Shrub-steppe Restoration

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Restoration of the semi-arid shrub-steppe ecosystem has gained increasing attention over the last 20 years. This is the result of growing recognition of the values intact shrub-steppe ecosystems provide to communities. Soil stabilization may be the highest value of intact shrub-steppe (Scott et al. 1998). Intact shrub-steppe ecosystems also moderate wildfire spread, while disturbed shrub-steppe ecosystems dominated by invasive cheatgrass (*Bromus tectorum)* cause increased fire frequency and intensity. In addition to increasing risk to lives and property, increased fire causes further loss of big sagebrush *(Artemisia tridentata*), the dominant plant in this ecosystem (Whisenant 1990). Intact shrub-steppe with sagebrush is needed as habitat for a number of birds (Rogers et al. 1988) such as the sage grouse (Connelly and Braun 1997), which is now rare. Highly diverse communities dominated by native plant species are likely to be more productive (Naeem et al. 1995) and thus support more diverse wildlife.

The Columbia Basin has been occupied by people for at least 12,000 years, and Indians employed fire to manage vegetation using low-intensity, high-frequent burns (U. S. Department of Agriculture 1996). The arrival of Europeans to the shrub-steppe in the mid-1800's, followed by heavy grazing of cattle and sheep, plus plowing for wheat (Rogers and Rickard 1988). By the early 1900's, a number of invasive plant species became widespread (Rogers and Rickard 1988). Today only 30% of original grasslands exist, and 70 % of shrublands, while all the landscape is potential habitat for invasive alien plant species (U. S. Department of Agriculture 1996).

While it is not possible that all shrub-steppe lands will be restored, it is possible to restore areas that are not likely to be further developed for agriculture and human habitation. This chapter reviews restoration in the shrub-steppe with particular attention to the difficulties of restoration in these semi-arid ecosystems.

Description of the shrub-steppe

The shrub-steppe eco-region (Fig. 11.1) is dominated by shrubs and perennial bunchgrasses over about 645,000 km^2 in North America (Daubenmire 1970; Rickard et al. 1988). The Snake/Columbia element of the shrub-steppe is lower in elevation than the Wyoming Basin.

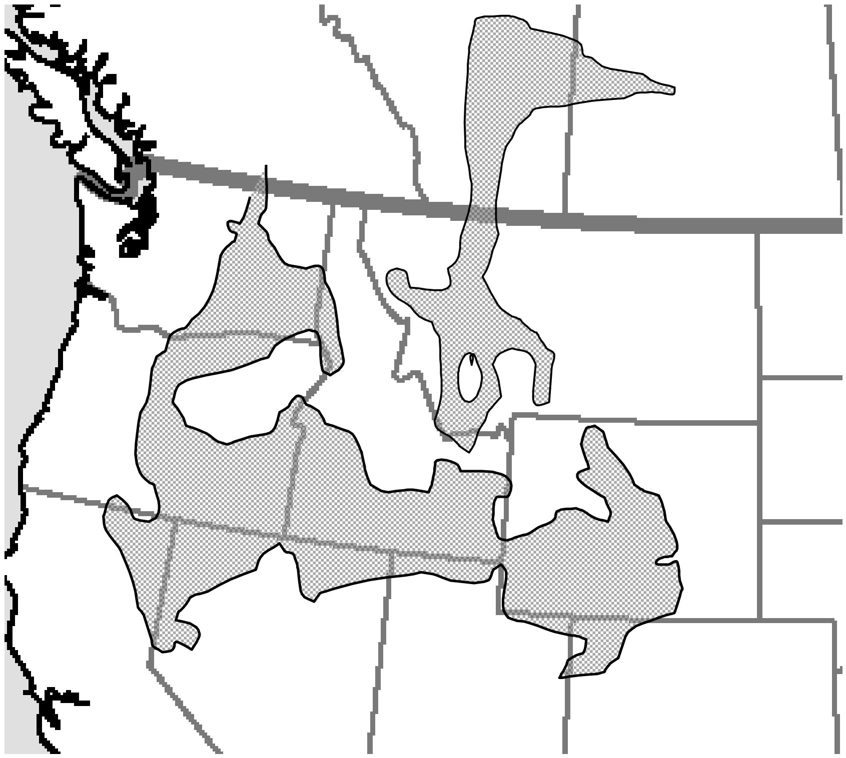

Figure 11.1: Approximate extent of the shrub-steppe in North America (Rickard et al. 1988).

Climate and distribution

At 6000 years before present (BP), the shrub-steppe occupied virtually the same geographical range as it does today. At 18,000 BP, it occupied areas that are now conifer and mixed forests. In the Great Basin, conifers were found within the current domain of the shrub-steppe (Thompson and Anderson 2000).

Present yearly average precipitation ranges from about 162 mm at the Hanford Site (Thorp and Hinds 1977) in Washington to about 420 mm at Columbia, Montana, which contains the most productive steppe community in the western US (Rickard et al. 1988).

Plant communities

The dominant natural vegetation of the shrub-steppe is sagebrush (*Artemisia* spp.), associated with wheatgrasses, Idaho fescue (*Festuca idahoensis*) or other perennial bunchgrasses (Franklin and Dyrness 1988). Cheatgrass is now dominant in many areas.

A number of different plant association zones occur in the Columbia Basin. The largest and driest of these zones is the big sagebrush (*Artemisia tridentata*)-bluebunch wheatgrass (*Pseudoroegneria spicata*) association (Daubenmire 1970). This association is characterized by four layers of vegetation, an overstory layer composed mostly of big sagebrush up to two meters tall, a tall understory layer of bluebunch wheatgrass, a short understory dominated by Sandberg's bluegrass (*Poa secunda*), and the microbiotic crust composed of algae, lichens and mosses on the soil surface. The microbiotic crust is a critical component of native grasslands and shrub-steppe communities (Link et al. 2000). Perennial and annual herbs are found in the understory layers. Other shrubs include rabbitbrush (*Ericameria* and *Chrysothamnus* spp.), bitterbrush (*Purshia tridentata*), hopsage (*Grayia spinosa*), and three-tip sagebrush (*Artemisia tripartita*). Other bunchgrasses include needle-and-thread (*Hesperostipa comata*), Indian ricegrass (*Achnatherum hymenoides,* Plate 1e), Cusick's bluegrass (*Poa cusickii=Poa secunda*) and Idaho fescue (*Festuca idahoensis*).

Other associations, such as big sagebrush-Idaho fescue, bluebunch wheatgrass-Sandberg's bluegrass, and bluebunch wheatgrass-Idaho fescue occur on moister sites within the big sagebrush-bluebunch wheatgrass association (Daubenmire 1970).

The primary large bunchgrasses in sand include needle-and-thread and/or Indian ricegrass. The dominant shrub in these associations can be either big sagebrush or bitterbrush.

On stony soils or extremely shallow soils over bedrock, various species of buckwheat (*Eriogonum*) and/or stiff sage (*Artemisia rigida*) dominate the shrub layer and Sandberg's bluegrass dominates the understory. In the driest areas, associations consist of big sagebrush-Sandberg's bluegrass, hopsage-Sandberg's bluegrass, and winterfat (*Krascheninnikovia lanata*)-Sandberg's bluegrass (Daubenmire 1970). These associations lack large perennial bunchgrasses. In saline-alkaline soils, *Distichlis stricta* and *Leymus cinereus* are the dominant grasses and *Sarcobatus vermiculatus* is the dominant shrub with lesser amounts of *A. tridentata* (Daubenmire 1970).

Plant species

There are numerous native plants to consider for restoration purposes (Table 11.1) and many invasive alien species in need of control (Table 11.2).

Table 11.1. Important native plants of the shrub-steppe. They are perennials unless noted. Names are from Hitchcock and Cronquist (1976) with the most current names obtained from the PLANTS database(USDA NRCS 2003).

Family *Species*	**Common Name**	**Life form**	**Habitat**
Cactaceae			
Opuntia polycantha	starvation pricklypear	succulent	upland
Chenopodiaceae			
Atriplex canescens	fourwing saltbush	shrub	upland
Atriplex confertifolia	spiny shadscale	shrub	upland
Grayia spinosa	hopsage	shrub	upland
Krascheninnikovia lanata	winterfat	shrub	upland
Sarcobatus vermiculatus	greasewood	shrub	riparian
Compositae			
Achillea millifolium	yarrow	herb	upland
Artemisia rigida	stiff sage	shrub	upland
Artemisia tridentata ssp. *tridentata*	basin big sagebrush	shrub	riparian/upland
Artemisia tridentata ssp. *vaseyana*	mountain big sagebrush	shrub	upland
Artemisia tridentata ssp. *wyomingensis*	Wyoming big sagebrush	shrub	upland
Artemisia tripartita	three-tip sage	shrub	upland
Balsamorhiza careyana	Carey's balsamroot	herb	upland
Balsamorhiza sagittata	arrowleaf balsamroot	herb	upland
Chrysopsis villosa	hairy goldaster	herb	upland
Chrysothamnus viscidiflorus	green rabbitbrush	shrub	upland
Crepis atribarba	slender hawksbeard	herb	upland

Family *Species*	**Common Name**	**Life form**	**Habitat**
Ericameria nauseosa	gray rabbitbrush	shrub	upland
Erigeron filifolius	threadleaf fleabane	herb	upland
Erigeron poliospermus	cushion fleabane	herb	upland
Erigeron pumulus	shaggy fleabane	herb	upland
Gutierrezia sarothrae	snakeweed	shrub	upland
Helianthus cusickii	Cusick's sunflower	herb	upland
Machaeranthera canescens	hoary aster	Biennial herb	upland
Cruciferae			
Erysimum asperum	rough wallflower	herb	upland
Stanleya tomentosa	woolly stanleya	herb	upland
Thelypodium laciniatum	thick-leaved thelypodium	herb	upland
Graminae			
Achnatherum hymenoides	Indian rice grass	bunchgrass	upland
Distichlis stricta	saltgrass	rhizomatous	riparian/upland
Elymus elymoides	squirreltail	bunchgrass	upland
Elymus lanceolatus	streambank wheatgrass	rhizomatous	upland
E. lanceolatus ssp. *lanceolatus*	Bannock	rhizomatous	upland
E. lanceolatus ssp. *lanceolatus*	Critana	rhizomatous	upland
E. lanceolatus ssp. *lanceolatus*	Schwendimar	rhizomatous	upland
E. lanceolatus ssp. *psammophilus*	Sodar	rhizomatous	upland
Elymus wawawaiensis	Snake River wheatgrass, Secar	bunchgrass	upland
Festuca idahoensis	Idaho fescue	bunchgrass	upland
Hesperostipa comata	needle-and-thread grass	bunchgrass	upland
Koeleria cristata	prairie junegrass	bunchgrass	upland
Leymus cinereus	giant wildrye	bunchgrass	riparian/upland
Pascopyrum smithii	western wheatgrass	rhizomatous	upland
Poa secunda	Sandberg's bluegrass	bunchgrass	upland
Pseudoroegneria spicata	bluebunch wheatgrass	bunchgrass	upland
Sporobolus cryptandrus	sand dropseed	bunchgrass	upland
Laminaceae			
Salvia dorrii	purple sage	shrub	upland
Leguminosae			
Lupinus leucophyllus	velvet lupine	herb	upland
Lupinus sericeus	silky lupine	herb	upland
Petalostemon ornatum	western prairieclover	herb	upland
Psoralea lanceolata	lanceleaf scurf pea	herb	upland
Liliaceae			
Calochortus macrocarpus	mariposa lily	herb	upland
Fritillaria pudica	yellow bell	herb	upland
Triteleia grandiflora var. *grandiflora*	largeflower triteleia	herb	upland
Linaceaea			
Linum lewisii	Lewis flax	herb	upland
Loasaceae			
Mentzelia laevicaulis	blazing-star	herb	upland
Malvaceae			
Sphaeralcea munroana	Munro's globemallow	herb	upland

Family *Species*	Common Name	Life form	Habitat
Onagraceae			
Oenothera pallida	pale evening primrose	herb	upland
Polemoniaceae			
Phlox longifolia	longleaf phlox	subshrub	upland
Phlox speciosa	showy phlox	subshrub	upland
Polygonaceae			
Eriogonum niveum	snow buckwheat	herb/shrub	upland
Eriogonum umbellatum	sulfur buckwheat	herb	upland
Eriogonum sphaerocephalum	rock buckwheat	shrub	upland
Eriogonum thymoides	thyme buckwheat	shrub	upland
Rumex venosus	winged dock	herb	upland
Ranunculaceae			
Delphinium nuttallianum	upland larkspur	herb	upland
Ranunculus glaberrimus	sagebrush buttercup	herb	upland
Rosaceae			
Purshia tridentata	bitterbrush	shrub	upland
Scrophulariaceae			
Penstemon acuminatus	sand beardtongue	herb	upland
Umbelliferae			
Cymopterus terebinthinus	turpentine springparsley	herb	upland
Lomatium macrocarpum	big seed bisquitroot	herb	upland
Lomatium triternatum	nine-leaf lomatium	herb	upland

Table 11.2. Common invasive aliens in the shrub-steppe. Names are from Hitchcock and Cronquist (1976), Taylor (1990), and Whitson et al. (1992) with the most current names obtained from the PLANTS database (USDA NRCS 2003).

Family *Species*	Common Name	Life cycle	Life form	Habitat
Boraginaceae				
Amsinckia lycopsoides	fiddleneck	annual	herb	upland
Caryophyllaceae				
Gypsophila paniculata	baby's breath	perennial	herb	riparian
Holosteum umbellatum	jagged chickweed	annual	herb	upland
Chenopodiaceae				
Halogeton glomeratus	halogeton	annual	herb	upland
Kochia scoparia	kochia	annual	herb	upland
Salsola kali	Russian thistle	annual	herb	upland
Compositae				
Centaurea diffusa	diffuse knapweed	annual/biennial	herb	upland
Centaurea maculosa	spotted knapweed	biennial	herb	upland
Centaurea repens	Russian knapweed	perennial	herb	riparian
Centaurea solstitialis	yellow-star thistle	annual/biennial	herb	upland
Chondrilla juncea	rush skeletonweed	perennial	herb	upland
Cirsium arvense	Canada thistle	perennial	herb	upland

Family Species	Common Name	Life cycle	Life form	Habitat
Cirsium vulgare	bull thistle	biennial	herb	upland
Lactuca serriola	prickly lettuce	annual	herb	upland
Onopordum acanthium	Scotch thistle	biennial	herb	upland
Tragopogon dubius	salsify	annual	herb	upland
Cruciferae				
Cardaria draba	white top	perennial	herb	riparian
Chorispora tenella	blue mustard	annual	herb	upland
Descurainia sophia	flixweed tansymustard	annual/biennial	herb	upland
Lepidium perfoliatum	yellow pepperweed	annual	herb	upland
Sisymbrium altissimum	tumblemustard	annual	herb	upland
Dipsacaceae				
Dipsacus sylvestris	teasel	biennial	herb	riparian
Euphorbiaceae				
Euphorbia esula	leafy spurge	perennial	herb	upland
Geraniaceae				
Erodium cicutarium	redstem storksbill	annual	herb	upland
Graminae				
Agropyron cristatum	crested wheatgrass	perennial	bunchgrass	upland
Bromus tectorum	cheatgrass	annual	grass	upland
Hordeum leporinum	hare barley	annual	grass	upland
Poa bulbosa	bulbous bluegrass	perennial	bunchgrass	upland
Secale cereale	cereal rye	annual	grass	upland
Taeniatherum caput-medusae	medusahead	annual	grass	upland
Vulpia myuros	rat-tail fescue	annual	grass	upland
Ranunculaceae				
Ranunculus testiculatus	hornseed buttercup	annual	herb	upland
Scrophulariaceae				
Linaria dalmatica	Dalmation toadflax	perennial	herb	upland

Define restoration purpose and strategy

The best strategy for restoring shrub-steppe ecosystems depends on the main functional objective. For example, a goal for restoration is often to reduce the risk of fire, primarily related to cheatgrass (Whisenant 1990). Returning shrub-steppe to a perennial based native plant community can break the cheatgrass-fire cycle. One strategy for reducing the fire risk is to establish strategically placed green strips can slow or stop the spread of a wildfire (Pellant 1990).. Green strips are about 9 meters wide can be restored along roads, where fires often originate. The vegetation planted in a green strip needs to be fire resistant and capable of surviving occasional burning. Bunchgrasses will serve this purpose very well. Forage kochia (*Kochia prostrata*), while not native, also functions well in green strips and can help reduce the risk of fire to nearby native plant communities (Pellant 1990).

Describe the restoration site

The topography and soils of a restoration site can strongly influence plant communities. For example, north facing slopes at the Hanford site are dominated by bluebunch and Sandberg's bluegrass while south facing slopes are dominated by cheatgrass (Sauer and Rickard 1979). Elevation, aspect, and slope should be determined so that weed control and native species composition for restoration can be adjusted accordingly.

Soils can have a strong effect on the success of new plantings. Soils in the shrub-steppe range in texture size from lithosols, gravels, sand, silt, to clay, with each supporting a different flora. Some plants are found on all substrates while others are restricted to only one type. For example, veiny dock (*Rumex venosus*) only grows in sand while cheatgrass seems to grow on most soils. Soil types can be coarsely recognized in the field or can be taken to a soil testing laboratory to define texture (Munshower 1994). Soil information can be found at http://soils.usda.gov/.

It is important to determine the bulk density of the soil. Bulk density can be determined by weighing a known volume of dry soil. Compacted soils lose macropores and become less permeable to water (Munshower 1994). Plants have a harder time establishing in such conditions.

Soil pH should be measured when the original plant community can not be determined, since it can have a strong effect on nutrient availability and species composition. Soil pH near the surface is slightly acidic at the Hanford Site (Link et al. 2000). Basic or alkaline soils favor halophytic species (*Atriplex, Sarcobatus, Grayia, Distichlis*).

Organic matter tends to be low in shrub-steppe soils, and very low in subsoils. Organic matter effects water and nutrient availability and can be determined using a muffle furnace or sent to a chemical testing laboratory.

Plant Selection

Creating an appropriate plant list for site restoration is best done by using surveys of nearby undisturbed ecosystems with similar soils and climatic conditions as reference ecosystems. A survey of flora that is on the restoration site of course also needs to be done, including both native and non-native. Floristic surveys should be done frequently over the course of a year.

The seed bank should be also analyzed. Past seed bank studies in the shrub-steppe can be referred to for methodology (Boudell et al. 2002; Hassan and West 1986; Young and Evans 1975). This can take a long time, and can slow projects down, experience shows that seed banks exist in most disturbed areas and may contain desirable species.

Obtain biological materials

There are many suppliers of shrub-steppe seed and plants. Some suppliers are listed in Table 11.3, and can be contacted on the web. The native seed network (http://www.nativeseednetwork.org) connects buyers with sellers. Information about current availability of plants can be found by searching for the scientific and/or common names of the plants of interest. Current and older names are found at the USDA NRCS (2003) plants webpage (http://plants.usda.gov).

Table 11.3. Suppliers of shrub-steppe plants.

Supplier	WEB address
Plants of the Wild	http://www.plantsofthewild.com
Methow Natives	http://www.methow.com
Raineer Seed	http://www.rainierseeds.com
Bitterroot Restoration	http://www.revegetation.com
Fouth Corner Nurseries	http://fourth-corner-nurseries.com
Wildlands Nursery	http://wildlands-inc.com

Seeds and seedlings

Today, there are many seed farms producing native shrub-steppe plants for restoration purposes. Many producers will grow plants for seed production (increase) from the local seed source under contract. This requires that seed is collected from areas very near the restoration site. Seed collection and processing techniques for many shrub-steppe species can be found in Young and Young (1986).

It is likely that using seed from plants of the local area will improve restoration success. Linhart (1995) suggests collecting seeds for herbaceous species no further than 100 meters, and woody species no further than 1 kilometer from the site. Genetic similarity will be narrower in self-pollinated than cross-pollinated species (Jones and Johnson 1998). It should be remembered that most commercial sagebrush seed is harvested from less than the full variation of genetic potential, since seeds are repeatedly harvested from favorable sites and varieties (Monsen 2002). Most sagebrush seed ripens in the winter and can be collected over a one-month window (Monsen 2002)

Species will exhibit genetic variation associated with varying climatic conditions. For example, bluegrass species from high elevations can grow faster at low temperatures than those from low elevations (Körner and Woodward 1987). Such differences can accumulate and cause an ecotype to fail if planted in climate conditions significantly different from that of its parent plants. Sandberg's bluegrass plants transplanted 533 meters higher than their original range grew poorly after five years, suggesting that low elevation ecotypes will not survive in colder conditions (Link et al. 2003b). Species can show significant genetic differences within short distances associated with steep environmental gradients.

When a species is rare, there are advantages to propagating from hand-collected seed. The likelihood of success increases if the plant has had an opportunity to grow to a seedling stage before planting. Some perennial species simply do not germinate and establish well in the field uless conditions are optimal. Spiny hopsage (*Grayia spinosa)* seedlings are rarely observed in eastern Oregon and southern Idaho, requiring very wet years and lack of competition to become established (Shaw and Haferkamp 1990).

When it is not possible to collect local seed, it can often be purchased from commercial providers (Table 11.3). It is important that the source of the seed is known, and that the species occurs or once did occur in the restoration area. The closer the seed source to the site the better. When purchasing such seed it is important to recognize that many chromosome races or varieties exist within a species. Restoration success is more likely if the proper variety is chosen. There are many shrub-steppe species with recognized varieties including bluebunch wheatgrass, giant wildrye, green rabbitbrush, and big sagebrush (Jones and Johnson 1998).

Raising and planting seedlings is more expensive than direct seeding, but can be more successful. Seedlings are recommended if the species is rare or few seeds are available. They can be used as; bareroot stock, container grown, or salvaged plants. Shrubs such as big sagebrush and gray rabbitbrush (Link et al. 1995), plus bitterbrush are commonly planted as seedlings or tublings (Munshower 1994)..

Small salvaged plants can be transplanted more successfully than larger older plants. In special construction circumstances it possible to remove the topsoil and biological material before construction and then place the material on disturbed areas when construction is finished.

Mycorrhizae

Endomycorrhizae are common in semi-arid undisturbed ecosystems, though there are few mycorrhizal plants found in severely disturbed soils (Reeves et al. 1979). Absence of mycorhizae severely reduces the establishment of many species (Allen and Allen 1988; Allen 1991). Gray rabbitbrush (*Ericameria nauseosa)* inoculated with endomycorrhizae had better growth and survivorship than those without after planting on coal mine spoils (Moorman and Reeves 1979). Allen and Allen (1988) found that mycorrhizae can regulate succession by improving competitive ability.

Site preparation

Geomorphic stability

The stability of planting surfaces needs to be considered before restoration is started. Many soils, especially sands are subject to wind erosion, particularly after fires. It is necessary to stabilize the surface before planting. Blowing sands can remove seeds and scour seedlings until they are blown out of the soil. Seed usually is applied before or with mulch. Mulches can be blown away also and can be stabilized by crimping and tackifiers (Munshower 1994). Crimping uses a disk, wheel, or punch to push part of straw mulch into the soil. This allows part of the straw to stand up which behaves like stubble to reduce wind speed at the surface and thus, erosion (Munshower 1994). Hydromulching combines water, mulch, often seed, and a glue-like binding agent to bind the material to the soil surface. Erosion control blankets or mats are a type of mulch used to control erosion on slopes. Seed can be incorporated into the mat or placed under the mat. Mats are usually pinned to the surface with large staples to keep them from blowing away (Munshower 1994).

Blowing sand can also bury plants. In areas that are vulnerable to deposition, snow fences can be used to reduce sand accumulation. Seeds of plants that can germinate from deep depths, such as Indian ricegrass (*A. hymenoides)* and needle and thread grass (*H. comata)* are more likely to survive deposition. Rhizomatous plants can also sometimes escape accumulating sands by growing away from them.

Soil ripping and gouging

Soils at some restoration sites are heavily compacted. Where this is the case, they can be ripped to reduce bulk density, thus improving long-term success of restoration projects (Montalvo et al. 2002). A variety of soil preparation tools and techniques are described in Munshower (1994). In the semi-arid shrub-steppe, soils can be prepared to concentrate water in local areas, which will aid in plant establishment. Gouged depressions (10-20 cm deep, 25-40 cm wide, up to 90 cm long) have been used in mine land restoration with success because they reduce runoff and concentrate water in the gouge. Seed is usually then broadcast in the roughened terrain.

Fertilizer

Fertilizer amendment of shrub-steppe soils usually results in promoting weedy annual growth, but has little beneficial effect on seeded perennials. Nitrogen and phosphorus fertilizer should only be used where soils have very low organic content such as subsoils, mine spoils, or moving sands. If soil organic matter exceeds 2% nitrogen should not be added (Munshower 1994). When low nitrogen organic amendments such as straw are added to a low organic soil, nitrogen needs to be added so that the ratio of carbon to nitrogen is kept between 12:1 and 20:1 (Munshower 1994).

Irrigation

Irrigation is an expensive addition to any restoration project and should be avoided if possible. It is always better to plant when water is available to give new plantings the best opportunity to establish. Generally, the best time to plant is in the fall after rains have begun and after enough rain has fallen to maintain new seedlings through a potentially dry winter. When planting is scheduled to take advantage of seasonal rains plants can establish roots and survive the following summer.

Seeding is also best done in fall to winter to mimic the natural history of shrub-steppe plants. For example, sagebrush species drop seed in the winter, and are often protected by snow cover. Most other shrub-steppe species drop their seed in the spring through the fall. Seeding in spring is less likely to be successful without supplemental water.

Water can be added using agricultural techniques such as sprinklers or drip irrigation. Water can also be added by placing a tube near the base of planted seedlings, then watering through the tube. This technique keeps water away form weeds near the surface. A condensation trap can be created around a seedling to direct evaporated water to the seedling. Organic polymer gels have also been used to provide water to seedlings, but they can dehydrate a seedling in very dry soils (Munshower 1994).

Weed management

Disturbed ground often has a strong component of invasive weeds. The shrub-steppe unfortunately has many invasive alien species to consider and control. There are many reviews and books on the topic of steppe weeds and weed control (DiTomaso 2000; Gaines and Swan 1972; Sheley and Petroff 1999; Taylor 1990; Whitson et al. 1992; Zimdahl 1999).

Strategies to control weeds, covered in more detail in Chapter XX, including hand pulling, hoeing, mowing, fire, mulching, competition, fertility management, biological, and chemical (Zimdahl 1999). The usefulness of a particular strategy depends primarily on the size of the area. Hand pulling and hoeing annuals can work in small areas, but over large areas, biological or chemical control may be the only cost effective strategy.

Extremely hot wildfires can reduce cover of cheatgrass by destroying most of the seed bank, but the benefits are often transient. Prescribed fires often are cooler than a mid-summer wildfire and are not very effective in reducing the seedbank of cheatgrass. But prescribed fire has been used to remove vegetation and litter as a first step to make herbicide application more efficient and spatially consistent. Link et al. (2003a) found there that prescribed fire applied in the fall had no effect on cheatgrass.

Mulching has been used to reduce weed competition in steppe riparian zones (Link and Bower 2004). It also retains water, especially helpful in the semi-arid shrub-steppe. Wide mulch resulted in higher survivorship of Ponderosa pine (*Pinus ponderosa*) and snowberry (*Symphocarpus alba)* than narrow mulch in riparian restoration efforts along the Touchet River in eastern Washington (Link and Bower 2004).

Glyphosate (Roundup) and imazapic (Plateau) are herbicides commonly used to control invasive species to prepare a site for restoration. Glyphosate is a broad spectrum, non- selective contact herbicide. At high enough concentration, it will kill anything that is actively growing. It should be applied with surfactant and fertilizer to increase growth and effectiveness. Its half-life ranges from 32-40 days. Imazapic is used as a pre-emergent and post-emergent herbicide. It needs soil contact to act as a pre-emergent, and can be active for up to a few years. After fire, the suggested application rate is 2 to 6 ounces per acre depending on expected precipitation. Application should be made in the fall before emergence. Application in the spring is not advised.

Serious Weeds of the Shrub-Steppe

Diffuse knapweed *(Centaurea diffusa)* and Spotted knapweed *(Centaurea maculosa)*

Diffuse knapweed is an annual that is found throughout the shrub-steppe. Control can be done by hand pulling plants if enough of the taproot is extracted to prevent regeneration (Roche and Roche 1999). Pulling needs to be repeated for a few years, and thus is only possible in small areas.

The herbicides picloram, clopyralid, and 2,4-D are effective ways to control knapweed, if applied when the plant is at the rosette stage (Roche and Roche 1999). Sheep grazing when the knapweed is green, but everything else brown is also effective.

Establishing competitive bunchgrasses can reduce diffuse knapweed, and is likely the best strategy for long-term control. An integrated approach that includes herbicide, grazing, and seeding of bunchgrasses can be very effective. There is also some hope for eventual biological control (Roche and Roche 1999).

Spotted knapweed also occurs throughout the shrub-steppe, but is more common where annual precipitation is above 200 mm. Control techniques are similar to those for diffuse knapweed (Sheley et al. 1999b).

Yellow starthistle *(Centaurea solstitialis)*

Yellow starthistle is an annual weed common in the western half of the shrub-steppe. It can be a dominant weed where precipitation is greater than 12 inches. Starthistle can be controlled using picloram, clopyralid, dicamba, glyphosate, and 2,4-D herbicides. It can be hand pulled in small areas. Grazing can provide control, but it has to be done before spines form around the flowerhead. It can also be controlled by planting competitive grasses (Sheley et al. 1999c).

Russian knapweed *(Centaurea repens)*

Russian knapweed is a perennial, thus control strategies differ from those for the other three knapweeds discussed above. It occurs only where it can get roots down to ground water, and is commonly found near wetlands. It grows by underground creeping roots that form clonal monocultures. Roots can be up to 7 meters deep!

Russian knapweed is difficult to control, although Whitson (1999) found that application of clopyralid plus 2,4-D three times, followed by seeding with Sodar wheatgrass resulted in suppression. There is hope that an integrated pest management approach using biological control and competitive grasses may provide a solution.

Rush skeletonweed *(Chondrilla juncea)*

Rush skeletonweed is a perennial found in the western half of the shrub-steppe. This plant has roots at least 2.4 meters deep, and can spread from underground runners.

Controlling skeleton weed is difficult, though an integrated weed management program can reduce populations. Effective strategies include competitive plantings, sheep grazing, biological control agents, and herbicides (picloram, 2,4-D, clopyrilid, dicamba) (Sheley et al. 1999a).

Tumblemustard *(Sisymbrium altissimum)*

Tumblemustard is susceptible to broadleaf herbicides including 2,4-D, MCPA, bromoxynil, atrazine, and chlorsulfon (Adams and Swan 1988; Eckert 1974; Kidder et al. 1988; Swensen et al. 1986). Phenoxy herbicides such as 2,4-D and MCPA provide the best control (90-99%) (Adams and Swan 1988; Kidder et al. 1988; Swensen et al. 1986).

Cheatgrass *(Bromus tectorum)*

Cheatgrass is an annual grass native to Eurasia. It has spread throughout the shrub-steppe and is considered to be the biological driver of the much increased fire frequency in the area (Whisenant 1990). It becomes more competitive with increasing aridity (Mosley et al. 1999). Cheatgrass control is only effective when combined with treatments that establish perennial species (Harris and Goebel 1976; Klemmedson and Smith 1964; Mosley et al. 1999). In areas where there already is a significant component of perennials present, chemicals can control cheatgrass if applied from two to five years consecutively (Mosley et al. 1999). Paraquat and glyphosate can be applied in the spring after the plants have reached the 2 to 3 leaf stage and until seedheads begin to emerge. Application rates should be just enough to kill cheatgrass (6.4 oz active ingredient/acre), yet not damage the perennials, which are killed at application rates of 9.6 oz active ingredient/acre (Mosley et al. 1999).

Two years of prescribed grazing in the spring can significantly reduce cheatgrass cover (Mosley et al. 1999). In heavily infested areas, prescribed fire in the fall, grazing and/or herbicide application in the spring, followed by seed application with a drill or broadcasting combined with animal trampling can control cheatgrass (Link et al. 2003a; Mosley et al. 1999). Seeding can also be delayed to the following fall or spring in a chemical fallow approach (Mosley et al. 1999).

Pre-emergent and early post-emergent herbicides (sulfometuron, Plateau) also can control cheatgrass. Sulfometuron can be applied in the fall or spring with perennials seeded one year later, but it can damage Sandberg's bluegrass (Mosley et al. 1999). Plateau can also be applied in the fall with perennials seeded in the spring. One year after applying Plateau at 8 oz/acre after a prescribe fire, Link et al. (2003a) did not observe damage to Sandberg's bluegrass.

In high precipitation parts of the shrub-steppe, it is possible to establish competitive bunchgrasses without using herbicides. After rototilling a cheatgrass infested field to a depth of 8 cm in August, wildrye was seeded the following May. After three years, cheatgrass had been reduced by 85% (Whitson and Koch 1998). In drier areas (Daubenmire 1975) noted that sand dropseed can maintain itself in areas with dense cheatgrass cover and that seedlings are more successful than those of bluebunch wheatgrass. It may be possible to broadcast dropseed into cheatgrass fields without first using herbicides. Squirreltail *(Elymus elymoides)* has also been noted to be competitive with cheatgrass.

Medusahead *(Taeniatherum caput-medusae)*

Medusahead is an annual grass native to Eurasia, now found in the western half of the shrub-steppe in areas or relatively high precipitation. Control is similar to that for cheatgrass except that grazing is not practical due to poor forage quality (Miller et al. 1999).

Planting seeds

Appropriate seeding rates are very important to restoration success. Too light will not produce an adequate density to compete with weeds, while too much can cause the desired species to compete with themselves and can lead to failure. The seed rate is the number of seeds placed in a unit area of soil. It seed rate can be expressed as the number or mass of seeds per acre or hectare. Confusion reigns when seeding rates are described for species mixtures based on mass because seed size varies widely. The number of seeds per unit mass can be obtained by searching the literature or by asking the seed provider. An estimate can be made by counting and weighing 30 seeds randomly selected from clean seed. It is important that the amount of seed be purchased based on the percent pure live seed. Pure live seed labeling is regulated by a state seed-certifying agency.

A seed rate of 20 pure live seeds per square foot is considered the minimum on drill-seeded applications, aiming for a fifty percent germination success. The seed rate can be increased or decreased depending on competition and other environmental stresses. Less seed may be applied to a north facing slope due to less water stress than on a south facing slope.

Each species will have differing requirements for successful germination (Young and Young 1986). Generally, small seeds should be placed near the soil surface while larger seeds can be buried more deeply (Montalvo et al. 2002). This is not a firm rule, as the small seeds of Sandberg's bluegrass can be placed to a depth of 25 mm (Evans et al. 1977) while the larger seeds of bluebunch wheatgrass are optimally planted at a depth of 6 mm (Plummer 1943) (McLendon 1997). Some seeds need exposure to light. Seeding strategies thus depend on the species-specific requirements.

Big sagebrush seed planted in the fall will germinate from mid-winter to early spring, and does best with a protective snow cover (Monsen 2002). Controlling annual and perennial weed competition is required for establishment (Monsen 2002).

Drill seeding is successful in rangelands where there are no tall plants, the land is relatively flat, and there are few rocks. The seeder has a box to hold the seed and commonly has 10 disks that open a furrow into which seed is dropped. The furrow is then closed with another wheel or a chain. This technique works best for large seed such as wheatgrasses and legumes (Munshower 1994). A carrier such as rice hulls can be used to keep small and large seeds well mixed.

Broadcast seeding can use any technique that disperses seed onto the surface. Aerial seeding is a broadcast technique used on rough ground. Broadcasting works better than drilling for very small seeds. Often a chain and cultipacker is used to cover the seed with soil

(Munshower 1994). Aerial seeding of sagebrush in late fall and mid-winter after a wildfire is successful after chaining the area to cover the seed. Without chaining, aerial seeding is only about 10% effective (Monsen 2002).

Hydroseeding is a form of broadcasting where seed is dispersed in a water-based mixture of mulch, tackifier, and fertilizer. This technique works best with small seeds (Montalvo et al. 2002). Often the soil-seed contact is better when dispersed without the mulch and tackifier,. which can be applied after the seed is dispersed (Munshower 1994). Hydroseeding is used on steep slopes or where common agricultural equipment cannot be used (Roberts and Bradshaw 1985). On sand slopes, the use of long-fibered flexible materials for mulch enhance establishment (Roberts and Bradshaw 1985).

A compression or compact type seeder is advised for sagebrush (Monsen 2002). A special sagebrush seeder has been successful in arid, southern Idaho (Boltz 1994). Sagebrush seed should be planted no deeper than 6 mm below the soil surface and should be seeded at rates between 0.11 and 0.22 kg ha^{-1} (Monsen 2002). The Dixon imprinter creates an depression in the soil in which dropped seeds can germinate in relatively safe microsites (Montalvo et al. 2002).

Planting seedlings and plant parts

Seedlings should be planted immediately after acquisition, and should never be allowed to sit in the sun. Seedlings can be stored in a 32 to 35° F cooler for several weeks, but should be examined every week to see if fungal growth exists on the stems or if the plants have broken dormancy.

Competition can be reduced by planting into weed cloth, scalping the surface, or using herbicide to kill nearby weeds. When digging a hole it is important not to compact the soil around the edge of the hole. This can restrict root growth beyond the hole. A fertilizer tablet can be placed in the hole and about 2 inches from roots. Make sure the seedling is upright and that the soil is firmly packed, but not compacted around the seedling. The rooting media should be covered by about 1/2 inch of soil.

Rhizomes can be used to establish species such as lanceleaf scurf pea in sandy areas. Rhizomes need to have at least one lateral bud, should be planted in the fall just before winter rains begin, and placed at least 2.5 cm deep (McLendon and Redente 1997).

Herbivore protection

Protection against herbivory is important in the first few years after planting (McLendon and Redente 1997). Grazing needs to be eliminated or controlled to allow establishment of seedlings and cuttings in riparian areas. *Salix lasiandra* and *S. exigua* were able to establish after four years where cattle grazing was controlled in one eastern Oregon site (Shaw 1992). There are a variety of herbivore protection screens and tubes to protect shrub and tree seedlings.

Monitoring

Monitoring can determine if a restoration has met objectives for species richness, species density, species frequency, and cover. Richness is the number of species in a specified area, usually measured in sample quadrats. An adequate sample size is determined using a species-area curve. The Modified-Whittaker plot technique captures a better sample than does transect techniques (Stohlgren et al. 1998). Density is the number of individual plants of a particular species in a known area. Some plants are clonal and spread below the surface with many shoots appearing above ground. Counting shoots of such plants give a shoot, but not plant density. Frequency is the percentage of plots where a species occurs. Species frequency gives an assessment of how common and widespread a species is within restoration area. Percent cover is the amount of ground covered by plants. Percent cover gives a measure of the importance or significance of a species in a community. Cover is estimated using line transects, point intercepts (Bonham 1989), and quadrats. Total foliar and soil cover can be estimated using the Modified-Whittaker plot technique and the Parker, large quadrat, and Daubenmire transect approaches (Stohlgren et al. 1998).

Case studies: Prototype barrier

Earthen barriers are being developed to prevent water from entering nuclear wastes at the Hanford Site in south-central Washington (Ward et al. 1997). Water draining through these wastes can enter the groundwater or surface water systems. One test barrier was established in 1994, with plants installed to minimize erosion and maximize loss of water from the surface soils (Link et al. 1998).

The upper surface of the barrier is constructed with 2 meters of fine soils over coarser material. Soils in the upper layers are silt loams (Gee 1987; Hajek 1966). These soils were excavated from below the surface to minimize the invasive alien seed bank. The upper test area of the barrier is about 0.67 acres (Link et al. 1995).

The prototype barrier surface and surrounding disturbed areas were planted in the fall of 1994. Restoration work was done separately for the establishment of perennial shrubs and the establishment of perennial grasses.

The barrier surface and surrounding disturbed area was planted in the fall of 1994. Restoration work was done separately for establishment of perennial shrubs and perennial grasses. Restoration with perennial shrubs was accomplished by collecting seeds, growing seedlings in a nursery, and then transplanting them to site. Seeds of big sagebrush and gray rabbitbrush were collected from local populations in December 1993. The entire inflorescence of sagebrush and the fruits of rabbitbrush were harvested and stored in plastic bags in the field. This material was transported to a laboratory and dried. It was stored in the dark at room temperature until shipped to a nursery. The seed was cleaned later that Spring, and sown in early May. Seedlings were grown in tubes (Gee et al. 1994). On November 7, planting was initiated and completed by the next day. Twenty-seven hundred holes were drilled, and two seedlings placed in each hole. All together 1350 rabbitbrush and 4050 sagebrush were planted.

Perennial grasses were hydroseeded onto the barrier surface and surrounding slopes. The mix included seeds, fertilizer, mulch, and a tacking agent. The seed mixture included Sandberg's bluegrass (34 kg ha^{-1}), streambank wheatgrass (5.6 kg ha^{-1}), Indian rice grass (22 kg ha^{-1}), Sherman big bluegrass (*Poa ampla)* (11 kg ha^{-1}), needle-and-thread grass *(H. comata)* (5.6 kg ha^{-1}), bluebunch wheatgrass (14 kg ha^{-1}), and squirreltail (3.4 kg ha^{-1}). Most of the perennial grasses originated from off-site sources. Fertilizer was applied as 67 kg ha^{-1} (60 lb $acre^{-1}$) of total nitrogen, 67 kg ha^{-1} of available phosphoric acid (P_2O_5), and 67 kg ha^{-1} of soluble potash (K_2O) in solution. Mulch was applied as 2,240 kg ha^{-1} of Eco-Fibre 100% virgin wood fiber. Degradable glue was added to the mulch as a tackifier at 67 kg ha^{-1}. Hydroseeding was done in early November in a slurry form. The material was mixed with water using power augers in a large tank on a truck, then dispersed under pressure from large hoses onto the ground.

In the first season after planting Russian thistle covered nearly 100% of the surface. But it was nearly eliminated once the native perennials became dominant. The number of annuals has varied from 12 to 16 while the number of perennials has increased from 11 in 1995 to 19 by 1997. In 1995, 55% of the species were annuals. In contrast, only 46% of the species were annuals in 1997.

After three years about 98% of the sagebrush shrubs had survived, but only 39% of the rabbitbrush did so. A significant number of new sagebrush seedlings became established in the third year. Sandberg's bluegrass was the most successful grass while squirreltail did not establish. Plants on the surface have been successful at eliminating wind and water erosion, and appear to have prevented water from accumulating in the soil (Ward et al. 1997).

Case Study: Management of fuel loading in the shrub-steppe

The widespread presence of cheatgrass has caused unnatural and severe fires to threaten much of the sagebrush steppe ecosystem. A project funded by the Joint Fire Science Program from 2002 to 2005 was initiated to develop strategies for returning steppe lands in the Columbia Basin and in the Intermountain West to a highly diverse assemblage of native species that bring fire risk back to natural levels.

Objectives include 1) finding a minimum concentration of herbicides that will shift the competitive balance to native species and away from cheatgrass 2) determine the effect of prescribed burns on the competitive balance, and 3) determine the effect of seeding native bunchgrasses on the competitive balance. The intent is also to determine a fuel management method that least impacts native species, and is least cost.

The establishment of the wheatgrass was believed to be the best likely solution for long-term reduction of cheatgrass and thus, reduction of fire risk. Wheatgrasses are competitive where soils and precipitation are advantageous. In areas near the study site that were seeded with bluebunch wheatgrass 17 years ago, there is relatively little cheatgrass present.

Experiments were initiated in 2002. Ninety split plots were established to test the effects of two herbicides, with five concentrations of each, followed by drill seeding of two bunchgrasses. Percent cover of each species, litter, soil, and soil cryptogams were measured in each plot. Plots were first burned, and the herbicide, Plateau, was applied in fall 2002. Snake River wheatgrass *(Elymus wawawaiensis*) and Sherman big bluegrass were seeded the following February, and Roundup was applied in March. The prescribed fire had no effect on cheatgrass cover, and significantly increased the cover of tumblemustard.

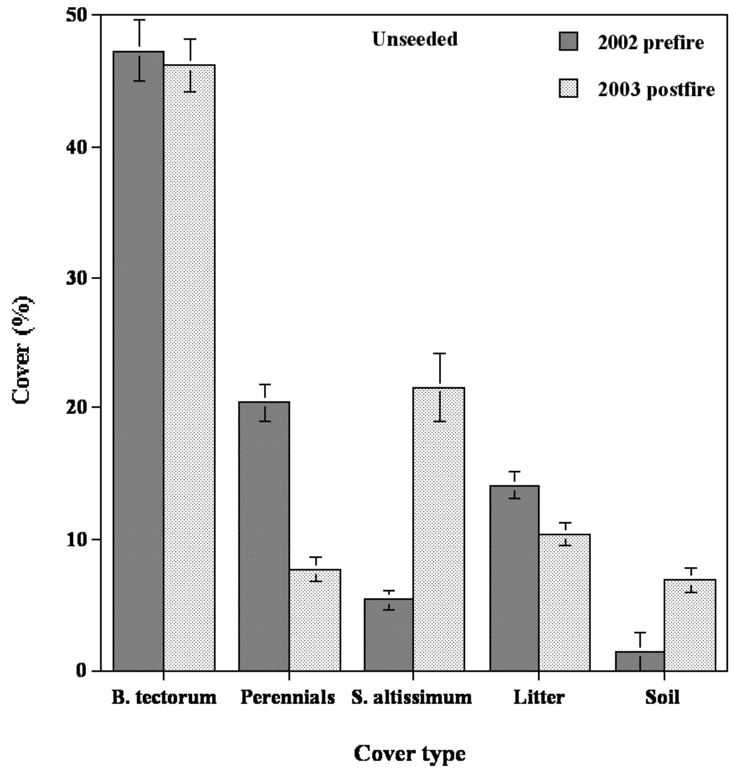

Fig. 11.2. Effect of prescribed fire on cover elements at the Columbia National Wildlife Refuge. Error bars are one standard error of the mean (n = 9).

Plateau, applied at 1 oz/acre, did not reduce cheatgrass cover, but nearly eliminated tumblemustard (Fig. 11.3).

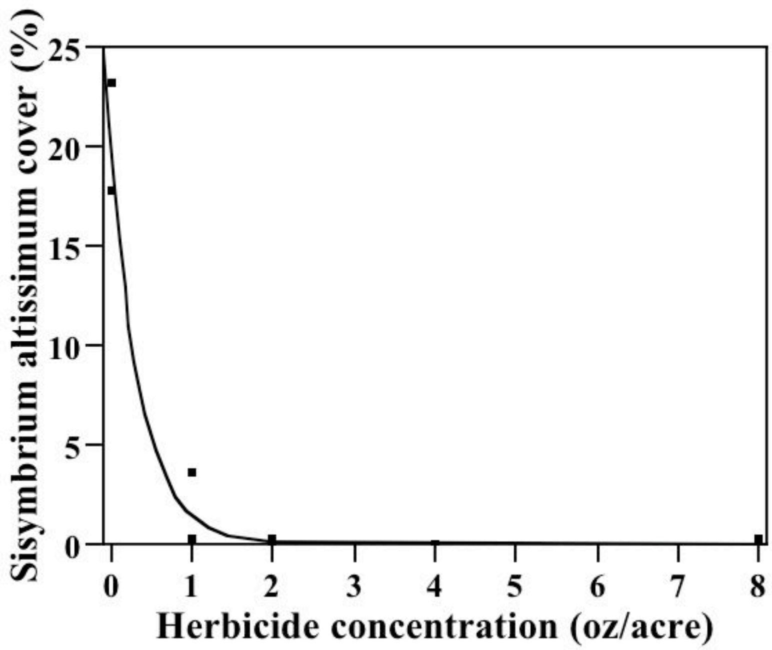

Fig. 11.3. Relationship between Plateau herbicide concentration and tumble-mustard cover.

This may have contributed to better establishment of the wheatgrass compared to Roundup applied at the same rate (Fig. 11.4).

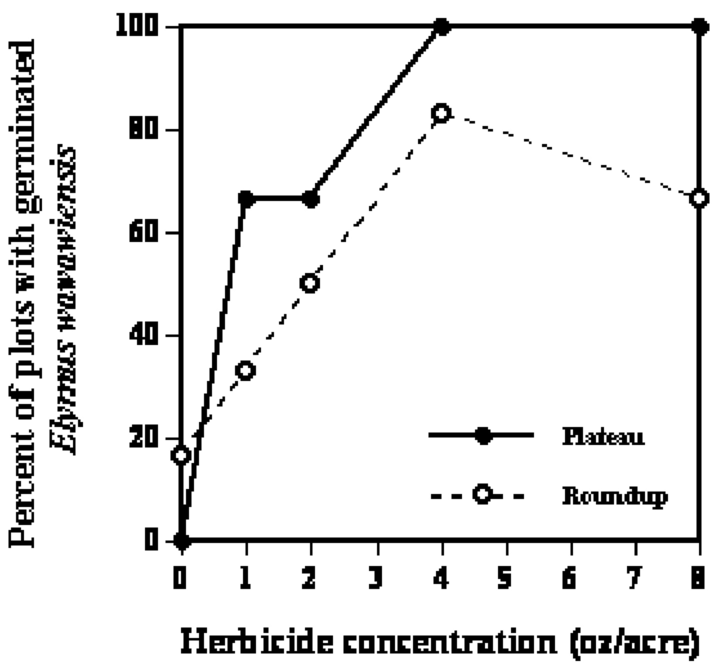

Fig. 11.4. Percent of plots with Snake River wheatgrass as a function of herbicide and herbicide concentration (Plateau n = 3, Roundup n = 6).

Cheatgrass cover was reduced at the highest rate of Plateau, and with increasing rates of Roundup. After fire, tumblemustard control may be more important than cheatgrass control for establishment of Snake River wheatgrass. Based on one year's results, Plateau may be better than Roundup for establishment of Snake River wheatgrass.

Case Study: Restoration of Upland Habitats at Columbia National Wildlife Refuge

Over the last 20 years, several attempts were made to restore native perennial vegetation to disturbed dry upland sites at Columbia National Wildlife Refuge. The highest priority for restoration were areas burned by wildfire or otherwise disturbed that had little or no shrubs remaining. A perennial grass was introduced, with selective herbicides to control broadleaf weedy invaders before herbaceous and shrub species were seeded or allowed to replenish naturally. Cheatgrass was suppressed using herbicides. Two restoration projects that may improve dry upland restoration techniques will be profiled.

The first area was a grassland that had been farmed and irrigated as recently as the 1970's. This 40-acre field was dominated by cheatgrass, but also had sparse crested wheatgrass *(A. cristatum)*, evidence of a conversion from agriculture to perennial grass. The restoration plan included using a glyphosate spray in mid-November 1996 followed by dormant season seeding bluebunch wheatgrass, streambank wheatgrass, giant wildrye *(L. cinereus)*, and Sandberg's bluegrass. The field was sprayed with 8 oz of Roundup acre^{-1} with surfactant and ammonium sulphate. Most of the field was sprayed in mid-November, but snowfall (which persisted until late February) prevented treatment of the last five acres until late winter. When the snow melted, it was noted that the single day of glyphosate contact before snowfall was enough to kill the cheatgrass that had germinated. The area was drill-seeded in early March, then sprayed with a low rate of glyphosate a week later after extensive germination of cheatgrass, but before any drilled seed had emerged. High winter moisture and late cheatgrass control provided excellent establishment. Additional cheatgrass and tumblemustard germinated after the last glyphosate treatment, but favorable soil moisture conditions were sufficient for establishment.

The second area (about 200 acres) had burned in a wildfire in mid-July 1997, and had also burned more than 15 years earlier. This area was dominated by cheatgrass, with scattered patches of Sandberg's bluegrass and bluebunch wheatgrass and little shrub cover. The restoration plan included a late fall glyphosate treatment followed by dormant season drill seeding of Idaho fescue (*F. idahoensis)*, bluebunch wheatgrass, and Sherman big bluegrass. Sherman big bluegrass is larger than native Sandberg's bluegrass, but with presumed native populations within 25 miles of the site. Additionally, giant wildrye was broadcast seeded on lower areas with deeper soils before drill seeding. Drill seeding was done the same the week using 4lb. Sherman big bluegrass, 2lb. bluebunch wheatgrass, and 1lb. Idaho fescue per acre. Roundup was sprayed from a fixed-wing aircraft in November. Another wildfire area was treated in a similar manner, but instead of drill seeding the grass seed was applied by aircraft at a 50% higher rate. This area had about 25 of 300 acres harrowed after seeding to improve soil contact, but a majority of the area was too rocky for equipment.

Results were dramatically different between the sites. Aerial seeding had very poor germination, while drill seeding got excellent results. By summer, it appeared that all of the new seedlings had died due to extreme heat and dry conditions. In 2002, it was noted that much of the grass, especially big bluegrass, had in fact survived and was doing well although cheatgrass continued to compete.

Since those projects in 1996-1997, there have been other experimental treatments at the Refuge to determine timing and rate using both glyphosate and imazapic (Plateau). Both products are effective in controlling cheatgrass, but timing is very important for level of control and to minimize impacts to native species. Both are most effective when litter is reduced following tillage, heavy grazing, wildfire, or prescribed burning.

As with the first example, multiple glyphosate applications can be successful, but application after seeded grasses have emerged will be counter-productive. Four to nine oz acre^{-1} applied from November to late March suppressed cheatgrass, but the higher rates and later applications had increasing impact on Sandberg's bluegrass, which greens up following fall rains or after snow melt. Nine ounces applied in late March browned out and weakened the bluegrass, but did not kill it. An 8 oz rate applied in mid-May caused noticeable injury to established bunchgrasses and was not effective in controlling cheatgrass.

Imazapic is a very effective contact herbicide when used with a surfactant. Its greatest value is when it is applied as a pre-emergent. Several native perennial grasses are tolerant up to 8-12 oz acre^{-1} if applied during dormancy, but new seedlings are more susceptible as the application period approaches germination. Imazapic controls cheatgrass and several weedy mustards. The 1996-97 restoration may have been more successful if imazapic was used instead of glyphosate. Unfortunately, snow cover precluded treatment.

The combination of imazapic with glyphosate appears to produce a synergistic effect, but one that needs further investigation. During the winter of 2002-2003 cheatgrass was treated by ground application (6 oz acre^{-1} glyphosate) in late-December and by helicopter application in mid-February (4 oz acre^{-1} imazapic, 5 oz acre^{-1} glyphosate, 3 oz acre^{-1} imazapic with 5 oz acre^{-1} glyphosate). The December application showed no injury to Sandberg's bluegrass but all of the February treatments produced some browning, with the combination showing the most injury. The stage of bluegrass was likely the reason as December had top growth, but was not growing rapidly while during February growth was faster with warmer weather. When early spring application is the only alternative, greatly reduced rates may still suppress competitive weeds enough to allow seeded bunchgrasses to establish.

Case Study: Canoe Ridge

An inadvertent road clearing project on Canoe Ridge in Benton County, Washington near the Columbia River, caused disturbance on land managed by the BLM. As mitigation, the disturbed area was to be restored to a condition similar to that of nearby undisturbed areas. Restoration efforts included assessment of an undisturbed reference area to arrive at restoration goals, planting, vegetation management, and monitoring the plant populations.

The BLM property is within a big sagebrush-needle-and-thread grass habitat type. Soils are a sandy loam and are weakly acidic in the upper 10 cm of the soil profile (Daubenmire 1970). The habitat type is dominated by big sagebrush, needle-and-thread grass, and Sandberg's bluegrass. Streambank wheatgrass was also common in the study area although it is not noted in Daubenmire.

The density of the major species in the reference area provided the planning goal for the restoration effort. The road clearing is 0.55 miles long. A plot size (5 m by 9.3 m) was chosen to accommodate a large number of the common plants, and to cover the width of the disturbed area. Within each of 25 randomly located plots, each large bunchgrass and shrub were counted in addition to each inflorescence of rhizomatous grasses. Burned stems of sagebrush were found in the undisturbed area, and small clusters of live sage were noted away from the study area. The density of the clusters was not determined.

The mean density of species in the undisturbed BLM property in September 1999 ranged from 3.77 plants m^{-2} for needle-and-thread grass to 0.00086 plants m^{-2} for Streambank wheatgrass. The overall density of mature bunchgrasses was over 15,000 plants per acre and the density of all shrubs over 600 plants per acre. Specific restoration goals were a survival of at least 800 shrubs and at least 7,500 native grass plants acre.

Restoration used hydromulching, drill seeding grasses, planting nursery grown shrub seedlings and transplanting plants from an adjacent area. Streambank wheatgrass, needle-and-thread grass, Indian rice grass, and Secar bluebunch wheatgrass were seeded. Big sagebrush seed was collected within two miles of the restoration site, and grown along with gray rabbitbrush to produce tublings that were later transplanted. Needle-and-thread grass was also transplanted from adjoining areas.

Maintenance activities (weed control and watering) occurred in February for two years. In February 2000 it was observed that cheatgrass was competing with the native grass plantings. Roundup was sprayed at a rate of 3 ounces $acre^{-1}$ on the area. It was believed that cheatgrass control would outweigh any loss of native species that might occur at this low application rate. The site was again visited in April to water the plants. At this time, soil moisture was about 10 cm (four inches) below the soil surface. Using previously installed watering tubes each planted shrub received approximately one quart of water. After watering, all tubes were removed and the holes filled with soil.

Monitoring was initiated in November to monitor the success of the restoration effort. Five randomly selected plots were observed for density of grasses and shrubs and two plots for survivorship of the transplanted bunchgrasses. Bunchgrass seedlings and shrubs were counted in addition to each shoot of a volunteer, thickspike wheatgrass *(A. dasytachyum)*. In two plots, live and dead transplanted bunchgrasses were counted to determine percent survival. Mean density data are expressed as the number of plants $acre^{-1}$. Individuals of big sagebrush and gray rabbitbrush were summed to compute shrub density.

The density of native grasses (live transplanted bunchgrasses + germinations from seeding + volunteers) was nearly 20,000 plants $acre^{-1}$. The density of shrubs was only 417 plants $acre^{-1}$, less than the minimum target of 800 shrubs $acre^{-1}$. As a result, more sagebrush shrubs were planted in February. A count of live and dead transplanted bunchgrasses on two sample plots yielded a mean density of 3,885 $acre^{-1}$. The density of live transplanted bunchgrasses was 304 $acre^{-1}$. The survivorship of transplanted bunchgrasses was measured at only 8.2%. Seeding bunchgrasses appears much more successful than transplanting mature bunchgrasses under the conditions of this test.

In March, the same five plots were re-examined. At this time a species list was compiled for plants in the study plots. Within each quadrat, bunchgrass seedlings, mature bunchgrasses, shrubs, and herbaceous broadleaf native plants were counted as well as each shoot of thickspike wheatgrass. The density of native grasses (live transplanted bunchgrasses + germinations from seeding + volunteers) was nearly 50,000 plants $acre^{-1}$. This density is much greater than the minimum required. It was expected that the number of surviving grasses would decline over time to a level closer to that of the undisturbed property. The density of shrubs was now 975 plants $acre^{-1,}$ which satisfied the minimum required. The density of broadleaf herbaceous native plants was over 5,000 plants $acre^{-1}$.

There were 21 native and 3 alien species identified in the undisturbed BLM property in September 1999. In March 2001 19 native species and 3 aliens were recognized on the restored road surface.

Example Budget

A well considered budget estimate can spell the difference between success and failure in restoration. Restoration is similar to agriculture and suffers from the vagaries of the weather. It is important that budgets accommodate factors beyond the control of restoration implementers. We present an example budget for restoration in the shrub-steppe for one acre. Prices are only estimates and will vary depending on local circumstances and the size of the restoration effort. Unit prices will go down with increasing area being restored.

Table 4. Estimated prices for restoration of one acre of shrub-steppe.

Task	**Unit price ($)**	**Items/acre**	**$/acre**
Planning	70/h		560
Site description	70/h		1680
Monitoring	70/h		3360
Herbicide application			
Ground	govt rate		10
Ground	private		100
Fixed wing	govt rate		7.5
Helicopter	govt rate		30
Planting			
Drill seeding	govt rate		100
Drill seeding	private		600
Broadcast	govt rate		50
Harrow	govt rate		31.25
Cultipacking	govt rate		33
Hydroseeding	private		800
Shrub seedling planting	3/plant	400	1200
Bunchgrass salvage/transplanting	1.5/plant	400	600
Materials			
Weed cloth 6' wide roll	0.04/sq.ft		1742
Roundup	25/gal		
Ammonium sulfate	1/acre		
Surfactant	1/acre		
Roundup+Ammonium+Surfactant		8 oz	3.6
Plateau	300/gal	8 oz	18.75
Herbivore protection	2/plant	400	800
Seed			

Task	Unit price ($)	Items/acre	$/acre
Elymus wawawaiensis	1/lb	5 lb. Drilled	5
Achnatherum hymenoides	10/lb	5 lb. Drilled	50
Elymus elymoides	45/lb	5 lb. Drilled	225
Hesperostipa comata	80/lb	5 lb. Drilled	400
Poa secunda	4.25/lb	5 lb. Drilled	21.25
Seedlings			
Artemisia tridentata	0.83	400	332
Grayia spinosa	4.25	100	425
Chrysothamnus viscidiflorus	8.95	50	448
Ericameria nauseosa	0.6	400	240
Sphaeralcea munroana	0.6	100	60
Purshia tridentata	1.4	200	280

Restoration challenges and research gaps

Using herbicides near water is restricted, which makes management of invasive species and establishment of native species more difficult. Strategies have to rely on integrated pest management practices with more emphasis on biological control and the use of weed cloth to promote establishment of planted seedlings. Reducing available soil nutrients can restrict growth of annual weeds allowing perennials to establish more effectively (Cione et al. 2002).

Restoration in highly disturbed soils and areas dominated by annual grasses potentially can be improved if soil microbiotic crust species can also be restored. Very little work has been done to restore soil microbiotic crusts in practice, though it is believed to be possible (Evans and Johansen 1999). A slurry of microbiotic crust was applied to burned areas with successful establishment of cyanobacteria and lichens within months (St. Clair et al. 1986). Dry microbiotic crust that has been broken up for application enhanced lichen cover and diversity in disturbed areas. Microbiotic crusts may enhance germination, establishment, and growth by providing cracks for favorable seed environments and nitrogen from nitrogen fixing algae and lichens (Evans and Johansen 1999).

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Plate 1. Native species used in restoration in the shrub-steppe [*Artemisia tridentata* (a), *Pseudoroegneria spicata* (b), *Salvia dorii* (c), *Oenothera pallida* (d), *Achnatherum hymenoides* (e), *Purshia tridentata* (f), *Sphaeralcea munroana* (g), *Poa secunda* (h)].