of a single chemical formulation can result in herbicide resistance • Multiple- or follow-up treatments may be necessary

Key considerations — Because herbicides contain chemical substances (i.e., active ingredients) that are toxic to plants or animals, airborne drift or contamination of ground water must be avoided. Serious attention should also be given to reading and understanding product labels and properly applying herbicides at your project site. A state license is required for commercial applicators and/or use of restricted products in Utah. All applicators must follow state and federal laws, know how to handle chemicals and operate application equipment, and wear personal protective equipment. Information about Licensing and Worker Protection Standards are maintained by the Utah Department of Agriculture and Food (https://ag.utah.gov/pesticides/private-pesticide-applicator-licensing.html).

How herbicides work — Understanding a few basic aspects of herbicide activity will allow you to select appropriate products to target a specific shrub species and recognize the signs of herbicide damage. Studying these details will improve your ability to choose the best herbicide, understand how to interpret plant injury, and minimize undesirable risks to your project site (Appendix 3). First, herbicides interfere with specific mechanisms critical to growth and development and some products contain chemical mixtures that complement each other, resulting in greater efficacy. Second, knowing how different herbicides are related to each other can help you avoid treating plants with similar chemicals that can lead to herbicide resistance in weed populations.

While some herbicides are non-selective and injure a broad spectrum of plants, others are formulated to be selective for a particular group of plants. Furthermore, some herbicides injure only the portions of a plant exposed to the herbicide, while others are absorbed and translocated throughout the plant resulting in a systemic effect. Herbicides can also be categorized by whether they are applied before or after seedling emergence; for the former, herbicides remain active in the soil until they are absorbed by seedlings after seed germination. Some herbicides remain active in the soil for a long time and may prevent recently planted desirable seedlings from establishing. Each herbicide label will explain product selectivity, how the active ingredient works within plants, and provide a detailed description of susceptible plant species and the visual symptoms that will appear on susceptible target plants. Thus, the time period between application and the appearance of visual symptoms will depend on the specific product applied and numerous factors associated with your application.

Application — Although herbicides are increasingly formulated to target undesirable plants and minimize injury to non-target species, you can improve the efficacy of your application through effective planning and preparation. The following checklist is a simple way to coordinate your herbicide applications, document your techniques, and consider the many factors that influence herbicide activity at your project site (Box 4).

Box 4. Herbicide application checklist to improve efficacy.

Application type

- ❑ Aerial
- ❑ Ground

Season

- ❑ Application date __________
- ❑ Pre-emergence – apply to moist soils or prior to rainfall events
- ❑ Post-emergence – use surfactants to improve stem and leaf absorption

Method

- ❑ Granule
- ❑ Spray

Spray criteria

- ❑ Product name and manufacturer __________
- ❑ Surfactant __________
- ❑ Solution pH - adjust between 6 to 8
- ❑ Tank pressure __________
- ❑ Rate __________
- ❑ Droplet size __________
- ❑ Spray volume __________
- ❑ Nozzle type and number __________

Site environmental conditions

- ❑ Air temperature __________
- ❑ Relative humidity __________
- ❑ Wind speed __________
- ❑ Most recent precipitation date __________
- ❑ Soil moisture level __________
- ❑ Soil depth, texture, and organic matter content __________

Target shrub criteria

- ❑ Target species name __________
- ❑ Plant developmental stage __________
- ❑ Re-sprouting potential __________
- ❑ Leaf surface (cuticular) type __________

Mechanical

Mechanical tools increase the efficiency of shrub manipulation and encompass a wide range of technologies from simple to sophisticated (Appendix 4). Mechanical shrub reduction allows fairly precise treatment of individual plants or patches, while preserving intact adjacent areas. Depending on the condition of vegetation and soil at your project site (Table 1), treated areas may require using a combination of tools such as herbicide, seeding, or prescribed grazing to achieve desired outcomes. In general, mechanical treatments should be applied outside of optimal spring growing conditions to minimize injury to ground nesting birds, avoid compacting wet soils, or damaging herbaceous vegetation. Mechanical tools create litter and woody debris that can be kept on site to help prevent erosion and soil loss.

Your choice of mechanical tools for reducing shrub abundance will first depend on shrub density. If your project site is relatively small, and density is low, hand tools are the most suitable choice. Hand tools such as the pruner, saw, axe, shovel, and pry lever can assist with cutting or uprooting (i.e., "grubbing") individual plants. Because labor costs increase with shrub density and the size of your project area, hand tools are not efficient or affordable for larger project areas. Treating larger areas with higher shrub density will typically require heavy machinery and consideration of slope, soil depth, and surface terrain when applying them to target shrubs (Figure 6). Choose belowground tools for target species that re-sprout, and aboveground tools for target species that do not re-sprout. Special caution should be taken to choose alternative and/or integrated methods if re-sprouting non-target shrubs or weedy annual species are present on your site. Weedy annuals will likely increase with any soil disturbance, especially if mechanical treatments disrupt biological soil crusts. Choose thinning tools to suppress aboveground growth and dominance of non-sprouting target shrubs and clearing tools for re-sprouting target shrubs. Your costs will likely change yearly and typically depend on the fuel efficiency of machinery used and cost of renting, contracting, or purchasing this equipment. Seeding is likely necessary following the use of clearing tools to expedite herbaceous vegetation recovery.

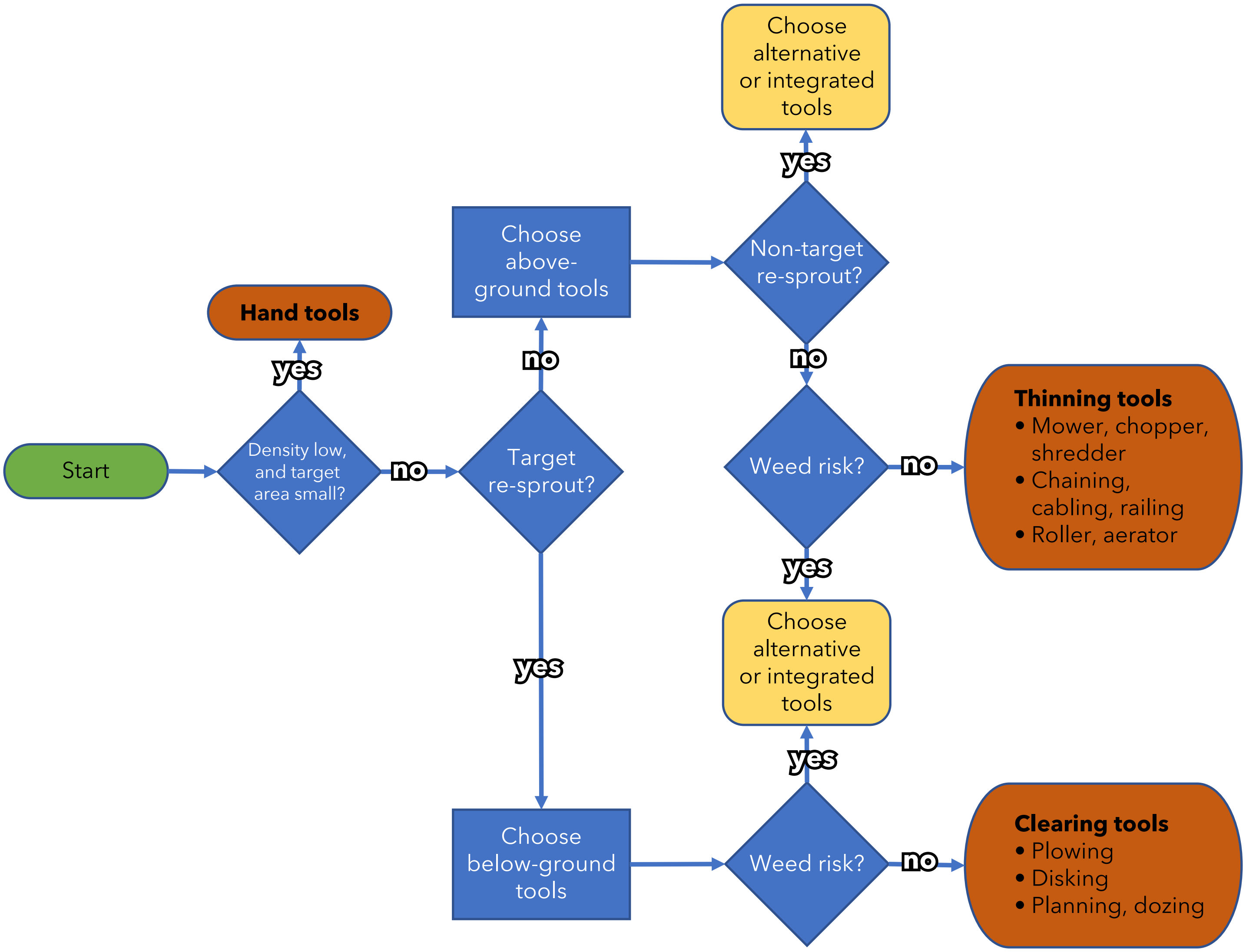
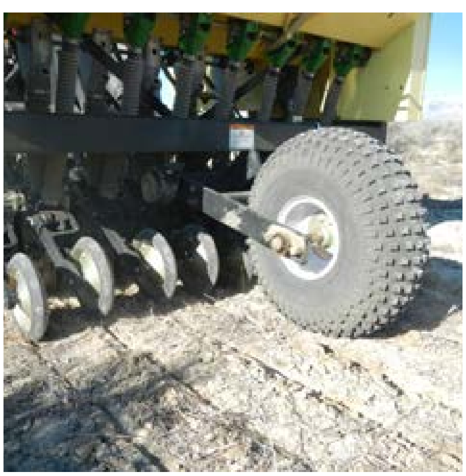


Figure 6. Flowchart to assist choosing suitable mechanical tools for manipulating shrub abundance.

Seeding



Seeding is often necessary to promote ecosystem services when the abundance of understory herbaceous species is inadequate due to past land use and disturbance. Seeding provides the reproductive potential for new populations to establish following shrub manipulation. Seeding also accelerates opportunities for plants to protect soils from environmental stresses, erosion, and weed invasions. Your management goals and land use will dictate the need for seeding. Site and environmental conditions, as well as your post-seeding management will influence whether seeding will help achieve these ecological benefits.

Seeding is a flexible technology because you choose the planting mixtures and how and when seeds are sown. This flexibility is important because decisions surrounding seeding must consider ecological criteria as well as practical factors including economics, aesthetic values of species, and environmental policies. To assist with making these decisions, published guidelines will help you achieve a successful seeding (Appendix 5). These guidelines emphasize the importance of seed quality, time of seeding, seedbed preparation, seeding depth, equipment, choice of plants, and weed control. Ultimately, careful planning will improve precision, minimize risk, and reduce cost of your seeding.

Precision — Seeds can be sown on the soil surface with broadcast seeding or planted to a desired soil depth using drill-seeding. Precision is enhanced by creating seedbed conditions suitable for different plant materials. While seed size largely dictates seeding depth, general guidelines suggest grasses should be planted ¼ to ½ inch deep whereas forb species should be ⅛ to ¼ inch deep. Creating suitable seedbed conditions will likely require herbicidal control of weeds, soil disking, plowing, raking/harrowing to improve soil tilth, and soil firming with rollers or imprinters to improve soil-seed contact (Appendix 5). Soil disturbance and loose, dry soils should be minimized because they increase water evaporation. Lack of seeding precision may be compensated for by increasing seeding rate, which as a rule is three-times higher for broadcast than drill seeding. No-till drills are also commonly utilized to minimize soil disturbances.

Risk — Enhancing desired ecosystem services and realizing the conservation benefits of seeding depend on ecological site conditions, the level of departure from desired conditions, and weather. High variability in these factors over space and time create considerable risk for the success of seedings and limit our ability to make broad generalizations about the effectiveness of seeding for semiarid shrubland ecosystems. Thus, we recommend applying seeding approaches that specifically accommodate the unique conditions of your project site. Fall-dormant seedings are applied as late as possible in the growing season so that cool conditions delay germination until spring when survival of new seedlings is greatest due to abundant moisture from winter snowfall. Fall-dormant seeding can also benefit many native species that require a cold/wet period to stimulate seed germination. In contrast, early-fall seedings carry much higher winter mortality because seeds can potentially obtain environmental conditions to germinate in seedbeds, but immature seedlings will lack adequate root development to withstand freezing temperatures. Inversely, when seeding warm-season grasses, risk can be minimized if they are seeded in late spring or early summer before monsoonal precipitation occurs.

Cost — Seeding cost will vary depending on your choice of species, seeding rate, and how seedbeds are prepared. Diverse mixes increase plant diversity and offer insurance against environmental stresses. A broad range of plant materials, including a variety of native and introduced species should be chosen based on their known performance and suitability to establish and persist on the project site. No amount of expense in site preparation and planning will override the importance of choosing the right plant materials that are best adapted to your site conditions. Once you choose appropriate plant materials, carefully plan how you will create the ideal seedbed conditions.

Grazing Management

Effective management after manipulating shrub abundance is essential to obtain desired results. Livestock and wildlife will be drawn to areas recently cleared of woody species because herbaceous vegetation has been released from shrub competition. Consequently, you will need to adjust grazing pressures to protect your investment and allow herbaceous species sufficient time to establish and produce adequate biomass. As a rule of thumb, livestock grazing should be deferred for at least two growing seasons after applying mechanical and burning treatments or administering a seeding to avoid damaging soils and allow desirable species to produce adequate seeds and stabilize your project site. After livestock grazing is resumed, careful annual monitoring should be conducted to see how herbaceous species are regenerating with resumed livestock pressure at your site. Livestock season-of-use and/or stocking rates should be adjusted adaptively if monitoring indicates that current grazing practices may be unsustainable in regard to post-treatment herbaceous cover and biomass.

Section 5 — Glossary, appendices, and further reading

Glossary

Abiotic factor: A physical, non-living component that influences an environment or ecosystem.

Adaptive management: A structured process of decision making when uncertainty is common and systematic assessments of treatment outcomes are used to inform decisions and adjust management.

Alternative stable vegetation state: A theoretical interpretation that predicts how ecosystems exist in different stable states that can potentially transition from one state to another and may be separated by ecological thresholds.

Biological soil crust: The community of microorganisms living on the soil surface that play a critical role in soil stability, water infiltration, and seed germination.

Biotic factor: A living organism that influences an environment or ecosystem.

Broadcast seeding: Plant propagation by scattering seeds on project sites soils.

Competitive ability: The relative capacity of one population of plant species to suppress another due to its superior acquisition of a limiting resource.

Contact herbicide: Herbicides applied to plant foliage after emergence that injure all the plant material they come in contact with.

Climatic feature: Used to characterize a region based on distinct atmospheric characteristics such as temperature, precipitation, wind, and solar intensity.

Cuticle: A waxy film covering the epidermis (surface) of plant leaves that prevents water loss and the absorption of external solutes.

Drill seeding: Plant propagation by dispersing seeds directly into furrows created by a tractor-driven series of disk openers.

Disking: A method of land cultivation wherein a tractor-drawn implement, comprised of a series of disks, overturn and disrupt soils and vegetation.

Early-fall seeding: Sowing seeds prior to favorable soil moisture conditions so seedlings develop enough growth to withstand winter freezing. See also Fall-dormant seeding.

Ecological Site: A distinctive kind of land with specific soil and physical characteristics that differ from other kinds of land in 1) its ability to produce a distinctive kind and amount of vegetation, and 2) how it responds to management actions and natural disturbances.

Ecological site descriptions: Reports that provide detailed information about a particular kind of land - a distinctive Ecological Site.

Ecological Site Information System (ESIS): An online repository for ecological site descriptions and information associated with the collection of forest and rangeland data.

Ecological threshold: See threshold.

Ecosystem service: A valued process, function, or product provided to society by an ecosystem, such as forage, clean water, cover, and soil stability.

Fall-dormant seeding: Sowing seeds in late fall to delay germination until favorable spring soil moisture conditions.

Harrowing: A cultivation method wherein a tractor-drawn implement is dragged over land, and teeth, spikes, or tines disrupt the soil surface and rake vegetation.

Herbicide resistance: When plants in a population develop tolerance to an herbicide due to repeated and intensive use of products with the same mechanism of action (MOA).

Growth form: A classification scheme used to differentiate shoot architecture among trees, shrubs, and herbaceous plants.

Integrated tools: Combining the application of multiple tools to manipulate shrub abundance when a single tool is deemed ineffective.

Mechanism of action (MOA): The specific mechanism through which an herbicide produces its harmful effect (e.g., inhibition of amino acid production or photosynthesis).

Meristematic tissue: Plant tissue located in zones of growth and comprised of undifferentiated cells that may develop into a flower, leaf, or shoot.

Monitoring: A pre-planned systematic method to document the status of vegetation, soils, or environmental variables over time.

Morphology: See plant morphology.

Non-target effects: Unintentional damage to soils, plants and other organisms associated with the application land management tools.

Palatability: Animal preference for consuming plants depending on plant structural composition (hairs, texture, succulence), aroma, nutritive qualities and prior experience with the plant.

Physiographic features: Used to characterize a region based on landscape features such as mountains, rivers, and other landforms and how they influence living organisms.

Plant community phase: Associated with the theory of succession, temporary stages of plant community development that readily shift over time or following land management activities.

Plant material: A source for seed or plants used for planting.

Plant morphology: External characteristics of plant structures and physical form used for distinguishing differences among plants and in plant identification.

Plow: A cultivation method that uses a tractor-drawn implement with a series of blades that turn over soil, disrupt vegetation, and mixes soils.

Pure live seed: A standardized measure of the percentage of seed that germinate that is calculated by multiplying percentage purity by percentage of seed that will germinate.

Raking: See Harrowing.

Resilience: Property of an ecosystem describing the amount of change it can experience and still maintain its structure, function, and feedbacks among ecological components.

Seed bank: A repository of viable seeds previously dispersed and currently residing within soils at your project site.

Seed quality: A term describing seed viability and seed purity.

Seeding rate: A calculation of the amount of seed necessary to achieve a desired plant density that considers pure live seed.

Soil tilth: A favorable soil condition determined by water drainage, water infiltration, aeration, and stability of aggregated particles.

State-and-transition model (STM): A conceptual diagram and tool for depicting vegetation states and plant communities that are connected by ecological processes or transitions.

Stakeholders: An organization, group, or person with interests in land management actions, policies, and objectives.

Surfactant: A soluble compound added to tank mixtures to increase herbicide absorption by plants.

Systemic herbicide: Herbicides that are readily translocated throughout the plant after absorption.

Threshold: Levels of underlying biotic and abiotic variables that control an ecological system and feedback to control change in the system, such as between alternative vegetation states.

Transition: Major shifts in vegetation structure, species composition, and soils that may be irreversible depending on whether ecological thresholds have been crossed.

Web Soil Survey (WSS): An online resource that provides soil data and information operated by the USDA Natural Resources Conservation Service.

List of Appendices

Appendix 1. Web Soil Survey and ecological sites.

- USDA https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
- UC Davis, California, Soil Resource Lab., soil mapping apps for smartphones, Google Earth, and desktop application. http://casoilresource.lawr.ucdavis.edu/drupal/node/902
- USDA-NRCS Ecological Site Descriptions for Rangeland and Forestland. https://esis.sc.egov.usda.gov/Welcome/pgESDWelcome.aspx
- Utah State University, Rangeland Extension, Introduction to Ecological Sites. https://extension.usu.edu/rangelands/pages/ecological-site-descriptions

Appendix 2. Monitoring guideline publications.

- USDA-ARS, Landscape Toolbox. http://www.landscapetoolbox.org/
- Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems. http://jornada.nmsu.edu/monit-assess/manuals/monitoring
- Utah State University Rangeland Management, Monitoring page. https://extension.usu.edu/rangelands/pages/range-monitoring
- USDA-NRCS, National Range and Pasture Handbook: Chapter 4 – Inventorying and Monitoring Grazing Land Resources. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/landuse/rangepasture/?cid=stelprdb1043084

Appendix 3. Herbicide terminology and application

- Utah State University Extension, Pesticide License Certification Course and Exam. https://extension.usu.edu/pesticidecert/
- Weed Science Society of America, Summary of Herbicide Mechanism of Action. http://wssa.net/wp-content/uploads/WSSA-Mechanism-of-Action.pdf
- The Nature Conservancy, Weed Control Methods Handbook: Tools & Techniques for Use in Natural Areas. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1532&context=govdocs

• Appendix 4. Mechanical shrub reduction technology

- USDA-NRCS, Brush Management as a Rangeland Conservation Strategy: A Critical Evaluation.

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1045798.pdf

- Texas A&M University, AgriLife Extension, Revegetation Equipment Catalog. http://greatbasinfirescience.org/RevegCatalog/control_fire-hand_tools.html
- Texas A&M University, Brush Busters. https://texnat.tamu.edu/about/brush-busters/
- USGS, Restoration Handbook for Sagebrush Steppe Ecosystems, Parts 1-3. https://doi.org/10.3133/cir1416

Appendix 5. Seeding and planting guidelines

- USDA-NRCS, Guidelines for Determining Stand Establishment on Pasture, Range, and Conservation Seedings. http://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/idpmstn10791.pdf
- USDA-ARS & Utah State University Extension, Intermountain Planting Guide. https://digitalcommons.usu.edu/extension_curall/1333/
- USDA-ARS, Revegetation Guidelines for the Great Basin: Considering Invasive Weeds. https://www.ars.usda.gov/ARSUserFiles/oc/np/RevegetationGuidelines/RevegetationGuidelines.pdf

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