Supplemental

Table S1. Description of Ecological Systems and Vegetation Classes for the Black Mountains UT

Aspen Woodland (ASP) **1011**	
Overview: The Aspen Woodland BpS is dominated by Populus tremuloides *and is commonly called "stable aspen." Aspen woodland is a debated BpS as it isassumed, but not proven, that soils prevent encroachment of conifers even with fire exclusion, therefore maintaining the relative cover of conifers to <25%. Where the BpS is adjacent to conifers, an occasional conifer seedling may occur, but conifers not drive the fire regime. Elevations generally range from 1,525 to 3,050 m (5,000'-10,000'), but occurrences can be found at lower elevations in some regions. Distribution of this ecological system is limited primarily by adequate soil moisture required to meet its high evapotranspiration demand, and secondarily by the length of the growing season or low temperatures. This BpS occurs commonly as multi-storied stands. Stands are usually closed. Aspen suckers 1.5 m to 4.6 m (5-15') tall will be present in all classes (min. 500 stems/acre). The Aspen Woodland BpS typically occurs above pinyon/juniper and adjacent to mountain big sagebrush. At elevations below 6,500 feet this group grades into black and narrowleaf cottonwood types along riparian corridors. On Great Basin ranges, the BpS is found both on dry sites and in more mesic areas where fir species are largely absent. Understory consists of abundant herbaceous and shrub components. Often species of tall forbs, perennial grasses and shrubs are found in the understory. The herbaceous layer may be lush and diverse.*	
A	***Early***: 10-100% cover of aspen <5m; 0-9 yrs
B	***Mid1-closed***: 40-99% cover of aspen <5-10m; 10-39 yrs
C	***Late1-closed***: 40-99% cover of aspen 10-25m; few conifers in mid-story; >39 yrs
D	***Late1-open***: 10-39% cover of aspen 10-25 m; conifers may be present but less than 25% relative cover; >99 yrs
U-*Depleted*	***Depleted-Open***: 10-39% cover of older aspen 10-25m; no or little aspen regeneration; mountain big sagebrush common in understory; few conifers in mid-story

U-*NAS* ***No-Aspen***: very few aspen stems present; dead clone of aspen, dead boles may be visible on the ground; 5-50% cover of mountain big sagebrush/mountain shrub; <50% herbaceous cover

Aspen-Mixed Conifer (ASM)

1061

Overview: The Aspen-Mixed Conifer BpS is perhaps the most widespread aspen type in Utah and is commonly called "seral aspen." Populus tremuloides *is the dominant tree species, except in late succession where prolonged fire exclusion and ungulate herbivory allow dominance by mixed conifers, such as white fir and Douglas-fir. The presence of even a single aspen tree in a stand provides strong evidence that the area historically supported aspen clones. This BpS typically occurs on flat to steep terrain (<80%) on all aspects. Elevation generally ranges from 2,135 m to 2,745 m (7,000' to 9,000') in southern Utah. Soils are highly variable, but generally cool. This type occurs above the pinyon-juniper and/or sagebrush zones but below the spruce-fir zone. Aspen stands that are difficult to "see through" are considered healthy. Shrub, forb, and grass species typical of mesic sites are very diverse and plant cover is very high.*

1 ***Early***: 10-100% cover aspen <5m; mountain snowberry and *Ribes* common; 0-9 yrs

2 ***Mid1-closed***: 40-99% cover aspen <5-10m; mountain snowberry and *Ribes* common; 10-39 yrs

4 ***Late1-closed***: 40-99% cover aspen 10-24m; conifer saplings visible in mid-story; mountain snowberry and *Ribes* common; 40-79 yrs

5 ***Late1-open***: 10-39% cover aspen 10-25 m; 10-25% mixed conifer cover 5-10 m; mountain snowberry and *Ribes* common; >80 yrs

6 ***Late2-closed***: 40-80% cover of mixed conifer 10-50m; <40% cover of aspen 10-25m; mountain snowberry and *Ribes* present; >100 yrs

U-*NAS* ***No-Aspen***: >50% white fir and Douglas-fir cover; aspen absent or in trace amount; dead aspen boles may be present

Basin Wildrye (BW)

1080bw

*Overview: The Basin Wildrye BpS is a Great Basin grassland dominated by basin wildrye (*Elymus cinereus*). The BpS is found at elevations from about 914 m to 1,829 m (3,000' to 6,000') with extensions to as high as 2,286 m (7,500') in valley bottoms. Typically soils are deep to very deep with loamy to coarse loamy textures. Soils are well drained with water tables below the rooting zone of the dominant shrubs. Salts, if present, can increase with depth. Soils were formed through alluvial processes and typically form valley bottoms with slopes generally less than 8%, and typically between 0 and 4%. Annual precipitation ranges from 20 to 35 cm (8" to 14"). Many locations occur along valley bottoms outside of the wet meadow areas, but within zones where water tables may attain heights of 150 to 75 cm (60" to 30"). On lower precipitation sites (20 to 25 cm or 8 to 10") these locations may be positioned at the base of slopes such that water may run onto these sites. Not much is written specifically about the dynamics of this BpS. This is a grassland-shrubland mixture dominated by basin wildrye, a deep-rooted cool-season bunchgrass, with basin big sagebrush subdominant (<15% cover) later in succession. Other shrubs generally represent less than 10 % of the overall cover and include various species and subspecies of rabbitbrush. Other grasses are generally cool season bunchgrasses, with the exception of some rhizomatous grasses on the dry meadows with deep soils and high precipitation. Forbs represent less than 10 % of the herbaceous cover.*

A	***Early***: 5-20% cover of basin wildrye; 0-10 yrs
B	***Mid-closed***: 21-80% cover of basin wildrye; <11% shrub cover; 11-75 yrs
C	***Late-open***: 11-20% cover of big sagebrush and rabbitbrush; <75% cover of basin wildrye; >75 yrs
U-*Annual Grass*	***Annual-Grass***: 5-40% cover of cheatgrass
U-*Depleted*	***Depleted***: >20% cover of native shrubs, especially basin big sagebrush and rabbitbrush; <5% basin wildrye; >20% mineral soil and litter cover
U-*Early-Shrub*	***Early-Shrub***: >20% cover of rabbitbrush species; native grasses present
U-*Exotic Forb*	***Exotic-Forb***: 5-100% exotic forbs (knapweed, tall whitetop, purple loosestrife)

U-*SAP*	***Shrub-Annual-Grass-Perennial-Grass***: 5-14% cover of cheatgrass; >10% cover of native shrubs; ≥0% basin wildrye
U-*SAP+*	***Shrub-Annual-Grass-Perennial-Grass+***: ≥15% cover of cheatgrass; >10% cover of native shrubs; ≥0% basin wildrye
U-*SDI*	***Seeded-Introduced***: >10% seeded introduced grasses, forbs, and shrubs
U-*SDI+AG*	***Seeded-Introduced+Annual-Grass****:* >10% seeded introduced grasses, forbs, and shrubs, ≥5% cover of cheatgrass
U-*Seeded Native*	***Seeded Native***: >10% seeded basin wildrye, forbs, and shrubs; <5% non-native annual species (if ≥5 non-native annual species, then ASPG or even AS)
U-*TEA*	***Tree-Encroached-Annual-Grass***: ≥10% cover of conifers; ≥0% (i.e., absent to common) cover annual grasses

Big Sagebrush semi-desert (BSsd)

1080bssd

Overview: The Big Sagebrush semi-desert BpS is a semi-desert clay loam that is similar to Wyoming big sagebrush semi-desert loam, but different from the basin wildrye loamy bottoms. The BpS is found at elevations from about 1,645 m to 1,737 m (5,400' to 5,700') on alluvial fans and flats with slopes between 0% and 2%. Typically soils are very deep (>152 cm or >60") clay loams. Soils are well drained and derived from sedimentary rock. Annual precipitation ranges from 25 to 30.5 cm (10" to 12"). Basin big sagebrush is dominant, but other shrubs, such as winterfat and low rabbitbrush, generally represent less than 10 % of the overall cover. Bottlebrush and Indian ricegrass are the most common grasses, with bottlebrush achieving high cover. Forbs represent a small component of the vegetation.

A	***Early***: ≥20% cover of native grasses (bottlebrush and Indian ricegrass); <10% shrub (various rabbitbrushes, snakeweed, and basin big sagebrush) cover; mineral soil abundant; 0-4 yrs
B	***Mid-closed***: 10-29% cover of basin big sagebrush and rabbitbrush; ≥20% native grass cover; 5-39 yrs
C	***Late-open***: ≥30% cover of basin big sagebrush, with other shrub (winterfat and low rabbitbrush) present; 5-25% cover of native grasses; pinyon and juniper saplings might be present; >40 yrs
U-*Annual Grass*	***Annual-Grass***: >10% cheatgrass cover; <10% shrubs, especially rabbitbrush and snakeweed; native grasses may be present
U-*Depleted*	***Depleted***: >30% cover of basin big sagebrush, rabbitbrush, and rabbitbrush; <5% native grass cover; >20% mineral soil and litter cover
U-*Early-Shrub*	***Early-Shrub***: >20% cover of rabbitbrush species; native grasses present
U-*SA*	***Shrub-Annual-Grass***: 5-14% cover of cheatgrass; >10% cover of basin big sagebrush and other shrubs; <5% native grasses
U-*SA+*	***Shrub-Annual-Grass***: ≥15% cover of cheatgrass; >10% cover of basin big sagebrush and other shrubs; <5% native grasses

U-*SAP* ***Shrub-Annual-Grass-Perennial-Grass***: 5-14% cover of cheatgrass; >10% cover of basin big sagebrush and other shrubs; ≥5% native grasses

U-*SAP+* ***Shrub-Annual-Grass-Perennial-Grass+***: ≥15% cover of cheatgrass; >10% cover of basin big sagebrush and other shrubs; ≥5% native grasses

U-*SDI-A* ***Seeded-Introduced-Early***: >10% seeded introduced grasses and shrubs; <10% native shrub (various rabbitbrushes, snakeweed, and basin big sagebrush) cover; <5% cheatgrass cover

U-*SDI-B* ***Seeded-Introduced-Mid***: >10% seeded introduced grasses and shrubs; 10-29% native shrub (various rabbitbrushes, snakeweed, and basin big sagebrush) cover; <5% cheatgrass cover

U-*SDI-C* ***Seeded-Introduced-Late***: >10% seeded introduced grasses and shrubs; ≥30% native shrub (various rabbitbrushes, snakeweed, and basin big sagebrush) cover; <5% cheatgrass cover

U-*Seeded Native* ***Seeded-Native***: >10% seeded native grasses, forbs, and shrubs; <5% cheatgrass cover

U-*SI-A+AG* ***Seeded-Introduced-Early+Annual-Grass***: >10% seeded introduced grasses and shrubs; <10% native shrub (various rabbitbrushes, snakeweed, and basin big sagebrush) cover; ≥5% cover of cheatgrass;

U-*SI-B+AG* ***Seeded-Introduced-Mid+Annual-Grass***: >10% seeded introduced grasses and shrubs; 10-29% native shrub (various rabbitbrushes, snakeweed, and basin big sagebrush) cover; ≥5% cover of cheatgrass

U-*SI-C+AG* ***Seeded-Introduced-Late+Annual-Grass***: >10% seeded introduced grasses and shrubs; ≥30% native shrub (various rabbitbrushes, snakeweed, and basin big sagebrush) cover; ≥5% cover of cheatgrass

U-*TEA* ***Tree-Encroached-Annual-Grass***: ≥10% cover of conifers; <20% cover of shrubs; **either** <5% cheatgrass cover **AND** <5% native grass cover **OR** ≥5% cheatgrass cover **AND** ≥5% native grass cover

Black Sagebrush (BS)

1079an

Overview: The Black Sagebrush BpS is found throughout the project area. Artemisia nova *is the dominant species. Black sagebrush tends to grow where there is a calcite-based root-limiting layer in the soil profile. Wyoming big sagebrush and basin big sagebrush generally occur with black sagebrush on moderately deep to deep soils that are well-drained. Elevations range from 1,500 m to 2,600 m (4,920' to 6,530'), although the BpS is sometimes found as high as 2,743 m (9,000'). The BpS mostly occurs on Great Basin alluvial fans, piedmonts, bajadas, rolling hills and mountain slopes. The BpS can also be found on flats and plains. Black sagebrush generally has relatively low fuel loads with low-growing and cushion forbs and scattered bunchgrasses such as Thurber needlegrass (*Achnatherum thurberianum), *Sandberg's bluegrass* (Poa secunda), *Indian ricegrass (*Achnatherum hymenoides*), and bluebunch wheatgrass (*Pseudoroegneria spicata*) at higher elevations. Forbs often include buckwheats (*Eriogonum *spp.), fleabanes (*Erigeron *spp.), phloxes (*Phlox *spp.), paintbrushes (*Castilleja *spp.), globemallows (*Sphaeralcea *spp.), and lupines (*Lupinus *spp.).*

A	***Early***: <10% cover rabbitbrush; 10-40% cover of grass; <50% cover mineral soil; 0-25 yrs
B	***Mid-open***: 10-19% cover of black sagebrush and rabbitbrush; 10-30% grass cover; <40% cover of mineral soil; 25-119 yrs
C	***Late-closed***: 1-10% pinyon-juniper sapling cover; 20-30% cover of black sagebrush; 10-30% cover of grasses; 120-194 yrs
D	***Late-open***: 10-40% cover of pinyon or juniper 3-8m tall; <10% black sagebrush cover; <10% grass cover; >195 yrs
U-*Annual Grass*	***Annual-Grass***: >10% cover of cheatgrass; <10% cover of shrubs
U-*Depleted*	***Depleted***: 20-50% cover of black sagebrush; <5% herbaceous cover; <10% pinyon or juniper sapling cover
U-*Early-Shrub*	***Early-Shrub***: 10-40% cover rabbitbrush species

U-*SA* ***Shrub-Annual-Grass***: 5-14% cheatgrass cover; 10-50% cover of black sagebrush; <5% cover of native grass; <10% pinyon or juniper sapling cover

U-*SA+* ***Shrub-Annual-Grass+***: ≥15% cheatgrass cover; 10-50% cover of black sagebrush; <5% cover of native grass; <10% pinyon or juniper sapling cover

U-*SAP* ***Shrub-Annual-Grass-Perennial-Grass***: 5-14% cheatgrass cover; 20-50% cover of black sagebrush; >5% cover of native grass; <10% pinyon or juniper sapling cover

U-*SAP+* ***Shrub-Annual-Grass-Perennial-Grass+***: ≥15% cheatgrass cover; 20-50% cover of black sagebrush; >5% cover of native grass; <10% pinyon or juniper sapling cover

U-*SDI-A* ***Seeded-Introduced-Early***: >10% seeded introduced species (crested wheatgrass, intermediate wheatgrass, or forage kochia); <10% cover of shrubs; native grasses and forbs may be present to abundant; <5% cheatgrass cover

U-*SDI-B* ***Seeded-Introduced-Mid***: >10% seeded introduced species (crested wheatgrass, intermediate wheatgrass, or forage kochia); 10-19% cover of black sagebrush and rabbitbrush; native grasses and forbs may be present to abundant; <5% cheatgrass cover

U-*SDI-C* ***Seeded-Introduced-Late***: >5% seeded introduced species (crested wheatgrass, intermediate wheatgrass, or forage kochia); 1-10% pinyon-juniper sapling cover; 20-30% cover of black sagebrush; native grasses and forbs may be present to abundant; <5% cheatgrass cover

U-*Seeded Native* ***Seeded***: >5% seeded native

U-*SI-A+AG* ***Seeded-Introduced-Early+Annual-Grass***: >10% seeded introduced species (crested wheatgrass, intermediate wheatgrass, or forage kochia); <10% cover of shrubs; native grasses and forbs may be present to abundant; ≥5% cheatgrass cover

U-*SI-B+AG* ***Seeded-Introduced-Mid+Annual-Grass***: >10% seeded introduced species (crested wheatgrass, intermediate wheatgrass, or forage kochia); 10-19% cover of black sagebrush and rabbitbrush; native grasses and forbs may be present to abundant; ≥5% cheatgrass cover

U-*SI-C+AG* ***Seeded-Introduced-Late+Annual-Grass***: >5% seeded introduced species (crested wheatgrass, intermediate wheatgrass, or forage kochia); 1-10% pinyon-juniper sapling cover; 20-30% cover of black sagebrush; native grasses and forbs may be present to abundant; ≥5% cheatgrass cover.

U-*TEA* ***Tree-Encroached-Annual-Grass***: >10% mature pinyon or juniper cover 3-8m tall; <5% shrub cover; **either** <5% native herbaceous cover **and** <5% cheatgrass; **OR** ≥5% cheatgrass **and** >0% native herbaceous cover

Curl-leaf Mountain Mahogany (CMM)

1062

*Overview: The Curl-leaf Mountain Mahogany BpS is usually found on upper slopes and ridges between 2,133 m to 3,200 m (7,000' to 10,500') elevation. Most stands occur on rocky shallow soils and outcrops. Stands are assumed to reach old age, >1,000 years, without fire. The BpS is present in two distinct forms due to soil differences: 1) savannas of old and well -dispersed trees form open and often grassy woodlands (with mature stand cover between 10-55%) with a diverse understory on soils with a large proportion of boulders above and below ground; and 2) dense thickets of old shrubs (56% to 100% cover) with thick litter and little understory cover form on soils without bouldering. Curlleaf mountain mahogany (*Cercocarpus ledifolius*) is both a primary early successional colonizer rapidly occupying bare mineral soils after disturbance and the dominant long-lived species. Seedlings require mineral soil without plant competition to reestablish after fire. Reproduction often appears dependent upon geographic variables (slope, aspect, and elevation) more than biotic factors. Where curl-leaf mountain mahogany has reestablished quickly after fire, rabbitbrush (*Chrysothamnus nauseosus*) may co-dominate. Litter and shading by woody plants inhibits establishment of curl-leaf mountain mahogany. Mountain big sagebrush is the most common codominant with curlleaf mountain mahogany, although chaparral species such as manzanita (*Arctostaphylos patula*), tobaccobrush (*Ceanothus velutinus*), and green ephedra (*Ephedra viridis*) often codominate on some sites. Snowberry, Utah serviceberry, and currant are present on cooler sites, with more moisture. Singleleaf and Colorado pinyon, western juniper, Douglas-fir, white fir, Rocky Mountain juniper, ponderosa pine, and limber pine may be present, with less than 10% total cover. In old, closed canopy stands, understory may consist largely of prickly phlox (*Leptodactylon pungens*).*

A ***Early***: <70% cover of mountain mahogany; other shrubs (snowberry, rabbitbrush) and grasses may be present; 0-20 yrs

B ***Mid-open***: 10-30% cover mountain mahogany and other shrubs; 20-60 yrs

C ***Mid-closed***: 30-70% cover of mountain mahogany, other shrubs (snowberry, rabbitbrush, big sagebrush, bitterbrush, black sagebrush) abundant; 60-150 yrs

D ***Late-open***: 10-30% cover of mountain mahogany; big sagebrush, black sagebrush, bitterbrush; grasses abundant; occasional ponderosa pine possible; 150+ yrs

E ***Late-closed***: >30% cover of mountain mahogany; 5-10% cover of pinyon-juniper; snowberry may be common; occasional ponderosa pine possible; 150+ yrs

U-*Annual Grass* ***Annual-Grass***: ≥10% cheatgrass cover; mountain mahogany largely absent; ≤80% cover of mineral soil, bedrock, and rock

U-*TA* ***Tree-Annual-Grass***: >5% cheatgrass cover; >10% cover of mountain mahogany; 40% cover of mineral soil, bedrock, and rock

Desert Wash (DWA)

1154w

Overview: The Desert Wash BpS comprises intermittent to dry desert drainages with mostly subsurface flow whose banks are deeply incised. Flash-flooding is the major disturbance in this BpS. Gravels and desert shrub species dominate the system with shrub cover increasing with time since last flood. Common species include desert almond, bursage, bladdersage, burrobrush, big sagebrush, Anderson's wolfberry, snakeweed, rabbitbrush, big galleta, bush muhly, Indian ricegrass, and squirreltail.

A ***Early***: 20-50% cover may be gravel, sands, and/or flood debris; 10-19% cover of desert almond, burrobrush, rabbitbrush, desert willows present; 5-15% cover of grasses (big galleta, bush muhly, Indian ricegrass, squirreltail); forbs present to abundant; 0-5 yrs

B ***Mid-closed***: 20-50% cover of desert almond, bursage, bladdersage, burrobrush, big sagebrush, Anderson's wolfberry, rabbitbrush; 5-10% cover of grasses (big galleta, bush muhly, Indian ricegrass, squirreltail); forbs present to abundant; <30% of gravel and rocks; 5-19 yrs

C ***Late-closed***: 30-50% cover of bursage, burrobrush, desert almond, bladdersage, big sagebrush, Anderson's wolfberry, rabbitbrush, 5-10% cover of grasses (big galleta, bush muhly, Indian ricegrass, squirreltail); forbs present to abundant; <10% of gravel and rocks; >20 yrs

U-*Bare Ground* ***Bare-Ground***: mineral soil exposed by human-caused disturbances

U-*Early-Shrub* ***Early-Shrub***: 20-50% cover of cholla, snakeweed or rabbitbrush species

U-*EFT* ***Exotic-Forb-Tree*****:** >5% cover of salt cedar or exotic forbs (knapweed, tall whitetop); 0-50% cover of bursage, burrobrush, big sagebrush, Anderson's wolfberry, rabbitbrush, desert almond.

U-*SA* ***Shrub-Annual-Grass***: 5-14% exotic species (*Bromus rubens, Bromus tectorum*, *Erodium cicutarium*) cover; 0-50% small trees and shrubs; <5% cover of native grasses; mineral soil may be common

U-*SA+* ***Shrub-Annual-Grass+***: ≥15% exotic species (*Bromus rubens, Bromus tectorum*, *Erodium cicutarium*) cover; 0-50% small trees and shrubs; <5% cover of native grasses; mineral soil may be common

U-*SAP* ***Shrub-Annual-Grass-Perennial-Grass***: 5-14% exotic species (*Bromus rubens, Bromus tectorum*, *Erodium cicutarium*) cover; 0-50% small trees and shrubs, ≥5% cover of grasses (big galleta, bush muhly, Indian ricegrass, squirreltail); mineral soil may be common

U-*SAP+* ***Shrub-Annual-Grass-Perennial-Grass+***: ≥15% exotic species (*Bromus rubens, Bromus tectorum*, *Erodium cicutarium*) cover; 0-50% small trees and shrubs, ≥5% cover of grasses (big galleta, bush muhly, Indian ricegrass, squirreltail); mineral soil may be common

Four-Wing Saltbush (FWS)

1081fws

Overview: *The Four-Wing Saltbush BpS occurs from 1,524 – 1,585 m (5,000 – 5,200'). It is part of the Mixed Salt Desert community, but the high stature and high density of four-wing saltbush (*Atriplex canescens*) makes it stand apart. Soils are alkaline, made of loamy fine sand, highly permeable, and very deep (>152 cm or >60"). Many soils are derived from eolian deposits and often associated with dunes. Average annual precipitation ranges from 0-25.4 cm (0 to 10"). This system generally occurs as small patches and stringers. Summers are hot and dry with many days reaching 30 degrees C (100 degrees F). Spring is the only dependable growing season with moisture both from winter and spring precipitation. Cool springs can delay the onset of plant growth and drought can curtail the length of active spring growth. Four-wing saltbush are tall shrubs found at high density (3-5 plants per sq. m) interspersed with low to mid-height bunch grasses. Other shrubs include basin big sagebrush (*Artemisia tridentata *ssp*. tridentata*) and rubber rabbitbrush (*Ericameria nauseosa*). Common bunch grass species are Indian ricegrass (*Achnatherum hymenoides*), needle-and-thread (*Hesperostipa comata*), and, where monsoonal influences are present, rhizomatous/sod forming grasses such as galleta grass (*Pleuraphis jamesii*) and sand dropseed (*Sporobolus cryptandrus*). The biophysical setting has not evolved with fire and fire is absent from the reference condition.*

A ***Early***: ≥10% Indian ricegrass, galleta grass, needle-and-thread, or bottlebrush cover;<5% young four-wing saltbush or rubber rabbitbrush cover; mineral soil common to abundant; 0-5 yrs

B **Mid1-*open***: 5-20% four-wing saltbush, basin big sagebrush, or rabbitbrush cover; >10% Indian ricegrass, galleta grass, needle-and-thread, or bottlebrush cover; mineral soil common to abundant; 6-19 yrs

C ***Late*1-*open***: >20% four-wing saltbush and basin big sagebrush cover >1m tall; 10-20% Indian ricegrass, galleta grass, needle-and-thread, or bottlebrush cover; ≥20 years

U-*Annual Grass* ***Annual-Grass***: ≥10% cheatgrass cover; <5% shrub cover; native grass may be present to common

U-*Depleted* ***Depleted***: 5-20% cover of four-wing saltbush, basin big sagebrush, or rabbitbrush; <10% native grass; <5% cheatgrass cover

U-*Early-Shrub* ***Early-Shrub***:

U-*SAP*	***Shrub-Annual-Grass***: 5-14% cheatgrass cover; ≥5% cover of four-wing saltbush, basin big sagebrush, or rabbitbrush; native grass may be present to common
U-*SAP+*	***Shrub-Annual-Grass+***: ≥15% cheatgrass cover; ≥5% cover of four-wing saltbush, basin big sagebrush, or rabbitbrush; ; native grass may be present to common
U-*SDI*	***Seeded-Introduced***: >10% seeded introduced grasses and shrub species (crested wheatgrass and forage kochia); <5% cheatgrass cover; native shrubs may be present to common
U-SDI+AG	***Seeded-Introduced+Annual-Grass***: >10% seeded introduced grasses and shrub species (crested wheatgrass and forage kochia); ≥5% cheatgrass cover; native shrubs may be present to common
U-*Seeded Native*	***Seeded-Native***: >10% native grass and four-wing saltbush seed mix cover; <5% cheatgrass cover

Gambel Oak-Mountain Shrub (GOMS)

1107

Overview: The Gambel Oak-Mountain Shrub BpS is one of three mountain shrub types. It is found on a variety of soil types, often rocky and potentially erosive, and on slopes that range from gentle to steep, on all aspects. Elevations range from 915 m to 2,438 m (3,000' to 8,000'), typically on mountain foothills and lower slopes. The BpS exists in two sub-types based on aspect and soils. The patchy form of the BpS is characterized by Gambel oak covering ≤60% of the area and generally occurs on sites less than 1,676 m (5,500 ') in elevation, more often on south- or west-facing slopes, and on shallower soils than the continuous form that has >60% Gambel oak cover and more often occupies higher elevations and northern and eastern slopes. There is, of course, overlap in the gradients for these two sub-types. The BpS is dominated by Gambel oak, often with serviceberry, big sagebrush, chokecherry, bitterbrush, and snowberry. Oak and most other associated shrubs will sprout readily after disturbance.

A ***Early***: 5-40% cover of Gambel oak sprouts ≤ 2 m (6.6') tall; <5% cover of sagebrush and other shrubs; grass and forb cover low in oak patches but abundant between patches; 0-4 years

B ***Mid1-closed***: >40% cover with patches of Gambel oak with stems 2-3+m tall; low herbaceous cover in oak patches; 5-20% cover of grass/herb/sagebrush/mountain shrub in interspaces between clones; 5-19 years

C ***Late-closed***: 40-80% cover of Gambel oak (greater at the periphery than center of patches due to self thinning) with trees reaching 3+-8m tall; herbaceous understory low; 20-30% cover of sagebrush and mountain shrubs (and other low shrubs) in interspaces between clones; in older patches (>50 yrs), Gambel oak adopts a tree form in southern Utah; >20 yrs

U-*SAP* ***Shrub-Annual-Grass-Perennial-Grass***: 5-14% non-native grass cover between oak patches; >5% cover of Gambel oak; native herbaceous cover usually present to abundant between oak patches

U-*SAP+* ***Shrub-Annual-Grass-Perennial-Grass+***: ≥15% non-native grass cover between oak patches; >5% cover of Gambel oak; native herbaceous cover usually present to abundant between oak patches.

Greasewood-Basin Big Sagebrush (GW)

1153

Overview: *The Greasewood-Basin Big Sagebrush BpS occurs on alluvial flats or lake plains usually adjacent to playas. Sites typically have saline to sodic soils, shallow water table, and flood intermittently, but remain dry for most growing seasons. The water table remains high enough to maintain vegetation, despite salt accumulations. Slope gradients of less than 2 percent are most typical. Elevations range from 1,158 to 1,768 m (3,800 to 5,800'). Average annual precipitation is 13 to 20 cm (5 to 8"); mean temperature is 45 to 50 degrees F; average growing season is 100 to 120 days. The surface layer normally crusts over, inhibiting water infiltration and seedling emergence. This BpS sometimes occurs as a mosaic of multiple communities, with open to moderately-dense shrublands dominated or co-dominated by* Sarcobatus vermiculatus *(greasewood).* Atriplex confertifolia *(shadscale) may be present or co-dominant. An herbaceous layer, if present, is usually dominated by salt-tolerant graminoids. There may be inclusions of* Sporobolus airoides *(alkali sacaton),* Distichilis spicata *(saltgrass), and basin wildrye (*Elymus cinereus*). Vegetation on this site is normally restricted to coppice mound areas that are surrounded by playa-like depressions or nearly level, usually barren, inner spaces. In eastern Nevada and Utah, this BPS also occurs along creek floodplains and in washes with fine saline to sodic soils. As ecological condition declines, herbaceous understory is reduced or eliminated and the site becomes a community of halophytic shrubs dominated by greasewood.*

A ***Early***: >5% herbaceous cover of inland salt grass, alkali sacaton, or basin wildrye; ≤5% young or resprouting greasewood; >25% mineral soil; flood debris may be abundant; 0-4 years

B ***Mid-closed***: >5% cover of mature greasewood with other shrubs possible (basin big sagebrush); >5% herbaceous cover of inland salt grass, alkali sacaton, or basin wildrye; mineral soil may be common; >4 years

U-*Annual Grass* ***Annual-Grass***: >10% cover of cheatgrass; <5% cover of mature greasewood and other shrubs

U-*SAP* ***Shrub-Annual-Perennial-Grass***: 5-14% cheatgrass cover; >5% cover of mature greasewood or basin big sagebrush; native grasses may be present to common; >4 years

U-*SAP+* ***Shrub-Annual-Perennial-Grass+***: >15% cheatgrass cover; >5% cover of mature greasewood or basin big sagebrush; native grasses may be present to common; >4 years

U-*SDI* ***Seeded-Introduced***: >10% seeded introduced grasses (usually Russian wheatgrass), forbs, and shrubs; greasewood and other shrubs may be present to common;<5% cheatgrass cover

U-*SDI+AG* ***Seeded-Introduced+Annual-Grass***: >10% seeded introduced grasses (usually Russian wheatgrass), forbs, and shrubs; greasewood and other shrubs may be present to common; ≥5% cheatgrass cover.

U-*Seeded Native* ***Seeded-Native*:** >10% cover of native; greasewood and other shrubs may be present to common

Juniper Savanna (JUN)

1115

Overview: The Juniper Savanna BpS was historically noted by the first explorers on the Spanish Trail. This ecological system is typically found at lower elevations ranging from 1,500-2,300 m (4,920 – 7,550 ft). Occurrences are found on lower mountain slopes, hills, plateaus, basins and flats. The Juniper savanna ecotype generally occurs in local, geologically confined, badland environments and is limited in its distribution. This system occurs at the lower altitudinal limits for tree species, below the pinyon-juniper woodland type but at or above sagebrush semidesert and salt desert shrubland in locations where soil moisture is limiting. The vegetation is typically open savanna, although there may be inclusions of more dense juniper woodlands. This savanna is typically dominated by Juniperus osteosperma *trees with sparse cover of black sagebrush and Wyoming big sagebrush. Perennial bunchgrass cover can be abundant creating a grassland aspect below the canopy of juniper. Most common grass species are* Elymus elymoides*,* Achnatherum hymenoides *(=* Oryzopsis hymenoides*),* Hesperostipa comata *(=* Stipa comata*), and* Pleuraphis jamesii *(=* Hilaria jamesii*) being most common. Pinyon trees are typically not present because sites are outside the ecological or geographic range of* Pinus edulis *and* Pinus monophylla*.*

A ***Early-open***: ≤10% herbaceous cover; charred stumps and trunks should be visible; 0-9 yrs.

B ***Mid1-open***: 10-20% herbaceous cover; 5-10% cover big sagebrush, black sagebrush, or bitterbrush <1.0m, 10-29 yrs..

C ***Mid2-open***: 11-20% cover of young (<100 yrs old) juniper <5m; >10% herbaceous cover; 10-20% shrub cover; 30-99 yrs.

D ***Late-open***: ≥20% cover of juniper <5m-9m; >10% herbaceous cover; 5-10% shrub cover; ≥100 yrs.

U-*Annual Grass* ***Annual-Grass***: >10% cheatgrass cover; dead juniper visible.

U-*Early-Shrub* ***Early-Shrub***: ≥10% cover rabbitbrush and snakeweed species.

U-*SAP* ***Shrub-Annual-Perennial-Grass***: >5% cheatgrass; 5-20% cover big sagebrush, black sagebrush, or bitterbrush <1.0m, <40% herbaceous cover.

U-*TA* ***Tree-Annual-Grass***: ≥20% cover of juniper <5m-9m, 5-10% shrub cover, >5% cheatgrass cover; ≥30 yrs.

Limber-Bristlecone Pine (LB)

1020

Overview: The Limber-Bristlecone Pine BpS is often the highest subalpine forest type. Elevation ranges from 2,438 m to 3,505 m (8,000' to 11,500') on mid to upper slopes. The areas are typically in rain shadows, and are the dry and cold extent of tree cover. Stands occur on thin, stony soils, high windswept ridges and open slopes with minimal ground cover. Pinus longaeva *and* Pinus flexilis *can exist separately or as mixed stands.* Picea engelmannii *and* Pseudotsuga menziesii *may occur incidentally with* Pinus longaeva*. Sparse forbs, grasses and short shrubs form an understory.*

A ***Early***: 0-10% limber and bristlecone pine cover 0-5m tall; abundant mineral soil or talus cover; sparse ground cover; 0-99 yrs

B ***Mid1-open***: 11-30% limber and bristlecone pine cover 5-10m tall; abundant mineral soil or talus cover; sparse ground cover; 100-249 yrs

C ***Late1-open***: very old trees; 11-30% limber and bristlecone pine cover 5-25m tall; abundant mineral soil or talus cover; sparse ground cover; >250 yrs

Low Sagebrush (LS)

1079aa

*Overview: The Low Sagebrush BpS is found primarily in the Beaver County portion of the project area. Low sagebrush (*Artemisia arbuscula*) is the dominant species. Low sagebrush tends to grow where there is a clay-based root-limiting layer in the soil profile. Big sagebrush species generally occur on deeper loamy soils. Elevations range from 1,500 m to 2,600 m (4,920' to 6,530'), although the BpS is sometimes found as high as 2,743 m (9,000'). The BpS mostly occurs on Great Basin alluvial fans, piedmonts, bajadas, rolling hills and mountain slopes. The BpS can also be found on flats and plains. Low sagebrush generally has relatively low fuel loads with low-growing and cushion forbs and scattered bunchgrasses such as Thurber needlegrass (*Achnatherum thurberianum), *Sandberg's bluegrass* (Poa secunda), *Indian ricegrass (*Achnatherum hymenoides*), and bluebunch wheatgrass (*Pseudoroegneria spicata*) at higher elevations. Forbs often include buckwheats (*Eriogonum *spp.), fleabanes (*Erigeron *spp.), phloxes (*Phlox *spp.), paintbrushes (*Castilleja *spp.), globemallows (*Sphaeralcea *spp.), and lupines (*Lupinus *spp.). Utah juniper* (Juniperus osteosperma)*, more than singleleaf pinyon* (Pinus monophylla)*, may occasionally establish in low sagebrush's harsh soils; however, low sagebrush does not generally support trees.*

A	***Early***: <10% cover rabbitbrush and other shrubs; >10% cover of grass; <50% cover mineral soil; 0-24 yrs
B	***Mid-open***: 10-19% cover of low sagebrush and rabbitbrush; >10% grass cover; <40% cover of mineral soil; 25-119 yrs
C	***Late-closed***: >20% cover of low sagebrush; <3% mature juniper (maybe pinyon) cover; ≤5% juniper (maybe pinyon) sapling cover; >5% cover of grasses; >120 yrs
U-*Annual Grass*	***Annual-Grass***: >10% cover of cheatgrass; <10% cover of shrubs (primarily rabbitbrush and snakeweed)
U-*Depleted*	***Depleted***: >20% cover of low sagebrush; <5% herbaceous cover; <3% mature juniper (maybe pinyon) cover; ≤5% pinyon or juniper sapling cover
U-*Early-Shrub*	***Early-Shrub***: 10-40% cover rabbitbrush species

U-*SA*	***Shrub-Annual-Grass***: 5-14% cheatgrass cover; >10% cover of low sagebrush; <5% cover of native grass; <3% mature juniper (maybe pinyon) cover; ≤5% pinyon or juniper sapling cover
U-*SA+*	***Shrub-Annual-Grass+***: ≥15% cheatgrass cover; >10% cover of low sagebrush; <5% cover of native grass; <3% mature juniper (maybe pinyon) cover; ≤5% pinyon or juniper sapling cover
U-*SAP*	***Shrub-Annual-Grass-Perennial-Grass***: 5-14% cheatgrass cover; >10% cover of low sagebrush; >5% cover of native grass; <3% mature juniper (maybe pinyon) cover; <5% pinyon or juniper sapling cover
U-*SAP+*	***Shrub-Annual-Grass-Perennial-Grass+***: ≥15% cheatgrass cover; >10% cover of low sagebrush; >5% cover of native grass; <3% mature juniper (maybe pinyon) cover; ≤5% pinyon or juniper sapling cover
U-*SDI-A*	***Seeded-Introduced-Early***: >10% seeded introduced species (crested wheatgrass, intermediate wheatgrass, or forage kochia); <10% cover of shrubs; native grasses and forbs may be present to abundant; <5% cheatgrass cover
U-*SDI-B*	***Seeded-Introduced-Mid***: >10% seeded introduced species (crested wheatgrass, intermediate wheatgrass, or forage kochia); 10-19% cover of low sagebrush and rabbitbrush; native grasses and forbs may be present to abundant; <5% cheatgrass cover
U-*SDI-C*	***Seeded-Introduced-Late***: >5% seeded introduced species (crested wheatgrass, intermediate wheatgrass. or forage kochia); <3% mature juniper (maybe pinyon) cover; ≤5% pinyon or juniper sapling cover; >20% cover of low sagebrush; native grasses and forbs may be present to abundant; <5% cheatgrass cover
U-*Seeded Native*	***Seeded-Native***: >5% seeded native grass and forb species; <10% cover of shrubs; <5% cheatgrass cover.
U-*SI-A+AG*	***Seeded-Introduced-Early+Annual-Grass***: >10% seeded introduced species (crested wheatgrass, intermediate wheatgrass, or forage kochia); <10% cover of shrubs; native grasses and forbs may be present to abundant; ≥5% cheatgrass cover
U-*SI-B+AG*	***Seeded-Introduced-Mid+Annual-Grass***: >10% seeded introduced species (crested wheatgrass, intermediate wheatgrass, or forage kochia); 10-19% cover of low sagebrush and rabbitbrush; native grasses and forbs may be present to abundant; ≥5% cheatgrass cover

U-*SI-C+AG* ***Seeded-Introduced-Late+Annual-Grass***: >5% seeded introduced species (crested wheatgrass, intermediate wheatgrass, or forage kochia); <3% mature juniper (maybe pinyon) cover; ≤5% pinyon or juniper sapling cover; >20% cover of low sagebrush; native grasses and forbs may be present to abundant; ≥5% cheatgrass cover.

U-*TA* ***Tree-Annual-Grass***: ≥3% mature pinyon or juniper cover; <10% low sagebrush and other shrub cover; ≥5% cheatgrass; >0% native herbaceous cover

U-*TE* ***Tree-Encroached***: ≥3% mature pinyon or juniper cover; <10% low sagebrush and other shrub cover; <5% native herbaceous cover; <5% cheatgrass

Mixed Conifer (MC)

1052

Overview: *The Mixed Conifer BpS is found at elevations ranging from 1,200 m to 2,743 m (4,000'-9,000'). Sites include lower and middle slopes of ravines, along stream terraces, moist concave topographic positions, and north- and east-facing slopes which burn somewhat infrequently. White fir (*Abies concolor*) and Douglas-fir (*Pseudotsuga menziesii*) are most common canopy dominants, but ponderosa pine (*Pinus ponderosa*), Engelmann spruce (*Picea engelmannii*), limber pine (*Pinus flexilis*), and bristlecone pine (*Pinus longeava*) may be occasional. Many cold-deciduous shrub, graminoid, and forbs species can occur, although litter is often the dominant understory cover. Aspen is absent and there is no evidence of remnant aspen boles.*

A ***Early***: 0-15% cover of tree/shrub/grass; <5m; 0-29 yrs

B ***Mid1-closed***: 35-100% cover of conifers <24m; 30-99 yrs

C ***Mid1-open***: 0-35% cover of conifers <24m; 30-99 yrs

D ***Late1-open***: 0-35% cover of conifers 25-49m; >100 yrs

E ***Late1-closed***: 35-100% cover of conifers 25-49m; >100 yrs

U-*Annual Grass* ***Annual-Grass***: saplings plus >10% annual grass cover

U-*TA* ***Tree-Annual-Grass***: any class A-E plus >5% annual grass cover

Mixed Salt Desert (MSD)

1081

Overview: *The Mixed Salt Desert BpS occurs from lower slopes to valley bottoms ranging in elevation from 1,158 – 1981m (3,800 - 6,500'). Soils are often alkaline or calcareous. Soil permeability ranges from high to low, with more impermeable soils occurring in valley bottoms. Water ponds on alkaline bottoms. Texture is variable becoming finer toward valley bottoms. Many soils are derived from alluvium. Average annual precipitation ranges from 7.5-25.4cm (3 to 10"); however, this system is in 12.7-30.3 cm (5-8") of effective moisture within this broader range. Thus, other site characteristics (e.g. aspect, drainage, soil type) should be considered in identifying this biophysical setting. At the precipitation extremes, this system generally occurs as small patches and stringers. Summers are hot and dry with many days reaching 30 degrees C (100 degrees F). Spring is the only dependable growing season with moisture both from winter and spring precipitation. Cool springs can delay the onset of plant growth and drought can curtail the length of active spring growth. Freezing temperatures are common from November through April. Mixed Salt Desert generally lies above playas, lakes, and greasewood communities. Up slope the BpS is bordered by low elevation big sagebrush groups, commonly Wyoming big sagebrush, low sagebrush, and black sagebrush communities. Mixed Salt Desert includes low (<0.91 m or 3') and medium-sized shrubs found widely scattered (often 6.1-9.1 m [20-30'] apart) to high density (3-5 plants per sq. m) shrubs interspersed with low to mid-height bunch grasses. Common shrubs are shadscale, winterfat, budsage, Nevada ephedra, horsebrush, low rabbitbrush, broom snakeweed, and spiny hopsage. Shrub dominance is highly dependent on the site. Some of these shrubs will be present. Common bunch grass species are Indian ricegrass, needle-and-thread, purple three-awn, and bottlebrush squirreltail, and where monsoonal influences are present one may find common rhizomatous/sod forming grasses such as galleta grass, sand dropseed, and blue grama. Globemallows are the most common and widespread forbs. The understory grasses and forbs are salt-tolerant, not particularly drought tolerant, and are variably abundant. The relative abundance of species may vary in a patchwork pattern across the landscape in relation to subtle differences in soils (e.g., sand sheets or other surface textural differences) and reflect variation in disturbance history. Total cover rarely exceeds 25% and annual precipitation is closely linked to prior 12 months precipitation. Stand-replacing disturbances (insects, extended wet periods and drought) shift dominance between shrub and grass species. Following drought coupled with insect infestations, the system will tend more toward bud sagebrush dominance. The biophysical setting has not evolved with fire and fire is absent from the reference condition.*

A	***Early***: 0-5% cover of young *Atriplex* spp. or other shrubs; Indian ricegrass and squirreltail common; 0-5 yrs
B	***Late1-open***: >5% cover *Atriplex* spp. or other shrubs; Indian ricegrass and squirreltail present to common; ≥6 yrs
C	***Late2-open***: >5% cover budsage <0.25m; Indian ricegrass and squirreltail present to common; ≥6 years
U-*Annual Grass*	***Annual-Grass***: ≥5% cheatgrass cover; <5% shrub cover
U-*Early-Shrub*	***Early-Shrub***: ≥10% cover rabbitbrush and snakeweed species.
U-*SAP*	***Shrub-Annual-Grass-Perennial-Grass***: 5-15% non-native annual species cover; ≥5% cover of *Atriplex* spp. or other shrubs; native grasses may be present to common.
U-*SAP+*	***Shrub-Annual-Grass-Perennial-Grass+***: >15% non-native annual species cover; ≥5% cover of *Atriplex* spp. or other shrubs; native grasses may be present to common.
U-*SDI*	***Seeded-Introduced***: >10% seeded introduced grasses, forbs, and shrubs; <5% cheatgrass cover; shrubs may be present to common
U-SDI+AG	***Seeded-Introduced+Annual-Grass:*** >10% seeded introduced grasses and shrubs; ≥5% cheatgrass cover; shrubs may be present to common.
U-*Seeded Native*	***Seeded-Native***: >10% native seed mix cover; <5% cheatgrass cover

Montane Riparian (MR)

1154

Overview: The Montane Riparian BpS is found within a broad elevation range above 1,220 m (4,000'). Riparian forests and woodlands require flooding and gravel for reestablishment. The BpS is found in low- to mid-elevation canyons and draws, on floodplains, in steep-sided canyons, or narrow V-shaped valleys with rocky substrates. Sites are subject to temporary flooding during spring runoff, although summer flash floods can have dramatic effects on succession. Underlying gravels may keep the water table just below ground surface, and are favored substrates for cottonwood and willow. In steep-sided canyons, streams typically have perennial flow on mid to high gradients. Surface water is generally high for variable periods. Soils are typically alluvial deposits of sand, clays, silts and cobbles that are highly stratified with depth due to flood scour and deposition. Codominant and diagnostic species include willow, buffaloberry, cottonwood, velvet ash, and conifers. Vegetation is very heterogeneous and diverse along river reaches.

A ***Early***: 0-40% cover of shrub—willow dominates after fire, whereas cottonwood and willow co-dominate after flooding; grass may co-dominate; <50% cover gravel, rock, and boulders, although this may be highly variable by reach; 0-5 yrs

B ***Mid-closed***: 31-100% cover of tall shrubs (willows, buffaloberry) and small trees (velvet ash, conifers) and small cottonwood trees; <20% gravel, rock, and boulders; 5-19yrs

C ***Late-closed***: 31-100% cover of cottonwood, willow, conifers and other trees 10-24m; <20% gravel, rock, and boulders; >20 yrs

U-*Annual Grass* ***Annual-Grass***: >10% cover of cheatgrass on dry incised banks; < 10% shrub cover

U-*Desertified* ***Desertified***: Incised river/creek with 10-50% cover of upland shrubs (e.g., big sagebrush, snakeweed, rabbitbrush); >5% native grass cover

U-*EFT* ***Exotic-Forb-Tree***: >10% cover of exotic forb or tree species (knapweed, tall whitetop, thistles, purple loosestrife, salt cedar, or Russian olive)

U-*SAP* ***Shrub-Annual-Grass-Perennial-Grass***: Incised river/creek with 10-50% cover of upland shrubs (e.g., big sagebrush); >5% cheatgrass cover; >5% native grass cover; ≤20% cover of pinyon-juniper

U-*SDA* ***Seeded-Annual-Grass***: Incised river/creek with >20% introduced grass species cover; >5% cheatgrass cover; pinyon-juniper may be present

U-*Seeded Native* ***Seeded-Native***: >10% seeded basin wildrye, other grasses native to deep loamy soils, forbs, and shrubs; <5% non-native annual species (if ≥5 non-native annual species, then ASPG or even AS)

U-*SFE* ***Shrub-Forb-Encroached***: 10-50% cover of Wood's rose, sumac, or other unpalatable forbs and shrubs in open areas or under tree canopy

U-*TE* ***Tree-Encroached***: Incised river/creek with >20% cover of pinyon or juniper; highly variable cover of riparian shrubs and cottonwood; degree of incision none to pronounced

Montane Sagebrush Steppe (MSS)

1126

Overview: The Montane Sagebrush Steppe BpS (a.k.a., mountain big sagebrush) is found above and intergrades with the mesic sites of the Wyoming Big Sagebrush BpS. Elevation is generally above 2,134 m (6,500') in the southern Great Basin. In general this system shows an affinity for mild topography, fine soils, and some source of subsurface moisture. Soils generally are moderately deep to deep, well-drained, and of loam, sandy loam, clay loam, or gravelly loam textural classes; soils often have a substantial volume of coarse fragments, and are derived from a variety of parent materials. This system primarily occurs on deep soiled to stony flats, ridges, nearly flat ridge tops, and mountain slopes. Vegetation types are usually dominated by Artemisia tridentata *ssp.* vaseyana*, but other high-elevation sagebrush species can be present, even dominant if they are big sagebrush species (e.g., Bonneville big sagebrush). A variety of other shrubs can be found in some occurrences, but these are seldom dominant. Abundant forbs are an indicator of good range condition. Grasses are abundant, sometimes very abundant, and often diverse.*

A	***Early***: 10-80% grass and forb cover; 0-10% canopy of mountain sage, mountain brush; 0-12 yrs
B	***Mid-open***: 11-30% cover of mountain sage, mountain shrub; >50% herbaceous cover; 13-38 yrs
C	***Mid-closed***: >30% cover of mountain sage (dominant) and mountain brush; 25-50% herbaceous cover; <10% conifer sapling cover; 39+ yrs
D	***Late-open***: 10-30% cover pinyon-juniper <3m; 25-40% cover of mountain sage (dominant) and mountain brush; >10% herbaceous cover; 80-129 yrs
E	***Late-closed***: >30% pinyon-juniper cover ≥3m; 6-20% shrub cover; >10% herbaceous cover; 130+ yrs
U-*Annual Grass*	***Annual-Grass***: >10% cover of cheatgrass; snakeweed or rabbitbrush may be present
U-*Depleted*	***Depleted***: >20% cover of mountain sage (dominant) and mountain brush; <5% herbaceous cover; <30% conifer sapling cover; litter and mineral soil common
U-*Early-Shrub*	***Early-Shrub***: >20% cover of snakeweed or rabbitbrush species

U-*SA* ***Shrub-Annual-Grass***: 5-14% cheatgrass cover; >10% cover of mountain sage (dominant) and mountain brush; ≤5% cover of native grass; <30% conifer sapling cover

U-*SA+* ***Shrub-Annual-Grass+***: ≥15% cheatgrass cover; >10% cover of mountain sage (dominant) and mountain brush; ≤5% cover of native grass; <30% conifer sapling cover

U-*SAP* ***Shrub-Annual-Grass-Perennial-Grass***: 5-14% cheatgrass cover; 11-50% cover of mountain sage (dominant) and mountain brush; occasional blackbrush above Mojave Desert slopes; >5% cover of native grass; <30% conifer sapling covers

U-*SAP+* ***Shrub-Annual-Grass-Perennial-Grass+***: ≥15% cheatgrass cover; >10% cover of mountain sage (dominant) and mountain brush; >5% cover of native grass; <30% conifer sapling cover

U-*SDI-A* ***Seeded-Introduced-Early***: >10% seeded introduced grasses and shrubs; 0-10% canopy of mountain sage, mountain brush; native grasses present to common; <5% cover of cheatgrass

U-*SDI-B* ***Seeded-Introduced-Mid-open***: >10% seeded introduced grasses and shrubs; 11-30% cover of mountain sage and mountain shrub; native grasses present to common; <5% cover of cheatgrass

U-*SDI-C* ***Seeded-Introduced-Mid-Closed***: >5% seeded introduced grasses and shrubs**;** >30% cover of mountain sage and mountain shrub; native grasses present to common; <10% conifer sapling cover; <5% cover of cheatgrass

U-*SDI-D* ***Seeded-Introduced-Late-Open***: >5% seeded introduced grasses and shrubs**;** 10-30% conifer cover; 25-40% cover of mountain sage and mountain shrub; native grasses present to common; <5% cover of cheatgrass

U-*Seeded Native* ***Seeded-Native***: >10% seeded native grasses, forbs, and shrubs

U-*SI-A+AG* ***Seeded-Introduced-Early+Annual-Grass***: >10% seeded introduced grasses and shrubs; 0-10% canopy of mountain sage, mountain brush; native grasses present to common; ≥5% cover of cheatgrass

U-*SI-B+AG* ***Seeded-Introduced-Mid-Open+Annual-Grass***: >10% seeded introduced grasses and shrubs; 11-30% cover of mountain sage and mountain shrub; native grasses present to common; ≥5% cover of cheatgrass

U-*SI-C+AG* ***Seeded-Introduced-Mid-Closed+Annual-Grass***: >5% seeded introduced grasses and shrubs**;** >30% cover of mountain sage and mountain shrub; native grasses present to common; <10% conifer sapling cover; ≥5% cover of cheatgrass

U-*SI-D+AG* ***Seeded-Introduced-Late-Open+Annual-Grass***: >5% seeded introduced grasses and shrubs**;** 10-30% conifer cover; 25-40% cover of mountain sage and mountain shrub; native grasses present to common; ≥5% cover of cheatgrass.

U-*TEA* ***Tree-Encroached-Annual-Grass***: >20% pinyon-juniper cover 3-8m tall; <5% shrub cover; <5% herbaceous cover; <5% cheatgrass cover **OR** >20% pinyon-juniper cover 3-8m tall; ≥5% cheatgrass cover; ≥5% shrub cover; ≥5% herbaceous cover

Pinyon-Juniper (PJ)

1019

Overview: The Pinyon-Juniper BpS is typically found from 1,675-2,440 m (5,500-8,000') above the black sagebrush and Wyoming big sagebrush zones. This BpS generally occurs on most soils and landforms, especially fire-safe sites of steep and rocky slopes. Soils supporting this system vary in texture ranging from stony, cobbly, gravelly sandy loams to clay loam or clay. Woodlands comprising this system can be dominated by a mix of Pinus monophylla, Pinus edulis, *and* Juniperus osteosperma*; by pure or nearly pure occurrences of* Pinus monophylla *or* Pinus edulis*; or solely by* Juniperus osteosperma*. Understory layers are variable. Grass and shrub species are often diverse and common, although not abundant.*

A ***Early-open***: 5-20% herbaceous cover; charred stumps and trunks; 0-9 yrs

B ***Mid1-open***: 11-30% cover big sagebrush, black sagebrush, or bitterbrush <1.0m, 10-40% herbaceous cover; 10-29 yrs

C	***Mid2-open***: 11-20% cover of young (<100 yrs old) pinyon and/or juniper <5m, 10-20% shrub cover, <20% herbaceous cover; 30-99 yrs
D	***Late-open***: 21-60% cover of pinyon and/or juniper <5m-9m, 10-40% shrub cover, <20% herbaceous cover; ≥100 yrs
U-*Annual Grass*	***Annual-Grass***: >10% cheatgrass cover; dead pinyon or juniper visible.
U-*Exotic Forb*	***Exotic-Forb***: 5-100% exotic forbs (e.g., thistles, knapweed).
U-*SAP*	***Shrub-Annual-Grass-Perennial-Grass***: >5% cheatgrass; 11-30% cover big sagebrush, black sagebrush, or bitterbrush <1.0m, <40% herbaceous cover
U-*SDI*	***Seeded-Introduced***: >10% seeded introduced grass and forbs; <5% cover of cheatgrass
U-SDI+AG	***Seeded-Introduced+Annual-Grass***: >10% seeded introduced grass and forbs; ≥5% cover of cheatgrass.
U-*Seeded Native*	***Seeded-Native***: >10% seeded native grasses, forbs, and shrubs; <5% cheatgrass cover.
U-*TA*	***Tree-Annual-Grass***: 20-60% cover of pinyon and/or juniper <5m-9m, 10-40% shrub cover, >5% cheatgrass cover; ≥30 yrs

Ponderosa Pine (PP)

1054

Overview: *The Ponderosa Pine BpS is found at the lower treeline/ecotone between grassland or shrubland and more mesic coniferous forests typically in warm, dry, exposed sites. Occurrences are found on all slopes and aspects, though moderately steep to very steep slopes or ridge tops are most common. The BpS generally occurs on igneous, metamorphic, and sedimentary material-derived soils, with characteristic features of good aeration and drainage, coarse textures, circumneutral to slightly acid pH, an abundance of mineral material, rockiness, and periods of drought during the growing season.* Pinus ponderosa *is the predominant conifer;* Pseudotsuga menziesii, Pinus edulis, Pinus monophylla*, and* Juniperus *spp. may be present in the tree canopy. The understory is usually shrubby, with* Artemisia nova, Artemisia tridentata, Arctostaphylos patula, Arctostaphylos uva-ursi, Cercocarpus montanus, Cercocarpus ledifolius, Purshia stansburiana, Purshia tridentata, Quercus gambelii, Symphoricarpos oreophilus, Prunus virginiana, Amelanchier alnifolia*, and* Rosa *spp. common species.* Pseudoroegneria spicata *and species of* Hesperostipa, Achnatherum, Festuca, Muhlenbergia*, and* Bouteloua *are some of the common grasses.* Pinus ponderosa / Arctostaphylos patula *represents the extreme with typically a high percentage of rock and bare soil present.*

A ***Early***: 5-60% cover of shrub/grass; conifer seedlings can be abundant <5m; 0-39yrs

B ***Mid-closed***: 31-60% cover of ponderosa pine, pinyon, juniper, Douglas-fir, and white fir 5-10m; dense shrub cover possible; 40-159 yrs

C ***Mid-open***: 5-30% cover of ponderosa pine (dominant), Douglas-fir, pinyon, juniper, and white fir 5-10m; abundant shrub and grass cover; 40-159 yrs

D ***Late-open***: 5-30% cover of ponderosa pine (dominant), Douglas-fir, pinyon, juniper,and white fir 11-50m; abundant shrub and grass cover; ≥160 yrs

E ***Late-closed***: 31-80% cover of ponderosa pine, Douglas-fir, pinyon, juniper, and white fir 11-50m; mountain snowberry common; ≥160 yrs

U-*Annual Grass* ***Annual-Grass***: saplings plus >10% annual grass cover

U-*TA* ***Tree-Annual-Grass***: Any class A,B,C,D,E plus >5% annual grass cover

Semi-Desert Grassland (SDG)

1135

*Overview: The Semi-Desert Grassland BpS occupies sandy soil and is found at approximately 1,450m to 2,320 m (4,750'-7,610') of elevation. Indian ricegrass (*Stipa hymenoides*) is often the diagnostic and dominant grass species. These grasslands occur in lowland and upland areas and may occupy swales, playas, mesa tops, plateau parks, alluvial flats, and plains, but sites are typically xeric. Substrates are often well-drained sandy or loamy-textured soils derived from sedimentary parent materials but are quite variable and may include fine-textured soils derived from igneous and metamorphic rocks. Where they occur near foothill grasslands, they will be at lower elevations. These grasslands occur on a variety of aspects and slopes. Sites may range from flat to moderately steep. Annual precipitation is usually from 20-40 cm (7.9"-15.7"). Grasslands within this system are typically characterized by a sparse to moderately dense herbaceous layer dominated by medium-tall and short bunch grasses, often in a sod-forming growth. The dominant perennial bunch grasses and shrubs within this system are all very drought-resistant plants.*

A ***Early***: <5% shrub cover (rabbitbrush); >10% cover of grasses (Indian ricegrass, big galleta, bush muhly, desert needlegrass); sandy soil cover may be high; 0-19 yrs

B ***Mid-closed***: ≥5% shrub cover (rabbitbrush, sagebrush); >25% cover of grasses (Indian ricegrass, big galleta, bush muhly, desert needlegrass); sandy soil cover may be high; ≥20 yrs

U-*Depleted* ***Depleted***: ≥5% shrub (mostly rabbitbrush, sagebrush) cover; <10% cover of grasses; 10-30% bare ground cover; <20% cover of pinyon or juniper saplings; sandy soil cover may be high

U-*Early-Shrub* ***Early Shrub***: 10-30% cover of rabbitbrush; 10-30% bare ground cover; <10% native grass cover; sandy soil cover may be high

U-*SAP* ***Shrub-Annual-Perennial-Grass***: 5-14% cover of annual grasses; ≥5% shrub (mostly rabbitbrush, sagebrush) cover; native grasses may be present to common; <20% cover of pinyon or juniper saplings; sandy soil cover may be high

U-*SAP+* ***Shrub-Annual-Perennial-Grass+***: ≥15% cover of annual grasses; ≥5% shrub (mostly rabbitbrush, sagebrush) cover; native grasses may be present to common; <20% cover of pinyon or juniper saplings; sandy soil cover may be high

U-*SDI* ***Seeded-Introduced***: >10% cover of introduced seeded grass species; <5% cover of cheatgrass; sagebrush and other shrubs may be present; sandy soil cover may be moderately high

U-*SDI+AG* ***Seeded-Introduced+Annual-Grass***: >10% cover of introduced seeded grass species; ≥5% cover of annual grasses; sagebrush and other shrubs may be present; sandy soil cover may be moderately high

U-*Seeded Native* ***Seeded-Native***: >10% seeded native grasses, forbs, and shrubs; <5% cheatgrass cover.

U-*TEA* ***Tree-Encroached-Annual-Grass***: >20% mature pinyon-juniper cover; <5% cover of shrubs; **either** <5% cover native grasses **AND** <5% cover of cheatgrass **OR** ≥5% cover of cheatgrass **AND** ≥5% cover native grasses; sandy soil cover may be moderately high

Stansbury Cliffrose (SC)

1086sc

*Overview: The Stansbury Cliffrose BpS is one of three mountain shrub types, where Stansbury cliffrose (*Purshia mexicana*) is the indicator species. Elevation ranges from 915 m to 2,438 m (3,000' to 8,000'), typically on mountain foothills and lower slopes. The BpS is found in small patches on different montane landforms with shallow unproductive soils. This cliffrose form of mountain shrub is usually at lower elevations and adjacent or imbedded in the montane zone adjacent to pinyon - juniper woodlands on moderate to steep slopes, and often follows linear geologic features (rock ledges).*

A ***Early***: 0-10% canopy of Stansbury cliffrose or desert bitterbrush (often resprouting); 10-80% grass and forb cover; 0-12 yrs

B ***Mid-open***: 11-20% cover of Stansbury cliffrose or desert bitterbrush; >25% herbaceous cover;<10% conifer sapling cover; 13-79 yrs

C	***Late-open***: 10-20% pinyon pine-juniper cover 3-8m; >21% cover of Stansbury cliffrose or desert bitterbrush; <30% herbaceous cover; 80-129 yrs
U-*Annual Grass*	***Annual-Grass***: >10% cover of annual grasses; snakeweed or rabbitbrush may be present; dead standing stems of Stansbury cliffrose or desert bitterbrush often present, with desert bitterbrush resprouts if the species is present.
U-*Depleted*	***Depleted***: >20% cover of Stansbury cliffrose or desert bitterbrush; <5% herbaceous cover; <10% conifer sapling cover
U-*Early-Shrub*	***Early-Shrub***: >10% snakeweed or rabbitbrush; <5% non-native annual species cover; native grass may be present; Stansbury cliffrose or desert bitterbrush may be present
U-*SAP*	***Shrub-Annual-Grass-Perennial-Grass***: 5-14% non-native grass cover; >5% cover of Stansbury cliffrose or desert bitterbrush; native herbaceous cover usually present; trees may be present
U-*SAP+*	***Shrub-Annual-Grass-Perennial-Grass+***: ≥15% non-native grass cover; >5% cover of Stansbury cliffrose or desert bitterbrush; native herbaceous cover usually present; trees may be present
U-SDI-A	***Seeded-Introduced-Early*:** >10% seeded introduced grass and shrubs; 0-10% canopy of Stansbury cliffrose or desert bitterbrush (often resprouting); 10-80% grass and forb cover; <5% cover of cheatgrass
U-SDI-B	***Seeded-Introduced-Mid-open***: >10% seeded introduced grass and shrubs; 11-20% cover of Stansbury cliffrose or desert bitterbrush; >25% herbaceous cover; <10% conifer sapling cover; <5% cover of cheatgrass
U-SDI-C	***Seeded-Introduced-Late-open***: >10% seeded introduced grass and shrubs; 10-20% pinyon pine-juniper cover 3-8m; >21% cover of Stansbury cliffrose or desert bitterbrush; <30% herbaceous cover; <5% cover of cheatgrass
U-*Seeded Native*	***Seeded-Native***: >10% seeded native grasses, forbs, and shrubs; <5% cheatgrass cover.

U-SI-A+AG ***Seeded-Introduced-Early+Annual-Grass***: >10% seeded introduced grass and shrubs; 0-10% canopy of Stansbury cliffrose or desert bitterbrush (often resprouting); 10-80% grass and forb cover; ≥5% cover of cheatgrass

U-SI-B+AG ***Seeded-Introduced-Mid-open+Annual-Grass***: >10% seeded introduced grass and shrubs; 11-20% cover of Stansbury cliffrose or desert bitterbrush; >25% herbaceous cover; <10% conifer sapling cover; ≥5% cover of cheatgrass

U-SI-C+AG ***Seeded-Introduced-Late-open+Annual-Grass***: >10% seeded introduced grass and shrubs; 10-20% pinyon pine-juniper cover 3-8m; >21% cover of Stansbury cliffrose or desert bitterbrush; <30% herbaceous cover; ≥5% cover of cheatgrass

U-*TEA* ***Tree-Encroached-Annual-Grass***: >10% mature pinyon-juniper cover 3-8m; **IF** ≥5% cover of non-native annual grasses and forbs **THEN** >0% cover of Stansbury cliffrose or desert bitterbrush **OR** >0% native herbaceous cover; **IF** <5% cover of non-native annual grasses and forbs **THEN** <5% cover of Stansbury cliffrose **AND** <5% native herbaceous cover.

Utah Serviceberry (US)

1086us

Overview: The Utah Serviceberry BpS is one of three mountain shrub types, where Utah serviceberry (Amelanchier utahensis) *is the diagnostic shrub in the absence of Gambel oak. The BpS occupies the same elevation band as pinyon-juniper woodlands and big sagebrush steppe. These shrublands occur between 1,500-2,900 m (4,921-9,515') elevation and are usually associated with exposed sites, rocky substrates, and dry conditions, which limit tree growth. Scattered trees or inclusions of grassland patches or sagebrush steppe may be present, but the vegetation is typically dominated by a variety of shrubs including* Amelanchier utahensis*,* Cercocarpus montanus*,* Purshia tridentata, Rhus trilobata, Ribes cereum, Symphoricarpos oreophilus*, or* Yucca glauca*. In Utah, true mountain mahogany* (Cercocarpus montanus) *is a resprouting shrub that sometimes dominates this ecological system, whereas* Ribes, Acer, *mountain ash (*Sorbus scopulina*), and* Chrysothamnus *are less common.* Artemisia tridentata *ssp.* vaseyana *and* Holodiscus *are more common shrubs on dry sites in Utah and the Great Basin. Grasses are represented as species of* Muhlenbergia *spp.*, Bouteloua *spp.*, Stipa *spp., and* Elymus spicatus*. Fire plays an important role in this system as the dominant shrubs are usually affected by severe die-back, although some plants will stump sprout.* Cercocarpus montanus *requires a disturbance such as fire to reproduce, either by seed sprout or root crown sprouting. Fire suppression may have allowed an invasion of trees into some of these shrublands, but in many cases sites are too xeric for tree growth. When trees are present, they include pinyon pine, juniper, and limber pine. Douglas-fir and white fir may be found on more mesic sites.*

A ***Early***: 0-10% canopy of serviceberry, antelope bitterbrush, or true mountain mahogany; 10-80% grass and forb cover; 0-4 yrs

B ***Mid-open***: 11-30% cover of serviceberry, antelope bitterbrush, or true mountain mahogany; >50% herbaceous cover; 5-19 yrs

C	***Mid-closed***: 31-50% cover of serviceberry, antelope bitterbrush, or true mountain mahogany; 25-50% herbaceous cover; <10% conifer sapling cover; 20-79 yrs
D	***Late-open***: 10-20% pinyon pine-juniper cover <5m; 25-40% cover of serviceberry, antelope bitterbrush, or true mountain mahogany; ≥5% herbaceous cover; ≥80 yrs
U-*Annual Grass*	***Annual-Grass***: ≥10% cover of cheatgrass; snakeweed or rabbitbrush may be present.
U-*Depleted*	***Depleted***: 31-50% cover of serviceberry, antelope bitterbrush, or true mountain mahogany; <5% herbaceous cover; <10% conifer sapling cover
U-*Early-Shrub*	***Early-Shrub***: 20-50% cover rabbitbrush species
U-*SAP*	***Shrub-Annual-Grass-Perennial-Grass***: 5-14% non-native grass cover; 5-40% cover of mountain shrubs; native herbaceous cover usually present; trees may be present
U-*SAP+*	***Shrub-Annual-Grass-Perennial-Grass+***: ≥15% non-native grass cover; 5-40% cover of mountain shrubs; native herbaceous cover usually present; trees may be present
U-SDI-A	***Seeded-Introduced-Early***: >10% seeded introduced grass and shrubs; 0-10% canopy of serviceberry, antelope bitterbrush, or true mountain mahogany; 10-80% grass and forb cover; <5% cover of cheatgrass
U-SDI-B	***Seeded-Introduced-Mid-open***: >10% seeded introduced grass and shrubs; 11-30% cover of serviceberry, antelope bitterbrush, or true mountain mahogany; >50% herbaceous cover; <5% cover of cheatgrass
U-SDI-C	***Seeded-Introduced-Mid-closed***: >10% seeded introduced grass and shrubs; 31-50% cover of serviceberry, antelope bitterbrush, or true mountain mahogany; 25-50% herbaceous cover; <10% conifer sapling cover; <5% cover of cheatgrass
U-SDI-D	***Seeded-Introduced-Late-open***: >10% seeded introduced grass and shrubs; 10-20% pinyon pine-juniper cover <5m; 25-40% cover of serviceberry, antelope bitterbrush, or true mountain mahogany; ≥5% herbaceous cover; <5% cover of cheatgrass
U-SI-A+AG	***Seeded-Introduced-Early+Annual-Grass***: >10% seeded introduced grass and shrubs; 0-10% canopy of serviceberry, antelope bitterbrush, or true mountain mahogany; 10-80% grass and forb cover; ≥5% cover of cheatgrass
U-SI-B+AG	***Seeded-Introduced-Mid-open+Annual-Grass***: >10% seeded introduced grass and shrubs; 11-30% cover of serviceberry, antelope bitterbrush, or true mountain mahogany; >50% herbaceous cover; ≥5% cover of cheatgrass
U-SI-C+AG	***Seeded-Introduced-Mid-closed+Annual-Grass***: >10% seeded introduced grass and shrubs; 31-50% cover of serviceberry, antelope bitterbrush, or true mountain mahogany; 25-50% herbaceous cover; <10% conifer sapling cover; ≥5% cover of cheatgrass
U-SI-D+AG	***Seeded-Introduced-Late-open+Annual-Grass***: >10% seeded introduced grass and shrubs; 10-20% pinyon pine-juniper cover <5m; 25-40% cover of serviceberry, antelope bitterbrush, or true mountain mahogany; ≥5% herbaceous cover; ≥5% cover of cheatgrass
U-*TA*	***Tree-Annual-Grass***: 10-20% pinyon pine-juniper cover 3-8m; ≥5% cover of non-native annual grasses and forbs; 25-40% cover of snowberry, antelope bitterbrush, or true mountain mahogany; <30% herbaceous cover
U-*TE*	***Tree-Encroached***: >21% pinyon pine-juniper cover 3-8m; <5% shrub cover; <5% herbaceous cover

Wet Meadow-Alkali Sacaton (WMas)
1145as

*Overview: The Wet Meadow-Alkali Sacaton BpS is wetted by an elevated water table or is spring-fed. Saturated soils support graminoid dominance. Soils are deep and saline. These wet meadows are found at the bottom of broad valleys and on alluvial flats at elevations of 1,630 m to 1,676 m (5,350 to 5,500') with slopes between 0-2%, usually surrounded by salt tolerant plant communities. Average annual precipitation ranges from 20 to 25 cm (8" to 10"). Alkali sacaton (*Sporobolus airoides*) dominates, although inland saltgrass (*Distichlis spicata*) may co-dominate on some soils. Black greasewood and four-wing saltbush may be present at low abundance.*

A	***Early-open***: 10-60% alkali sacaton or inland saltgrass cover; 0-2 yrs
B	***Mid-closed***: 61-100% alkali sacaton or inland saltgrass cover; 3-22 yrs
C	***Late-open***: 5-10% shrub (greasewood and four-wing saltbush) cover; 60-80% alkali sacaton or inland saltgrass cover; >22 yrs
U-*AGPG*	***Annual-Grass-Perennial-Grass***: <10% cover of native shrubs; ≥10% alkali sacaton or inland saltgrass cover; ≥5 cheatgrass cover; >10% mineral soil cover
U-*Annual Grass*	***Annual-Grass***: >10% cover of cheatgrass; <10% alkali sacaton or inland saltgrass cover; <10% shrub cover; >10% mineral soil cover
U-*Depleted*	***Depleted***: ≥10% shrub cover (greasewood and other shrubs); <60% of inland saltgrass and Baltic rush cover; 10-30% cover of bare ground.
U-*Exotic Forb*	***Exotic-Forb***: >5% exotic forbs (tall whitetop, knapweed, purple loosestrife, Russian thistle)
U-*SAP*	***Shrub-Annual-Grass-Perennial-Grass***: ≥10% cover of native shrubs; >10% alkali sacaton or inland saltgrass cover; ≥5 cheatgrass cover; >10% mineral soil cover

Wet Meadow-Montane (WM)
1145wm

Overview: The Wet Meadow-Montane BpS is wetted by an elevated water table adjacent to creeks or rivers, or is spring-fed. Saturated soils support graminoid dominance. Rushes and sedges dominate with tufted hairgrass and Sandberg bluegrass common. The presence of shrubs (aspen, willow, Wood's rose, sagebrush) at the meadow's edge increases during consecutive drought years and decreases during consecutive high water years.

A	***Early-open***: 10-60% herbaceous cover – mostly graminoids; 0-2 yrs
B	***Mid-closed***: 61-100% herbaceous cover – mostly graminoids; 3-22 yrs
C	***Late-open***: 5-10% tree-shrub (willow, Wood's rose, sagebrush, aspen) cover; 60-80% herbaceous cover – mostly graminoids; >22 yrs
U-*Annual Grass*	***Annual-Grass (on incised meadow)***: >5% cover of cheatgrass; < 10% shrub cover
U-*Desertified*	***Desertified (= incised)***: Entrenched water table with 10-50% cover of sagebrush
U-*Exotic Forb*	***Exotic-Forb***: >5% exotic forbs (knapweed, purple loosestrife, thistles)
U-*Hummocked*	***Hummocked***: Trampled by ungulates; graminoids present to common in and out of holes created by ungulate hoofs.
U-*SA*	***Shrub-Annual-Grass (on incised meadow)***: >10% cover of native shrubs; <5% native grass cover; 5-30% cover of cheatgrass
U-*SDI*	***Seeded-Introduced***: ≥10% cover of introduced undesirable forage species (e.g., smooth brome); >10% native graminoid cover
U-*SFE*	***Shrub-Forb-Encroached***: >10%% cover of less palatable grasses and forbs (e.g., *Iris missouriensis*) **OR** >10% shrub cover (willow, Wood's rose, sagebrush, aspen); 10-30% cover of bare ground
U-*TEA*	***Tree-Encroached-Annual-Grass (on incised meadow)***: >20% conifer cover 10-25m; <5% shrub cover; <5% native herbaceous cover; ≥0% cover of cheatgrass

Winterfat (WF)
1081wf

*Overview: The Winterfat BpS is generally considered part of the mixed salt desert scrub communities. Winterfat communities occupy saline silty or gravelly silty soils on shallow slopes between 1,158 – 1981m (3,800 - 6,500'). Such sites are often found in shallow washes. Average annual precipitation ranges from 7.5-25.4cm (3 to 10"); however, this system is in 12.7-30.3cm (5-8") of effective moisture within this broader range. Winterfat (*Krascheninnikovia lanata*) is the dominant shrub, often monotypic. Snakeweed and rabbitbrush also can be common shrubs. Common grasses are Indian ricegrass, squirreltail, and needle-and-thread.*

A	***Early***: >10% Indian ricegrass, squirreltail, other native grasses; ≤5% cover of rabbitbrush, snakeweed, and other salt desert shrubs; <60% mineral soil <0.5m; 0-49 yrs
B	***Mid1*-open**: 5-20% cover winterfat, rabbitbrush, and other desert shrubs <0.5m; >10% native grass cover; 50-149 yrs
C	***Late1-closed**:* >20% cover winterfat, rabbitbrush, and other salt desert shrubs; >5% grass cover; *>150 yrs*
U-*Annual Grass*	***Annual-Grass***: >10% cheatgrass cover; <5% cover of native shrubs
U-*Depleted*	***Depleted***: >5% cover of winterfat or other shrubs; ≤5% native grass cover; ≤5% cheatgrass cover; ≤5% exotic forb cover

U-*Exotic Forb*	***Exotic-Forb***: >5% cover halogeton or exotic mustards; <10% cover of cheatgrass; >50% mineral soil
U-*SA*	***Shrub-Annual-Grass***: 5-14% cheatgrass cover; >5% cover of winterfat or other shrubs; ≤5% native grass cover
U-*SA+*	***Shrub-Annual-Grass+***: ≥15% cheatgrass cover; >5% cover of winterfat or other shrubs; ≤5% native grass cover
U-*SAP*	***Shrub-Annual-Grass-Perennial-Grass***: 5-14% cheatgrass cover; >5% cover of winterfat or other shrubs; >5% native grass cover
U-*SAP+*	***Shrub-Annual-Grass-Perennial-Grass+***: ≥15% cheatgrass cover; >5% cover of winterfat or other shrubs; >5% native grass cover
U-*SDI*	***Seeded-Introduced***: ≥5% introduced species (crested wheatgrass, forage kochia) seed mix cover; <5% cheatgrass cover
U-*SDI+AG*	***Seeded-Introduced+Annual-Grass***: ≥5% introduced species (crested wheatgrass, forage kochia) seed mix cover; ≥5% cheatgrass cover
U-*Seeded Native*	***Seeded-Native***: ≥10% native grass species seed mix cover; <5% cheatgrass cover

Wyoming Big Sagebrush upland (WSup)
1080

*Overview: The Wyoming Big Sagebrush upland BpS is common in the Basin and Range province. It ranges from 1,219 m to 2,132 m (4,000' - 7,000') in elevation, and occurs on well-drained soils on foothills, terraces, slopes and plateaus. It is found on soil depths greater than 45 cm (18") and up to 152 cm (60+"). The BpS is found between low elevation salt desert shrub typically unfavorable to tree establishment and higher elevation mountain big sagebrush zones where pinyon and juniper can establish. The BpS occurs from 10 cm to 35 cm (4 to 14") precipitation zones; however, Wyoming big sagebrush requires 20-30 cm (8-12") of effective moisture within this broader range. Thus, other site characteristics (e.g. aspect, drainage) should be considered in identifying this BpS. At the precipitation extremes, this BpS generally occurs as small patches and stringers. Shrub canopy cover generally ranges from 5 to 25%, but can exceed 30% at the upper elevation and precipitation zones. Wyoming big sagebrush sites have fewer understory species relative to other big sagebrush types. Rubber rabbitbrush may be co-dominant and basin big sagebrush might occur on concave sites with finer soils. Perennial forb cover is usually <10% and perennial grass cover reaches 20 - 25% on more productive sites. Bluebunch wheatgrass may be a dominant species following replacement fires and as a co-dominant after 20 years, but only in precipitation zones above 25 cm (10"). Bottlebrush squirreltail and Indian ricegrass are common on more xeric sites. Percent cover and species richness of understory are determined by site limitations. Pinyon pine (*Pinus monophyla *and* Pinus edulis*) and juniper (generally* Juniperus osteosperma*) are present, occasionally reaching 50% canopy cover in areas that have escaped fire.*

A	***Early***: 10-25% herbaceous cover; <10% cover of rabbitbrush species; <10% cover of Wyoming big sagebrush; 0-20 yrs
B	***Mid-open***: 11-20% cover of Wyoming big sagebrush; 10-25% herbaceous cover; 20-60 yrs
C	***Late1-closed***: >20% cover of Wyoming big sagebrush; 10-20% native herbaceous cover; 60-100 yrs;
D	***Late2-open***: 0-15% pinyon or juniper sapling <5m tall; 10-25% cover of Wyoming big sagebrush; <15% native herbaceous cover; 100-150 yrs;
E	***Late2-closed***: >20% pinyon or juniper cover <10m tall; <10% cover of Wyoming big sagebrush; ~5% native herbaceous cover; 150+ yrs
U-*Annual Grass*	***Annual-Grass***: >10% cover of cheatgrass
U-*Depleted*	***Depleted***: >20% cover of big sage (dominant); <5% herbaceous cover; <30% conifer sapling cover; litter and mineral soil common

U-*Early-Shrub*	***Early-Shrub***: >10% cover rabbitbrush species
U-*SA*	***Shrub-Annual-Grass***: 5-14% cover cheatgrass; ≥10% Wyoming big sagebrush <0.5m; scattered pinyon-juniper saplings may be present; native grasses rare
U-*SA+*	***Shrub-Annual-Grass+***: ≥15% cover cheatgrass; ≥10% Wyoming big sagebrush <0.5m; scattered pinyon-juniper saplings may be present; native grasses rare
U-*SAP*	***Shrub-Annual-Grass-Perennial-Grass***: 5-14% cover cheatgrass; ≥10% Wyoming big sagebrush <0.5m; 5-20% cover native grasses; scattered pinyon-juniper saplings may be present
U-*SAP+*	***Shrub-Annual-Grass-Perennial-Grass+***: ≥15% cover cheatgrass; ≥10% Wyoming big sagebrush <0.5m; 5-20% cover native grasses; scattered pinyon-juniper saplings may be present
U-*SDI-A*	***Seeded-Introduced-Early***: ≥10% cover of introduced forage species (e.g., crested wheatgrass, intermediate wheatgrass, or forage kochia); <10% cover of rabbitbrush species; <10% cover of Wyoming big sagebrush; native grass may be present to common; <5% cover of cheatgrass
U-*SDI-B*	***Seeded-Introduced-Mid-open***: ≥10% cover of introduced forage species (e.g., crested wheatgrass, intermediate wheatgrass, or forage kochia); 11-20% cover of Wyoming big sagebrush; native grass may be present to common; <5% cover of cheatgrass
U-*SDI-C*	***Seeded-Introduced-Late1-closed***: ≥10% cover of introduced forage species (e.g., crested wheatgrass, intermediate wheatgrass, or forage kochia); 20-40% cover of Wyoming big sagebrush; native grass may be present to common; <5% cover of cheatgrass
U-*SDI-D*	***Seeded-Introduced-Late2-open***: ≥10% cover of introduced forage species (e.g., crested wheatgrass, intermediate wheatgrass, or forage kochia); 0-15% pinyon or juniper sapling <5m tall; 10-25% cover of Wyoming big sagebrush; native grass may be present to common; <5% cover of cheatgrass
U-*Seeded Native*	***Seeded-Native***: >10% seeded native grasses, forbs, and shrubs; <5% cheatgrass cover.
U-*SI-A+AG*	***Seeded-Introduced-Early+Annual-Grass***: ≥10% cover of introduced forage species (e.g., crested wheatgrass, intermediate wheatgrass, or forage kochia); <10% cover of rabbitbrush species; <10% cover of Wyoming big sagebrush; native grass may be present to common; ≥5% cover of cheatgrass
U-*SI-B+AG*	***Seeded-Introduced-Mid-open+Annual-Grass***: ≥10% cover of introduced forage species (e.g., crested wheatgrass, intermediate wheatgrass, or forage kochia); 11-20% cover of Wyoming big sagebrush; native grass may be present to common; ≥5% cover of cheatgrass
U-*SI-C+AG*	***Seeded-Introduced-Late1-closed+Annual-Grass***: ≥10% cover of introduced forage species (e.g., crested wheatgrass, intermediate wheatgrass, or forage kochia); 20-40% cover of Wyoming big sagebrush; native grass may be present to common; ≥5% cover of cheatgrass
U-*SI-D+AG*	***Seeded-Introduced-Late2-open+Annual-Grass***: ≥10% cover of introduced forage species (e.g., crested wheatgrass, intermediate wheatgrass, or forage kochia); 0-15% pinyon or juniper sapling <5m tall; 10-25% cover of Wyoming big sagebrush; native grass may be present to common; ≥5% cover of cheatgrass
U-*TEA*	***Tree-Encroached-Annual-Grass***: 11-60% cover of trees 5-9m; cheatgrass may be present to abundant; native grasses absent or trace amounts

Supplemental

File S2. Custom Python computer program to conduct resampling

A – Script

```
#-------------------------------------------------------------------------------
# Name:        Black Mountain Resampling
# Purpose:     Resample land cover raster from 5-m to 50-m resolution, while prioritizing/preserving
select systems and classes.
# Author:      tanderson
# Modified:    March 31, 2017
#-------------------------------------------------------------------------------
# Import ArcGIS modules
import arcpy
from arcpy import env
from arcpy.sa import *

# Make sure the Spatial Analyst extension is on
arcpy.CheckOutExtension("spatial")

# Set environment settings
env.workspace = r"K:\GIS3\Projects\CCFO_BLM\Geodata\Scripts\BM_Resample"
Workspace = env.workspace
env.overwriteOutput = True

# Cast rasters and set local variables
orig_rast = arcpy.Raster("fnl_BM_sysxcla042017.tif")
rule_table = "BMRanks_042417.dbf"

# Create and save a new raster based on the Ecological System x Vegetation Class field
orig_lu = arcpy.sa.Lookup(orig_rast, "SYSXCLA")
orig_lu.save("orig_lu")

# Join raster with table holding priority codes
arcpy.JoinField_management("orig_lu", "VALUE", rule_table, "SYSXCLA", ["PRIOR"])

# Create and save a new raster based on the priority code field
prior_lu = arcpy.sa.Lookup("orig_lu", "PRIOR")
prior_lu.save("prior_lu")

# Extract values with non-zero priority codes, execute block statistics (maximum) with 60-m window,
and resample at 60 m resolution
priorityExtract = ExtractByAttributes("prior_lu", "VALUE > 0")
priorityExtract.save("prior_extr")
nbr = NbrRectangle(10,10,"CELL")## change these numbers to the value that results from dividing the
resampled resolution by the original resolution
priorityBlockStat = BlockStatistics("prior_extr", nbr, "MAXIMUM", "DATA")
priorityBlockStat.save("prior_blst")
arcpy.Resample_management("prior_blst", "prior_resamp", "50", "NEAREST")
arcpy.JoinField_management("prior_resamp", "Value", "orig_lu", "PRIOR", ["VALUE"])
prior_lu2 = arcpy.sa.Lookup("prior_resamp", "VALUE_1")
```

```
prior_lu2.save("prior_resamp2")
# Run Majority Filter on original raster w/o regard to PRIORITY codes, then resample at 60-m resolution
outMajFilt = MajorityFilter("orig_lu", "FOUR", "MAJORITY")
outMajFilt.save("orig_majfil")
arcpy.Resample_management("orig_majfil", "orig_resamp", "50", "NEAREST")## change this value to
resampled resolution value

# Mosaic resampled rasters (order is important), join other fields, and extract with 50-m mask.  Change
"mosaic_50m" to new resampled resolution size
arcpy.MosaicToNewRaster_management("prior_resamp2; orig_resamp", Workspace, "mosaic_50m", "",
"32_BIT_SIGNED", 50, 1, "FIRST", "")## change
arcpy.JoinField_management("mosaic_50m", "VALUE", orig_rast, "SYSXCLA", ["SYS_NAME",
"SYS_CODE", "CLA_NAME", "CLA_CODE", "SYSXCLA"])
arcpy.CopyRaster_management("mosaic_50m", "BM_50m_062417.tif") ##change name of file
```

B – Priority Ranks

Ranking table does not contain any vegetation system or classes that were not given a priority ranking. The higher the ranking the higher the priority was in the resampling script.

Ecological System	System Code	Vegetation Class	Class Code	Ranking
Wet Meadow-montane	11450	U:Exotic Forb	108	298
Wet Meadow-montane	11450	U:SFE	337	297
Wet Meadow-montane	11450	C:Open	32	296
Wet Meadow-montane	11450	B:Closed	21	295
Aspen Woodland	10110	U-Depleted	403	294
Aspen Woodland	10110	C:Closed	30	293
Montane Riparian	11540	U:EFT	106	292
Saline Meadow	11451	U:Exotic Forb	108	291
Basin Wildrye	10801	U:Exotic Forb	108	290
Montane Riparian	11540	A:All	10	289
Montane Riparian	11540	B:Open	21	288
Montane Riparian	11540	C:Closed	30	287
Montane Riparian	11540	U:Desertified	304	286
Montane Riparian	11540	U:SAP	324	285
Montane Riparian	11540	U:SFE	337	284
Mixed Conifer	10520	B:Closed	21	283
Mixed Conifer	10520	C:Closed	22	282
Mixed Conifer	10520	C:Open	32	281

Supplemental

Table S3.1. Rasters uploaded to ST-Sim.

Name	Affects	Source
Ecological Systems	Stratifies STSMs	Local remote sensing raster
Vegetation Classes	Populates STSM "boxes"	Local remote sensing raster
Land Ownership	Stratifies restoration & budgets	Public data: https://gis.utah.gov/data/
Digital Elevation Model	Modifies spread of fire; used to calculate slope to constraint some restoration equipment to <15% slope	https://geography.wr.usgs.gov/ sfcreek/dem.html
Non-random Fire Initiation	Assigns fire ignition probability to each pixel	Federal lightning strike detection data: https://www.vaisala.com/en/products/data/data-sets/nldn
Sage-grouse leks	Prevents mechanical shrub removal within a certain radius of leks	State of Utah's Division of Wildlife Resources restricted spatial lek data
Utah prairie dog population management areas	Determines the primary focal areas for prairie dog habitat improvements	State of Utah's Division of Wildlife Resources restricted Utah prairie dog polygon data

Supplemental

File S4. Creating transition multipliers for ST-Sim

Table S4.1. Non-quantitative hypotheses of climate timeseries affecting important ecological processes.

Ecological Process Affected	Source of Data	Contribution
Exotic Species Invasion	CO_2 projection for A2 scenario 2007 IPCC report	Fertilizes exotic forbs and trees
Exotic Species invasion	SPI 12mo scale in September for current year (t)	Wet Year as correlated surrogate for annual flows that increase soil moisture and propagule transport, and, therefore, fertilizes exotic forb and tree invasion
May Hard Freeze	Min Temperature in March from Cedar City (UT) Airport	Early spring thaw in aspen from higher than normal minimum temperature woodland that causes early budding
May Hard Freeze	Min Temperature in April from Cedar City (UT) Airport	Early spring thaw in aspen from higher than normal minimum temperature woodland that causes early budding
May Hard Freeze	Min Temperature in May from Cedar City (UT) Airport	Hard freeze in aspen woodland that kills buds and loss of clone
36-month drought mortality	SPEI 36mo scale in September over previous (t-1), current (t), and next (t+1) years	100% drought-induced failure of introduced seedings during the current year (t) of seeding and two years following (t+1, t+2) the seeding
24-month drought mortality	SPI 24mo scale in September for previous year (t-1) and current year (t)	100% drought-induced failure of native species seedings the current year (t) and next year (t+1)
Severe Drought	SPI 72mo scale in September of current year (t)	Drought-induced mortality for most shrub and tree in upland systems and stalls woody succession in most moist and upland systems
Shrubland Fire Activity	SPI 24mo scale in Sept. for two previous years (t-2, t-1)	Greater soil moisture increases fine fuel accumulation prior to current year
Shrubland and Forest Fire Activity	SPI 8mo scale in September for current year (t)	Ignition and spread of fire during current dry year more likely

Table S4.1. Non-quantitative hypotheses of climate timeseries affecting important ecological processes.

Ecological Process Affected	Source of Data	Contribution
Wet Year	SPI 4mo scale in June of current year (t)	Increases non-native annual species cover in already invaded uplands and shrub cover thinning in wet meadows
Very Wet Year	SPI 6mo scale in May of current year (t)	Mortality of mixed salt desert shrubs by drowning of salt desert roots during winter high water table and shrub mortality in wet meadows
Annual Species Invasion	SPI 9mo scale in June of current year (t)	Higher than normal soil moisture favors non-native annual species germination and establishment during winter, spring and summer
Tree (native) Invasion	SPI 6mo scale in September of current year (t)	Higher than normal soil moisture favors tree germination and establishment during spring and summer

The hypotheses described in Table S4.1 are expressed below in graphical and equations (Table S4.1). SPI (shown as SPEI in figures below) is expressed as 100 × SPI, which implies 100 × ±Standard deviations from average SPI. We used the number of standard deviations to differentiate between levels of severity, such as wet-year at $100 \leq SPI < 200$ vs. very-wet-year at $SPI \geq 200$. Average drought varied between $-100 < SPI < 100$. SPI is expressed monthly for a specified month (e.g., September) and lagged backwards for a specified number of months (e.g., the last 4 months, last 12 months, or last 72 months).

Table S4.2. Variability factors used to build temporal multipliers for ecological processes directly affected by temperature and precipitation, or through water stress, as expressed by the Standard Precipitation Index (SPI), and CO_2 concentrations. The symbol "×"indicates multiplication of the two temporal multipliers.

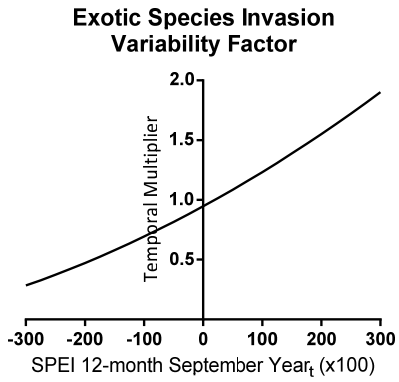
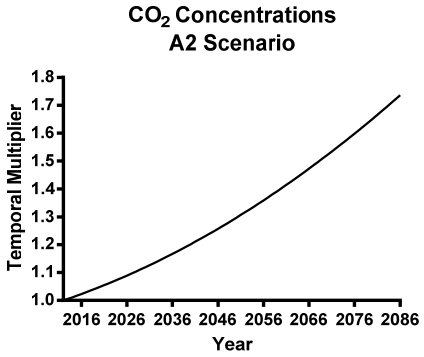
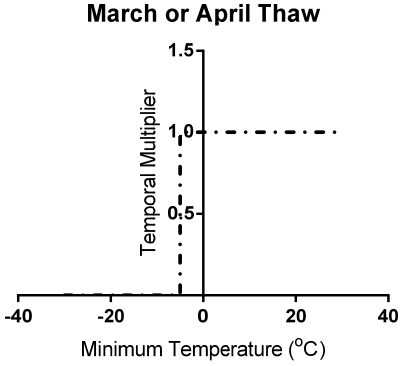
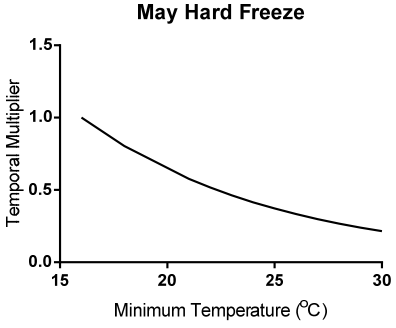
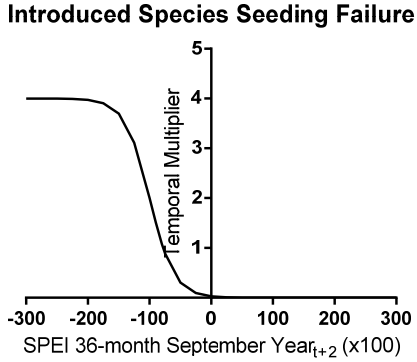
Ecological Process Affected	First factor	Second Factor
Exotic Species Invasion[1]: TM# corresponding to the 12-month SPI of that year (regressed to represent annual flows in riparian corridor) is multiplied by the TM for CO_2 enrichment of the same year if the management scenario includes climate variability forcing.		× 
May Hard Freeze[2]: TM obtained by multiplying binary functions for early spring thaw in March and April causing bud breaks followed by bud kill during hard May freeze.		× 
36-month drought mortality[3]: Three-year drought one year prior and two years into the future will cause introduced species failure.		

Table S4.2. Variability factors used to build temporal multipliers for ecological processes directly affected by temperature and precipitation, or through water stress, as expressed by the Standard Precipitation Index (SPI), and CO_2 concentrations. The symbol "×"indicates multiplication of the two temporal multipliers.

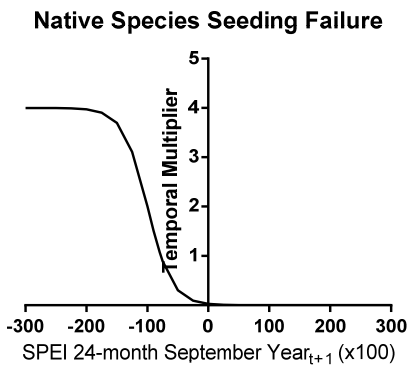
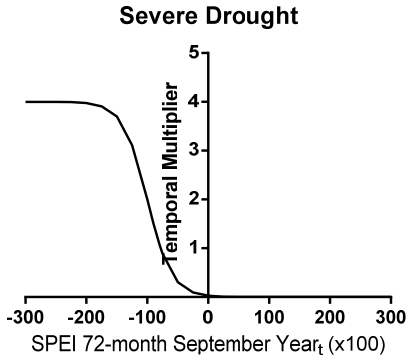
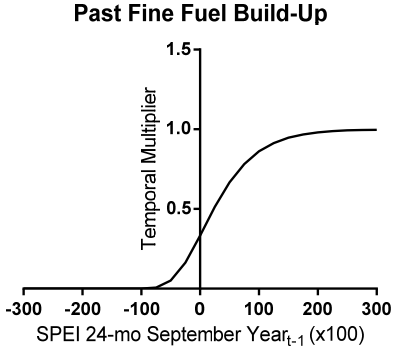
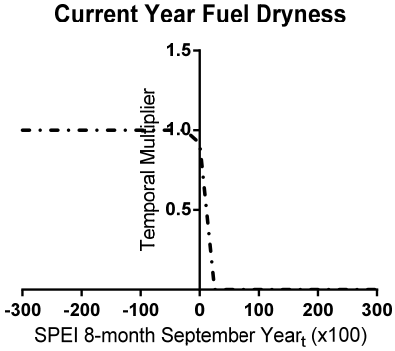
Ecological Process Affected	First factor	Second Factor
24-month drought mortality[3]: Two-year drought one year prior and one year into the future will cause native species failure.		
Severe Drought[3]: Five-year drought for the current and past four years will cause shrub and tree thinning, and affect woody succession in wet systems.		
Shrubland Fire Activity[4]: Greater fire activity occurs in shrub systems if fine fuels first accumulate two years prior to the current year, followed by year with dry fuels. The resulting functions multiplied the historic maximum fire size of each landscape. TM is calculated from the estimated area burned.	 × 	

Table S4.2. Variability factors used to build temporal multipliers for ecological processes directly affected by temperature and precipitation, or through water stress, as expressed by the Standard Precipitation Index (SPI), and CO_2 concentrations. The symbol "×"indicates multiplication of the two temporal multipliers.

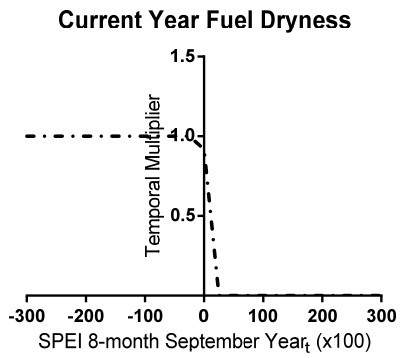
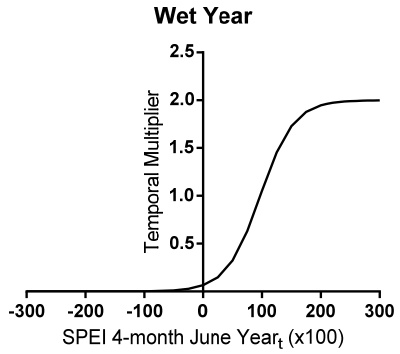
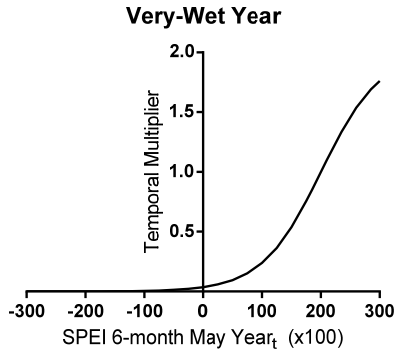
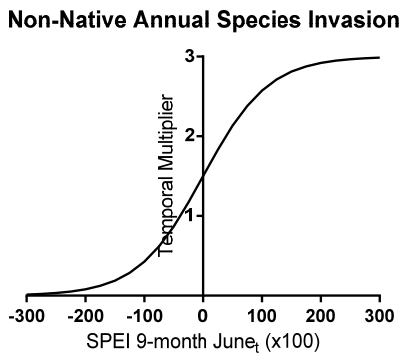
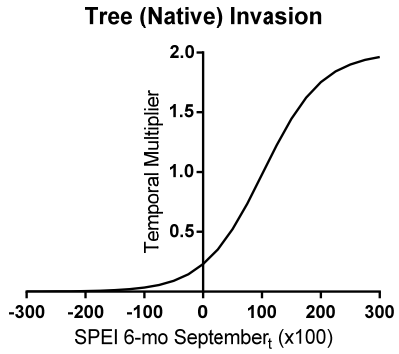
Ecological Process Affected	First factor	Second Factor
Forest Fire Activity[4]: Greater fire activity occurs in forest systems if current year is dry. The resulting functions multiplied the historic maximum fire size of each landscape. TM is calculated from the estimated area burned.		
Wet Year[5]: A wet year is equal to one standard deviation more moisture than the mean; TM = 1 when SPI = 100. Wet years primarily fertilize cheatgrass cover-increase in upland systems, and slightly reverse woody succession in saline and wet meadows.		
Very-Wet year[6]: A very-wet year is equal to two standard deviations more moisture than the mean; TM = 1 when SPI = 200. Wet year was only used as a stand replacing event in salt desert communities through root rot.		

Table S4.2. Variability factors used to build temporal multipliers for ecological processes directly affected by temperature and precipitation, or through water stress, as expressed by the Standard Precipitation Index (SPI), and CO_2 concentrations. The symbol "×"indicates multiplication of the two temporal multipliers.

Ecological Process Affected	First factor	Second Factor
Annual Species Invasion[7]: Non-native annual species can invade even during droughts: Invasion is enhanced at SPI>-0.42 STDEV from mean.		
Tree (Native) Invasion[8]: Conifer species (primarily pinyon and juniper) germinate and establish during wet years: Invasion is enhanced at SPI>+1 STDEV from mean.		

Footnotes for Table S4.1 are listed below:

[1] Annual Flow$_t$ = 49.9158 + 0.1421·SPI$_{Sept[t]}$ + 0.000085259·SPI$_{Sept[t]}^2$

[#] All Temporal Multipliers (TMs) are calculated by dividing each yearly value by temporal average.

[2] March or April Thaw$_t$ variability factor = 1 if minimum temperature$_t$ ≥5°C, = 0 if <5°C. May Hard Freeze$_t$ variability factor = $e^{-0.11\cdot(\text{Minimum May Temperature}_t - \text{Historic May Temperature from 1948 to 2013})}$

[3] General Drought$_t$ variability factor = $4\cdot e^{-2\cdot(0.01\cdot SPI_{t+2})}/(1+e^{-2\cdot(0.01\cdot SPI_{t+2})})$, where SPI$_t$ can be 24-month, 36-month, or 72-month SPI Sept$_t$.

[4] Shrubland Area Burned$_t$ variability factor = $\text{MaxFire}_{SH}\cdot e^{-1.1\cdot\exp(-0.02\cdot SPI_{Sep[t-1],24mo})}\cdot(1-e^{-2.5\cdot\exp(-0.5\cdot SPI_{Sep[t],8mo})})$; Hamlin Valley maximum fire size = 3189, Black Mountain maximum fire size = 10592 acres.

[5] Wet Year$_t$ variability factor = $2\cdot e^{3.5\cdot(0.01\cdot(SPI_{June[t],4mo}+213)-3.1)}/(1+e^{3.5\cdot(0.01\cdot(SPI_{June[t],4mo}+213)-3.1)})$

[6] Very-Wet Year$_t$ variability factor = $2\cdot e^{2\cdot(0.01\cdot(SPI_{May[t],6mo}+264)-4.64)}/(1+e^{2\cdot(0.01\cdot(SPI_{May[t],6mo}+264)-4.64)})$

[7] Non-Native Annual Species Invasion$_t$ variability factor = $3\cdot e^{1.8\cdot(0.01\cdot SPI_{June[t],9\text{-}mo})}/(1+e^{1.8\cdot(0.01\cdot SPI_{June[t],9\text{-}mo})})$

[8] Tree (Native) Invasion$_t$ variability factor = $2\cdot e^{2\cdot(0.01\cdot(SPI_{Sep[t],6\text{-}mo}+288)-3.9)}/(1+e^{2\cdot(0.01\cdot(SPI_{Sep[t],6\text{-}mo}+288)-3.9)})$

Temporal multipliers for peak flooding depend on peak flow time series, temperature and precipitation, but the process to estimate future peak flows from the temperature and precipitation generated by the SWG was complex because peak flow is not directly estimated by the SWG. The temporal multiplier for flood events was simply calculated from estimated

future peak flows in the traditional manner (yearly value divided by temporal average), but obtaining these estimates was challenging.

The first step of peak flow forecasting was to obtain the flow thresholds for the 7-year, 20-year, and 100-year flood events. This step was unchanged from the original study where 7-year, 20-year, and 100-year flood thresholds were, respectively, 707.9, 907.8, and 1015.5 cfs (Provencher et al. 2015). All peak flows that were estimated (see below) were filtered according to these thresholds: (a) Yearly estimated peak flow <707.9 cfs was zero for the lowest threshold of 7-year flood events, but peak flow ≥707.9 cfs at least qualified as a 7-year event; (b) yearly estimated peak flow <907.8 cfs was zero for the 20-year event, but peak flow ≥907.8 cfs threshold at least qualified as a 20-year event; and (c) yearly estimated peak flow <1015.5 cfs was zero for the 100-year event, but peak flow ≥1015.5 cfs threshold qualified as a 100-year event. Many replicates spanning 60 years did not experience a single 100-year event.

The next step was to separate different sources of monthly peak flow to estimate yearly peak flow. We assumed that summer (July to September) monthly peak flow is caused by cloud bursts, whereas non-summer monthly peak flow is related to snow accumulation and temperatures causing rapid snow melt. Furthermore, we assumed that peak flow was the excess flow above base flow and the sum of base flow and peak flow did not exceed the maximum monthly peak flow ever observed in the landscape. Base flow was estimated to be the lowest monthly mean flow ever observed from August to October on Beaver River near Beaver, UT (# USGS 10234500 BEAVER RIVER NEAR BEAVER, UT). Base flow probably varies per year, but we chose estimation among all years of record for simplification. Base flow, which was 10.7 cfs, was the contribution of the water table to flow when all surface runoff ends. Maximum peak flow was obtained as the highest recorded value of peak flow at the same USGS gage: 1080 cfs. Equations for future monthly peak flow were:

$$\text{Summer Peak Flow}_i = \text{Base Flow}_i + (\text{Max Flow}_i - \text{Base Flow}_i)\cdot e^{-10\cdot\exp(-0.03\cdot[P_i - \underline{P}_i])},$$

where i = 7, 8, or 9 for, respectively, July, August, or September, P_i is future precipitation for month i, and $\underline{P}_i$ is the monthly average precipitation for month estimated among all years of record. Monthly average precipitation for July, August, and September were, respectively, 30.3, 39.2, and 21.8 mm. Summer peak flow is estimated using a Gompertz equation (Figure S4.1).

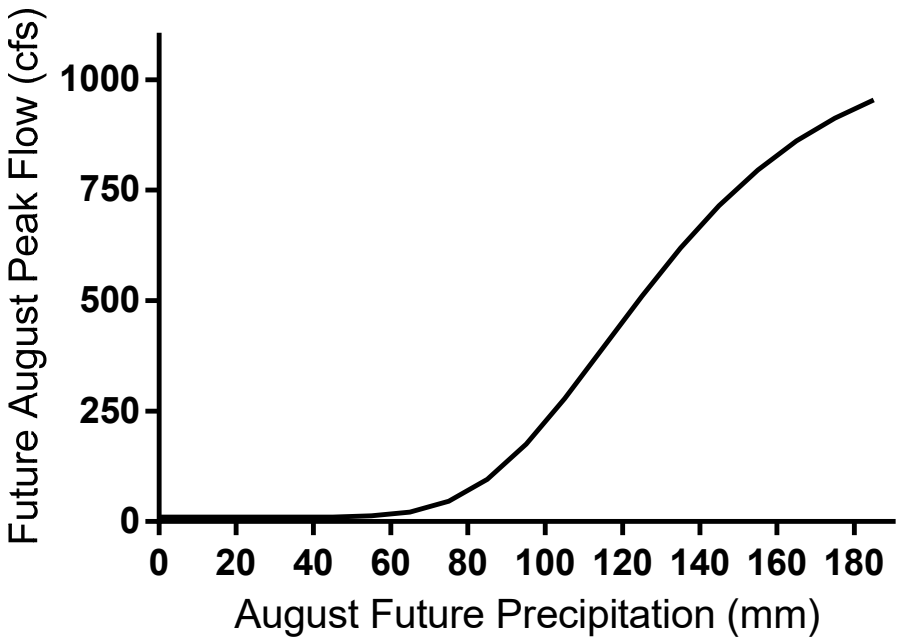


Figure S4.1. Estimated future August peak flow based on forecasted August precipitation. The same relationship is used for the months of July and September.

Monthly peak flow was assumed to depend on snow accumulation (more precipitation in all previous and current months causing more flow) and monthly minimum temperature (higher minimum temperature causing more snowmelt and runoff). Monthly minimum temperature was considered important to snowmelt because above-freezing nighttime temperature will allow snowmelt during the whole day, whereas nighttime freezing would buffer the snowpack against rapid snowmelt as temperature rises during daytime (Figure S4.2):

$$\text{Snowmelt Peak Flow}_i = \text{Base Flow}_i + (\text{Max Flow}_i - \text{Base Flow}_i) \cdot e^{-1 \cdot \exp[\text{Tmin}_i]} \cdot e^{-10 \cdot \exp[-0.03 \cdot (\Sigma\text{Precip}_i - \text{Average } \Sigma\text{Precip}_i)]}$$

where Tmin_i is the minimum temperature in month i, ΣPrecip_i is the cumulative winter precipitation estimated by the SWG from December to month i (i ≤June), and Average ΣPrecip_i is the average cumulative winter precipitation from December to month i assessed over the 65-year period (Table S4.2).

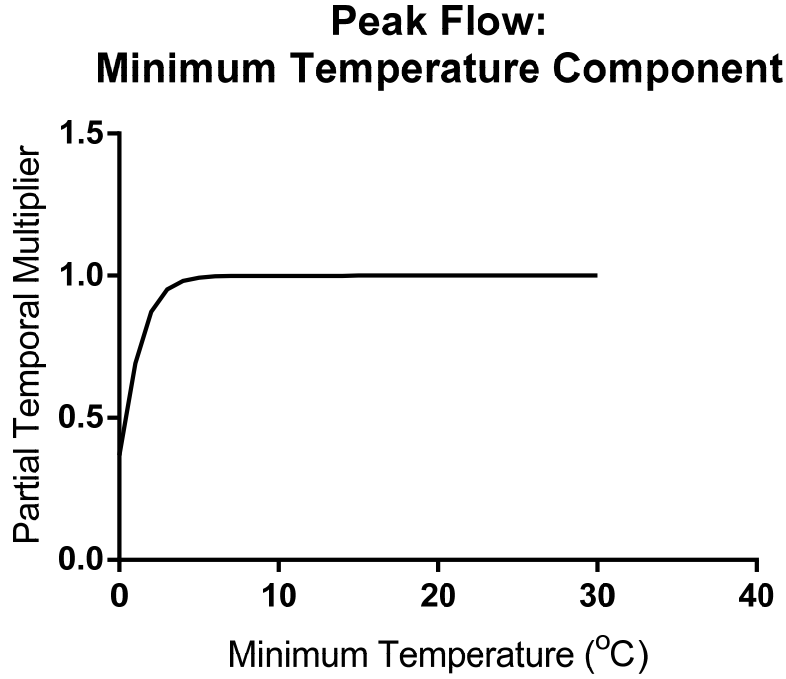


Figure S4.2. The contribution of minimum temperature to peak flow for the months of December to June. Partial temporal multiplier is equal to $e^{-1 \cdot \exp[Tmin_i]}$.

Table S4.1. Average cumulative precipitation corresponding to the period of potential snowmelt. Precipitation is assumed to accumulate as snow, and then contribute to surface runoff during thawing.

Snowmelt Month	Average Cumulative Precipitation to Month
December	28.36
January	51.90
February	79.51
March	113.61
April	148.16
May	177.72
June	192.66
October	N/A
November	N/A

Peak flow was estimated for all months of each year. The highest peak flow of any of the 12 monthly values of peak flow was selected as the yearly peak flow for that year. This process was repeated for each of the 65 years of each time series forecasted by the SWG. The temporal multiplier was obtained by dividing the yearly peak flow by the 60-year temporal average of peak flow.

Supplemental

File S5. Range Shifts.

Range shifts are more likely to occur at the lowest elevation and warmest slope for any system where the impact of increasing temperatures and water stress will be experienced by a species within its range. Each pixel's heat loading index based on aspect and slope was calculated using the "hli" function in R package 'SpatialEco' (Evans 2017). A score that decreases from 1 was used to quantify the elevational range occupied by each system in the landscape, where 1 equals the lowest elevation of the area occupied by each ecological system. Therefore, a value of 1 indicates a higher propensity to experience a range shift based on elevation alone.

To increase control over the rate of range shift, which was modeled as a disturbance, it was hypothesized that shifts occur during stand replacing events as adults would be far more resistant to climate warming variability than seedlings; therefore, range shifts only happened during the first year any pixel if probabilistically selected for transition to an early successional class (Halofski et al. 2013; Creutzburg et al. 2015; Provencher et al. 2016) and happen only once in a 60-year simulation, thus affording greater control on estimating range shift rates. The 100-year range shift rate expressed in the first year of an early-succession class, or the probability per year, was gradually introduced to the simulation under the assumption that climate variability forcing was currently very low (although present) and ramped up over time. The transition multiplier causing range shifts to increase over 100 years below and then above the base rate was weekly quadratic:

$$\text{Transition multiplier for range shifts} = 0.03066 + 0.009181 \cdot \text{Year} + 0.0001523 \cdot \text{Year}^2.$$

Moreover, the temporal average of values over 100 years was roughly one, meaning that the full range shift rate would only be realized over a century. However, over the 60 years of the study's simulation period, the temporal average was approximately 0.5, which indicated that half of the 100-year conversion rate was experienced.

Finally, the rates of conversion from original to recipient ecological system(s) were determined by four factors: (1) their productivity; (2) whether the losing and gaining indicator species are the same (for example, Wyoming big sagebrush on upland soils to Wyoming big sagebrush on semi-desert soils); (3) different species that are already overlapping at the same location (for example, Wyoming big sagebrush to Mixed Salt Desert); and (4) species not currently present in the landscape requiring long distance dispersal. The highest rates of range shifts (50% or 60% over 100 years, depending on the system) were used when three conditions were met: (1) the original and recipient indicator species were the same; (2) the pixels were in ecological systems with intermediate to high productivity; and (3) systems were at montane to subalpine elevations. All rates for shifts among the same indicator species dropped by 10% for low productivity ecological systems.

BLM and TNC staff hypothesized several ecological systems were recipient of pixels experiencing range shifts and distributed the 100-year conversion rates among the most probable recipient systems according to their best expert opinion. These allocations were added to the ST-Sim range shifts pathways (i.e., the range shift was proportionally divided among recipient systems and their matching vegetation classes).

In addition to the allocation, the 100-year conversion rates were converted to per-year rates. The realized range shift rate per system in ST-Sim was difficult to estimate because it depended on the 100-year conversion rate, the number of early succession classes in any ecological system, the total rate of

stand-replacing events in each ecological system, and the proximity to any other system(s) with very different fire return intervals. Estimating the realized rate was a trial-and-error process.

Table S5.1. Hypothesized directions and rates of range shifts for the Black Mountains. Ecological systems are approximately arranged by elevation in the Great Basin.

Original Ecological System	100-yr Conversion (%)	Prob./yr in ST-Sim	New (Replacing) Ecological System	Allocation by new Ecological Systems (%)#
Limber-Bristlecone Pine	5	0.0166	Mixed Conifer	3
			Curl-leaf Mountain Mahogany	2
Aspen-Mixed Conifer	20	0.0714	Mixed Conifer	10
			Montane Sagebrush Steppe	5
			Ponderosa Pine	5
Mixed Conifer	10	0.0264	Pinyon-Juniper	5
			Ponderosa Pine	5
Curl-leaf Mountain Mahogany	5	0.0451	Black Sagebrush	2
			Pinyon-Juniper	2
			Wyoming Big Sagebrush	1
Aspen Woodland	20	0.0714	Montane Sagebrush Steppe	15
			Utah Serviceberry	5
Gambel Oak-Mountain Shrub	10	0.0604	Utah Serviceberry	2
			Wyoming Big Sagebrush	4
			Pinyon-Juniper	4
Ponderosa Pine	15	0.2048	Pinyon-Juniper	10
			Curl-leaf Mountain Mahogany	5
Pinyon-Juniper	5	0.0776	Black Sagebrush	2.5
			Wyoming Big Sagebrush	2.5
Montane Riparian	50	0.1640	Desert Wash	40
			Basin Wildrye	10
Montane Sagebrush Steppe	10	0.0302	Black Sagebrush	5
			Wyoming Big Sagebrush	5
Wet Meadow	50	0.0930	Basin Wildrye	35

Original Ecological System	100-yr Conversion (%)	Prob./yr in ST-Sim	New (Replacing) Ecological System	Allocation by new Ecological Systems (%)[#]
			Gambel Oak-Mountain Shrub	5
			Alkali Sacaton-Wet Meadow	10
Low Sagebrush	5	0.0409	Mixed salt Desert	5
Basin Wildrye	20	0.0620	Four-Wing Saltbush	8
			Greasewood-Basin Big Sagebrush	8
			Wyoming Big Sagebrush	4
Utah Serviceberry	10	0.0403	Wyoming Big Sagebrush	10
Stansbury Cliffrose	10	0.0302	Mixed Salt Desert	2.5
			Juniper Savanna	5
			Black Sagebrush	2.5
Black Sagebrush	5	0.0102	Mixed Salt Desert	5
Wyoming Big Sagebrush-upland soil	40	0.0080	Wyoming Big Sagebrush – semidesert soil	30
			Semi-Desert Grassland	10
Juniper Savanna	1	0.0776	Semi-Desert Grassland	1
Wyoming Big Sagebrush – semidesert soil	5	0.0040	Mixed Salt Desert	5
Semi-Desert Grassland	1	0.0040	Greasewood-Basin Big sagebrush	1
Mixed Salt Desert	5	0.0027	Greasewood-Basin Big sagebrush	5
Four-Wing Saltbush	5	0.0040	Mixed Salt Desert	5
Saline Meadow	5	0.0188	Greasewood-Basin Big Sagebrush	5
Greasewood-Basin Big Sagebrush	5	0.0010	Pickleweed	4
			Playa	1

[#] Percentage reflects current abundance.

Literature Cited

Creutzburg MK, Halofsky JE, Halofsky JS, Christopher TA (2015) Climate change and land management in the rangelands of central Oregon. Environmental Management 55:1–13

Evans, JS (2017) SpatialEco. R package version 0.0.1-7, <URL: https://CRAN.R-project.org/package=spatialEco>.

Halofsky JE, Hemstrom MA, Conklin DR Halofsky, JS, Kerns, BK, Bachelet, D (2013) Assessing potential climate change effects on vegetation using a linked model approach. Ecological Modeling 266:131-143.

Provencher L, Frid L, Czembor C, Morisette JT (2016) State-and-Transition Models: Conceptual vs. Simulation Perspectives, Usefulness and Breadth of Use, and Land Management Applications. p 371-407. In: Germino MJ, Chambers JC, Brown CS, editors. Exotic Brome Grasses in Arid and Semi-arid Ecosystems of the Western U.S.: Causes, Consequences and Management Implications. Springer Environmental Series. Zug, Switzerland. 439 pp.

Supplemental

File S6. Greater sage-grouse RSFs and habitat suitability

Breeding (Nesting) Season

For the breeding season, the first RSF established generally-decreasing habitat suitability with the distance between a nest site and the closest lek beyond 5km. More recent studies have shown that being too close to a lek may be detrimental to sage-grouse nesting, because predator activity is greatest closer to leks. Therefore, habitat suitability linearly increased with distance from the closest lek reaching a maximum value of one at 5km, and then decreased as in the original RSF (Figure S6.1).

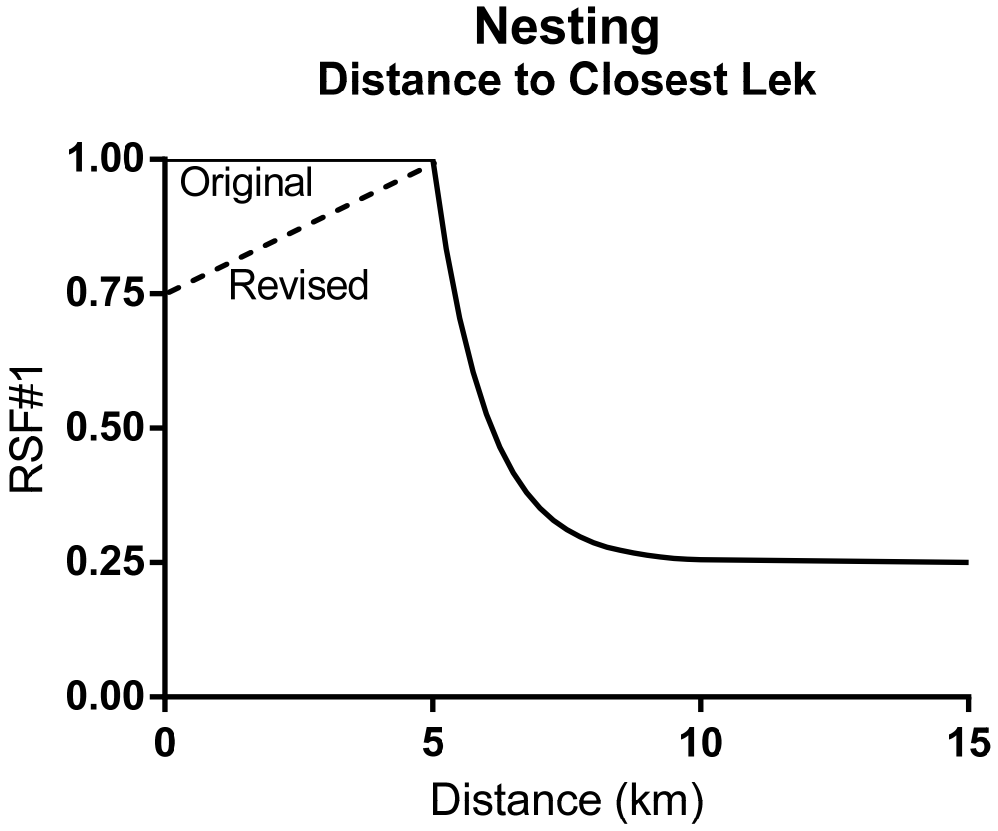


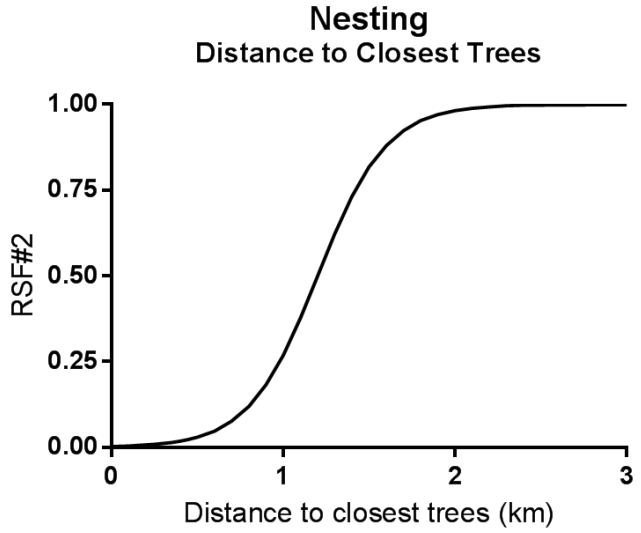
Figure S6.1. Revised first breeding RSF for greater sage-grouse.

The second RSF ($RSF_{N,2}$) was based on the distance of each pixel to the closest trees, which hens avoid:

$$RSF_{N,2} = e^{5 \times (\text{Distance to closest trees}-1.2)}/(1 + e^{5 \times (\text{Distance to closest trees} - 1.2)})$$

where 1.2 is the inflection point and 5 determines the curvature. This equation was simply used for curve fitting (figure below) and has no inherent ecological components. Trees farther than 2 km are not

expected to affect nesting. Certain Ecological System – Vegetation Class combinations were defined as "trees" for this analysis; Table S6.1 contains a list of these System-x-Class combinations.



The third breeding RSF represents increasing habitat suitability with increasing proportion of nesting shrub cover surrounding a potential nest site (Figure S6.2). Originally, shrub cover was considered only between the nearest lek and a given pixel. In the revised version, this variable was simplified as other research has shown the importance of shrub cover within the area all around a nest (Kane et al. 2017), and because distance from lek was already accounted for in the first breeding RSF. For the new third breeding RSF, a moving window of 1000m was used to estimate the proportion of sagebrush classes within that window.

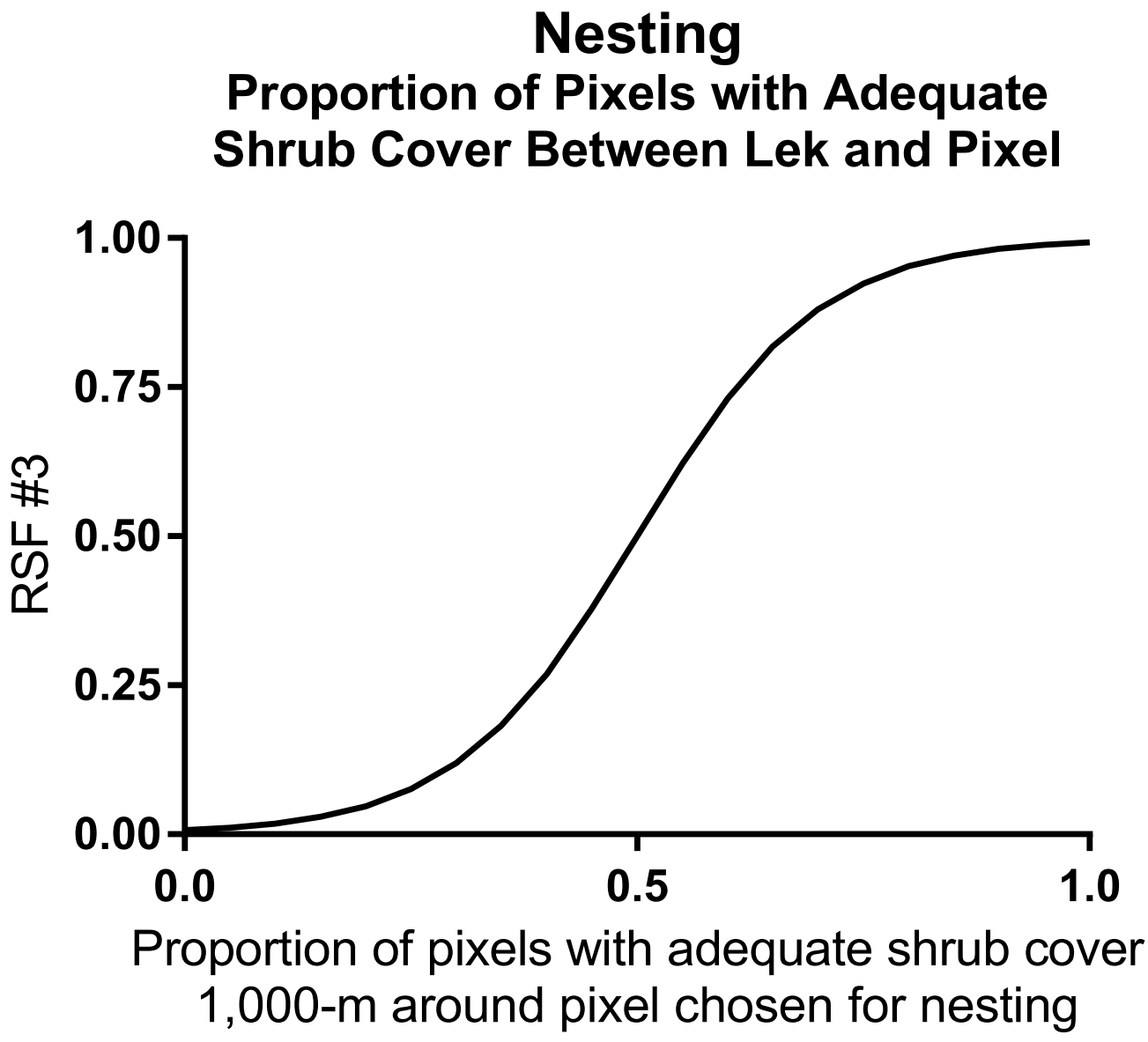


Figure S6.2. Revised third breeding RSF for greater sage-grouse.

Table S6.1. Ecological System – Vegetation Class combinations defined as "trees."

Ecological System	Vegetation Class
Aspen Woodland	ASP-A:Closed
	ASP-B:Closed
	ASP-C:Closed
	ASP-D:Open
	ASP-U:Depleted
Aspen-Mixed Conifer	2-Mid:Closed
	4-Late:Closed
	5-Late:Open
	6-Late:Closed
Basin Wildrye	BW-U:TEA
Black Sagebrush	BS-D:Open
	BS-U:TEA
Curl-leaf Mountain Mahogany	CMM-A:All
	CMM-B:Open
	CMM-D:Open
	CMM-E:Closed
	CMM-U:Annual Grass
Gambel Oak-Mountain Shrub	GOMS-A:All
	GOMS-B:Closed
	GOMS-C:Closed
	GOMS-U:SAP
Limber-Bristlecone Pine	LB-B:Open
	LB-C:Open
Low Sagebrush	LS-U:TA
	LS-U:TE
Mixed Conifer	MC-B:Closed
	MC-C:Open
	MC-D:Open
	MC-E:Closed
Montane Riparian	MR-C:Closed
	MR-U:EFT
Montane Sagebrush Steppe	MSS-E:Closed
	MSS-U:TEA
Pinyon-Juniper	PJ-A:All
	PJ-B:Open
	PJ-C:Open
	PJ-D:Open
	PJ-U:Annual Grass
	PJ-U:SDI+AG
	PJ-U:TA
Ponderosa Pine	PP-A:All
	PP-B:Closed
	PP-C:Open
	PP-D:Open
Stansbury Cliffrose	SC-C:Closed
	SC-U:TEA
Utah Serviceberry	US-D:Open
	US-U:TA
	US-U:TE
Wyoming Big Sagebrush upland	WSup-E:Closed

	WSup-U:TEA

The fourth breeding RSF measures the effect of busy and/or paved roads on decreasing nest site selection (Figure S6.3). In the original study, this RSF was used only in the Black Mountains. In this supplemental study, the fourth RSF remained unchanged.

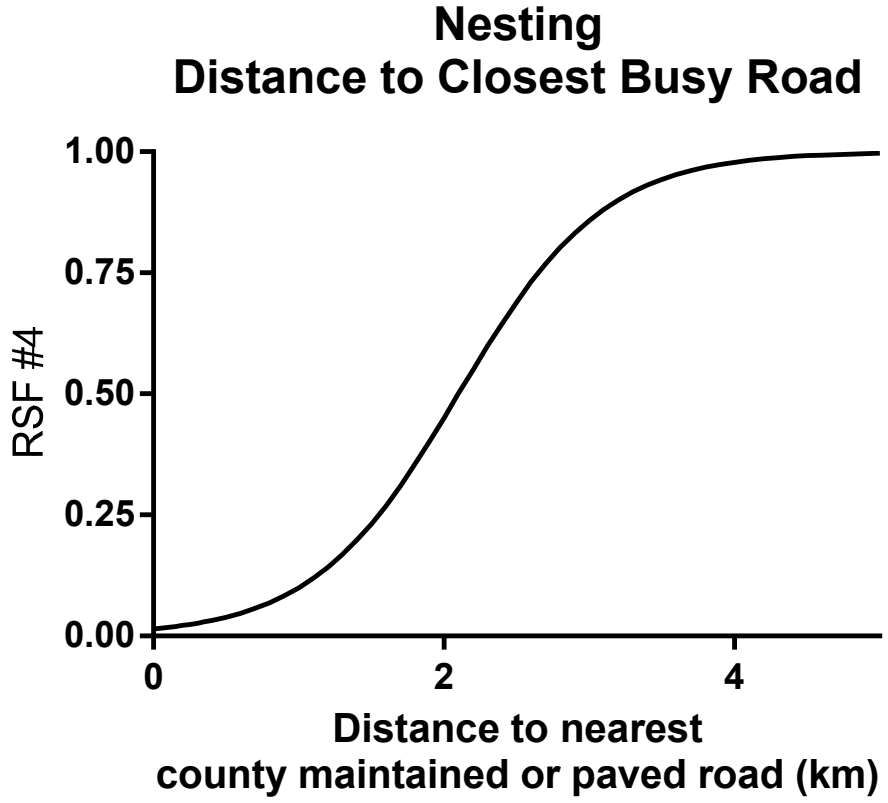
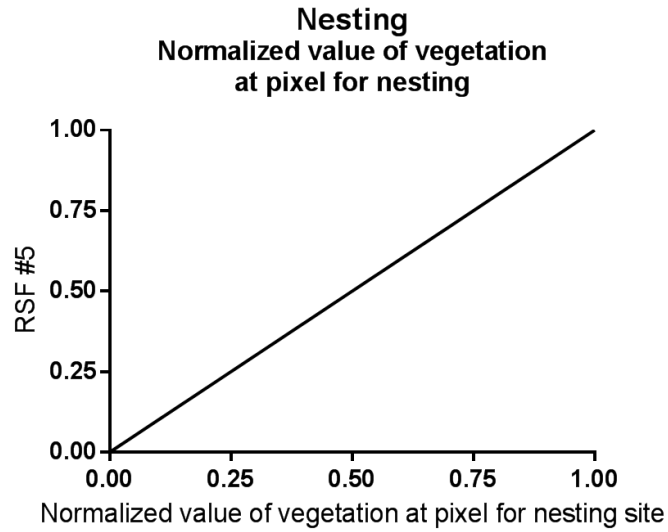


Figure S6.3. Fourth breeding RSF for greater sage-grouse, unchanged from original version but now applied in both landscapes.

The fifth RSF ($RSF_{N,5}$) was equal to the expert-defined normalized nesting value of the vegetation class (see Table S6.3 at end of this Appendix) to breeding habitat for each pixel (nest site).



The overall habitat suitability of the nesting season was:

RSF_N = average{ $RSF_{N,1}$, $RSF_{N,2}$, $RSF_{N,3}$, $RSF_{N,4}$, $RSF_{N,3}$} = $\sum_{i=1}^{5} \frac{RSF_{N,i}}{5}$.

Summer Season

In the original study, the summer season was represented by five RSFs. This supplemental study uses four summer RSFs; two of the prior summer RSFs were combined to remove redundancy among them.

For summer RSF #1, the first step was to measure the distance between the nest-site pixel and the closest sagebrush pixel at or above 2,134m (7,000 ft.) elevation. The relationship is designed as a surrogate for birds reaching montane sagebrush steppe and other high-elevation shrublands that are late-brood habitat. This assumption is mentioned because it was also used in the second RSF during the original study. Then the second step was to measure the distance between the nest pixel and the closest moist vegetation, which originally included high-elevation mountain shrublands, wet meadows, and riparian systems. Because the distance to high-elevation shrublands is accounted for in the first step, and it is increasingly known that hens and chicks avoid riparian corridors populated with willows and tall riparian shrubs and trees (increased predation risk), we only measured the distance to wet meadows (Figure S6.4). The two distance maps – to high-elevation shrublands and to wet meadows – were combined to calculate summer RSF #1.

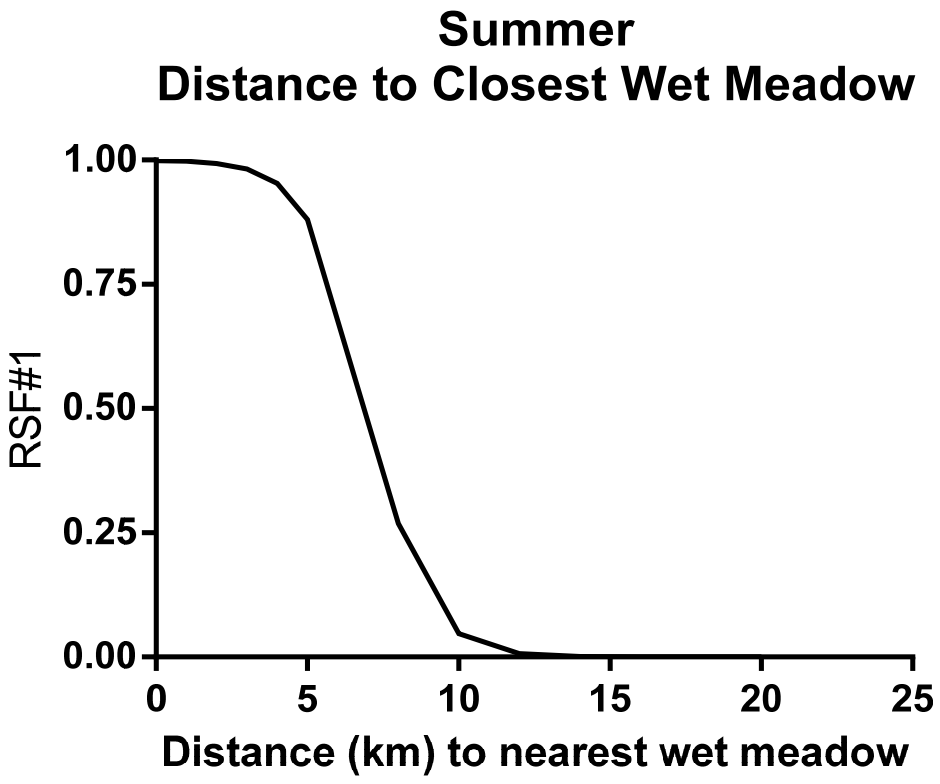


Figure S6.4. Revised first summer RSF for greater sage-grouse, combining distance to high-elevation shrublands and to wet meadows.

Winter Season

The winter season is represented by three RSFs. The shapes of these winter RSFs remained unchanged in this supplemental study. However, the estimation of the proportion of sufficiently dense cover of sagebrush was different between R and ArcGIS for the first RSF (Figure S6.5). First the proportion of sagebrush pixels was estimated using a moving window of 1,015 m (approximately 2,500 acres). Then the distance of all pixels was measured to the nearest pixel with a value of 0.75 from the moving window analysis.

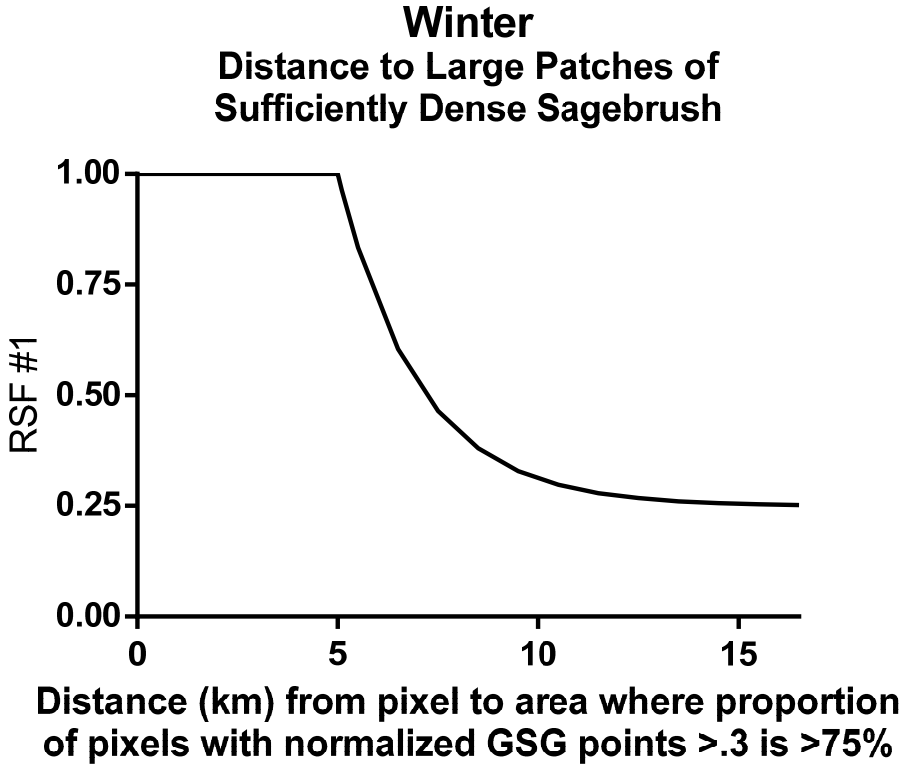


Figure S6.5. First winter RSF for greater sage-grouse, same shape as in original study but with different method for determining sufficiently dense cover of sagebrush.