

South Snake Range NV Landscape Conservation Forecasting
NPS Cooperative Agreement P22AC00266-00
Final Report to the National Park Service Great Basin National Park and
Eastern Nevada Landscape Restoration Project



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Executive Summary

Goals

In 2010, Great Basin National Park and The Nature Conservancy entered into a Cooperative Agreement that resulted in (i) high resolution (2-m) map layers of ecological systems and their vegetation classes, (ii) creation of non-spatial state-and-transition simulation models (STSM) to compare the effects of alternative management scenarios on a subset of focal ecological systems, and (iii) estimation of ecological departure from reference conditions, cost of restoration actions, and ecological return-on-investment among management scenarios. Since 2010 Great Basin National Park has completed and continues to propose restoration projects and amended its Fire Management Plan. In addition, the Strawberry, Black, and Granite Fires transformed parts of the larger landscape such that the 2010 vegetation layers are outdated after 12 years.

The science and software used to model the landscape have advanced by becoming spatial and climate driven, allowing greater realism of fire spread and treatment implementation, and interacting with other software platforms either custom-scripted or made by others. Questions and extent of simulations can today encompass the Park and surrounding partners to study fire management, habitat improvement for dispersing populations, and hydrologic outcomes all at meaningful and ambitious multi-jurisdictional scales. Therefore, staff of National Park Service (NPS) Great Basin National Park, Bureau of Land Management (BLM) Ely District Bristlecone Pine Field Office, Nevada Department of Wildlife Ely Office, and US Forest Service Ely Ranger District joined forces with The Nature Conservancy through a SNPLMA-funded cooperative agreement to work together with a focus on fire management and bighorn sheep habitat improvement in the very biodiverse south Snake Range.

Partners proposed six guiding objectives:

- Map potential and current vegetation, and ecological condition as expressed by ecological departure from reference condition (formerly Fire Regime Condition).
- Maintain overall condition of and restore degraded native upland and wetted ecological systems to reference conditions or desired future conditions given climate change.
- Maintain and enhance bighorn sheep habitat given climate change.
- Treat Wildland-Urban Interface (WUI) areas and reduce fuel loads to help protect human settlements and cultural resources in and around the project area from wildfire.
- Meet wilderness area objective of maintaining or enhancing wilderness characteristics using wildland fire for resource benefit and/or targeted prescribed fire.
- Help NPS and BLM meet objectives specified in management plans.

Methods

The methodology of Landscape Conservation Forecasting was deployed to achieve these objectives:

1. Map ecological systems and their current vegetation classes at high spatial resolution;
2. Upload updated and new vegetation layers into spatially explicit state-and-transition simulation models for each ecological system to forecast a set of partner-defined land management actions for a custodial management scenario (a.k.a., No-Action in NEPA parlance) and an active preferred management scenario; and
3. Compare metrics of success for a set of focal systems, namely non-spatial and spatially explicit ecological departure from reference condition, maps of bighorn sheep habitat suitability, fire effects on riparian health, runoff and recharge per hydrologic basin, and the areas of vegetation classes affected by treatments.

One image from WorldView 2/3 multispectral satellite was ordered in May 2022 for capture in mid-June. About 82,780 acres covered the 2010 area of interest, which was partitioned between 77,180 acres of Great Basin National Park and 5,600 acres Keyhole Property inserted sideways on the west-central slope of the Park, and 316,413 acres covered the remaining Bureau of Land Management, US Forest Service (USFS), and private lands in the area of interest. Remote sensing analysis was applied to classify the WorldView image. Two different methods were applied to the analysis of the WorldView imagery: 1) change detection measuring the spectral differences between the 2007 QuickBird (used to create the 2010 map) and the 2022 WorldView imageries for GBNP and the Keyhole Property and 2) traditional remote sensing analysis applied to the rest of the area of interest (i.e., new mapping).

Imagery from 2007 (QuickBird) and 2022 (WorldView) were compared using a variety of standard algorithms of change detection analysis. Image-to-image analysis and manual evaluation led to the development of a data layer indicating areas of spectral difference for further investigation in the field. Field visits to all 445 spectral differences were accomplished for the purposes of describing: 1) the potential agent of change (e.g., fire, restoration treatment, climatic/weather impact); and 2) current land cover classification ecological system and vegetation class. The land cover classification ecological system and vegetation class assignment was selected from the same discrete classification scheme employed in the original project area mapping effort but modified with a substantially upgraded description.

New mapping started with an unsupervised classification of imagery to associate unique spectral combinations of red, blue, green and near infrared and image texture to specific ecological systems and vegetation classes. Field work for remote sensing was conducted from 8-24 July and 17-24 October 2022. On BLM-managed land, USFS-managed land, and allowable private lands, 9,927 rapid observation points (9,043 on BLM, 285 on USFS, and 599 on private lands), which were obtained from 4WD exploration and hiking, were collected to ensure that a large percentage of the landscape was visited.

Spatial Solutions LLC, a contractor to TNC, delivered the vegetation map of ecological systems and vegetation classes on September 20, 2023. The resolution of the delivered imagery was 2 m; however, WorldView 2 contains spatial resolutions from 65 cm to 2 m that were all used for imagery analysis. The classified 2-m resolution raster of system-class was resampled to 14 m for simulations to stay within the limits imposed by hardware and simulation software. To avoid losing small, narrow, and ecologically important vegetation types (i.e. wet meadows), ecological systems and vegetation classes were resampled according to a user-defined hierarchy scripted

in Python. This final vegetation class raster represented the “current condition” vegetation. The ecological system and vegetation class map layers were uploaded in the simulation database.

A first hybrid management workshop with Great Basin National Park, BLM, and Nevada Department of Wildlife experts was conducted in Baker NV at the Great Basin Visitor Center on November 7-9th, 2023 to:

- Review of Landscape Conservation forecasting methodology.
- Review the vegetation map and propose map revisions (three class revisions were proposed).
- Review results of non-spatial and spatial ecological departure for 2022.
- Review and improve a draft expert-driven bighorn sheep habitat suitability model and 2022 suitability results.
- Define joint inter-agency guiding management objectives.
- Choose focal systems that will be simulated to receive management actions.
- Define the anticipated annual total budget for implementing management actions not exceeding \$200,000 for Great Basin National Park and ranging between \$400,000 and \$600,000 for BLM before 2047.
- Define management scenarios as a set of sequenced actions and the “order-of-magnitude” desired implementation rates.
- Define a 50-year duration of simulations (2023-2072) with 2023 being the first year of treatment implementation.
- Specify cost per unit area and the use of each management action per system.
- Define the success and failure rates, and ecological outcomes of each management action.
- Describe the regulatory and spatial land management constraints where different types of actions can or cannot be deployed and, if any, specific conditions only applicable to one agency.
- View results of draft custodial management scenario simulation and, if time and interest allowed, draft simplistic active management scenarios.

Following the first workshop, The Nature Conservancy implemented all actions, budgetary details, regulatory and spatial constraints, and drafted the custodial management and only one preferred management scenario in the simulation database. Development of scenarios, vegetation map revisions, and creation of spatial constraint rasters, especially grazing rasters, consumed several months of trial-and-error work.

After the completion of new draft simulations, a second hybrid workshop was conducted in Ely NV on March 13th, 2024 . The goals of the second workshop were:

- Review key decisions from, and changes made after, the first workshop.
- Review revised bighorn sheep habitat suitability model and results.
- Review results of both management scenarios and revise implementation rates, if needed.

All workshop revisions were incorporated in simulation models and scenarios rerun, again using a trial-and-error process to respect budgetary limits.

Outcomes

All results started with the 2022 initial conditions. Future results were presented in three years at the request of partners: 2035, 2047, and 2072. Perhaps the most important year was 2047 because it was past the active treatment implementation phase ending in 2039 and had allowed delayed restoration effects associated with natural recovery of rested vegetation classes (e.g., fenced areas in aspen). The year 2035, on the other hand, represented active or recent actions where seedings were still in the early successional phase. The final year 2072 marked a long-term response with cumulative climate effects and lack of treatment since 2040 during which pre-2022 ecological processes might have resumed degrading the newly restored systems (e.g., fire exclusion).

- *Ecological Systems.* Fifty-two systems were mapped but six were not vegetated ecological systems or were highly manipulated (such as agriculture, barren-rock-mud, developed, unpaved and paved roads, and water). The five most common ecological systems across all ownerships were: black sagebrush (116,802 acres), montane sagebrush steppe on upland soils (36,790 acres), pinyon-juniper woodland (25,524 acres), mixed salt desert (23,806 acres), and curl-leaf mountain mahogany (20,248 acres). The five smallest ecological systems across all ownerships were: badland (0.2 acres), subalpine riparian (5.5 acres), four-wing saltbush (8.9 acres), antelope bitterbrush-Wyoming big sagebrush (20.9 acres), and montane-subalpine grassland (47.8 acres). The list of most and least common systems were substantially different among ownerships.
- *Change Detection.* The vegetation map of GBNP and the Keyhole property from 2010 was compared to the new map of 2022; however, the comparison was not between the 2007 QuickBird and WorldView 2/3 satellite imageries as conducted by the remote sensing contractor, but between the interpreted and more lumped maps created for modeling by TNC in 2010 and 2022. We eliminated many changes due only to scientific renaming, splitting, and reinterpretation of systems, and focused on all changes at the class level that were possible in the STSMs.
 - The Strawberry, Black, Granite, and Cave Spring Fires, the Kious Basin antelope bitterbrush conifer removal, the Lehman Creek basin wildrye conifer removal, and Baker Creek Road tree removal in montane sagebrush steppe were captured as changes in addition to many other natural changes (e.g., avalanches and small to large patches of conifer mortality).
- *Non-spatial Ecological Departure.* Of the 22 focal systems selected by agency experts, 3 were at low departure, 11 were moderately departed, and 8 were highly departed from reference conditions.
- *2022 Single-system Spatially Explicit and Stochastic Ecological Departure.*
 - Great Basin National Park: Using a 1,400-m search radius around each pixel to determine spatially explicit ecological departure, the Park was found to contain many areas of moderate departure patchily distributed among low departure areas for aspen-mixed conifer, aspen subalpine conifer, and montane sagebrush steppe (i.e., moderately departed was Fire Regime Condition Class 2 in old jargon). Parts of the Park with higher departure were found in Strawberry Creek, around Lehman's Cave Visitor Center, the western end of the Snake Creek Road, the north slope above the southern headwaters of Pole Creek, the Lexington Arch area, and small areas at

the NPS boundary south of Kious Basin down to Clay Springs. These more departed areas often matched fires from the last 10 years. The area of lowest departure was the barren rock around Wheeler Peak surrounded by smaller patches of alpine and limber-bristlecone pine woodland. Areas of lower departure were scattered at all elevations within the Park in different ecological systems.

- BLM-managed land. The most extensive areas of higher spatially-explicit ecological departure formed a lower elevation ring around the Snake Range on BLM-managed land. In these areas, non-native annual species were either dominant after fires or occupied the understory of shrublands. Depleted (a.k.a., decadent) sagebrush was also common at middle elevations. Areas of low departure were around Windy Peak in all three types of aspen forests, the area north of the Keyhole Property with a diverse group of mixed conifers, curl-leaf mountain mahogany, aspen-mixed conifer, and aspen woodland, and the subalpine ridge west of Murphy Creek and John's Wash where various subalpine conifers (both dry and mesic limber and bristlecone pine forest and Engelman's spruce) and mountain shrublands were common. Interestingly, areas of low departure were found in the southwest and southeast corners of the area of interest where larger wet meadow complexes, winterfat (west side), semi-desert grassland (west side), and greasewood were mapped.
- *Future Single-system Spatially Explicit and Stochastic Ecological Departure*
 - Only the 2047 single-system spatially-explicit departure was estimated for all scenarios (management and climates) as it took weeks to months to process just one year on a server. Single system spatially-explicit departure was highly scattered such that visually detecting change from 2022 to 2047 was not possible, and differences between custodial and preferred management scenarios among climate were not evident. Variances among replicates was low to absent.
- *2022 Full-system Spatially Explicit and Stochastic Ecological Departure.*
 - Great Basin National Park: Full-system ecological departure measured the dissimilarity between the current and reference proportions of all systems for which the classes per system were pro-rated to the relative sizes of each system in a 1,400-m radius moving window. The 2022 full-system ecological departure showed substantially more departure than the single-system ecological departure. In the single-system spatial departure, there was a fine patchwork of low departure and moderate departure systems distributed everywhere in the Park. Because the moderate departure was well distributed, the full-system departure's moving window was repeatedly capable of including the vegetation classes responsible for moderate departure, such as aspen dominated by either mixed conifers or subalpine conifers and montane sagebrush steep dominated by pinyon and juniper. This likely was the reason for high full-system departure up the eastern and middle slope of the Snake Range. Only the subalpine and alpine elevations that have long fire return intervals were less departed in the single system departure and full-system ecological departure.

- On all other land ownerships, full-system departure was highly departed, except in the subalpine vegetation, in steep areas, and, again, in the southeast and southwest corners where both types of wet meadows, greasewood, and semi-desert grasslands provide reference classes in proportions not too dissimilar from the reference conditions. Also, at those middle to lower elevations, non-native annual grasses would commonly be dominant or present within a moving window with a 1,400 m radius in the understory of all shrubland from mixed salt desert to montane sagebrush steppe, and bitterbrush. In other words, it proved hard to not include non-native annual species or conifer encroachment at middle or lower elevations within the metric's moving window.
- *Future Full-system Spatially Explicit and Stochastic Ecological Departure*
 - Only the 2047 full-system spatially-explicit departure was estimated for all scenarios (management and climates) as done for single-system spatially-explicit departure. Full-system spatially-explicit departure slightly and locally improved (decreased) from 2022 to 2047, mostly found north and south of Snake Creek and on the southeast high-elevation ridge ending near Big Spring Ranch. Preferred management slightly improved (decreased) single-system spatially-explicit departure in the same locations but more visibly in the ACCESS1 and HadGEM-ES climates. Variances among replicates was low to null.
- *Expert-driven bighorn sheep habitat suitability*
 - 2022 Suitability. Bighorn sheep habitat suitability was greatest at the highest elevations on rocky or exposed ridges and near escape habitat during the growing season. Suitability was very low downslope from the break between the toe of mountains to the bottom of alluvial fans. Suitability was zero in the valley bottoms. Also noteworthy was the high suitability in areas that bighorn sheep do not currently occupy despite easy access as a function of distance and where humans are not present. The high elevations in the southeast portion of the area of interest on BLM-managed land, the ridge extending from Pyramid Peak through Horse Heaven along the north side of Snake Creek, and the northwestern ridge north of Windy Peak were such examples.
 - Future Suitability. In all reporting years (2035, 2047, and 2072) and all climates, bighorn sheep growing season and winter habitat suitability consistently improved (increased) or degraded (decreased) for the preferred management scenario in the same parts of the landscape compared to the custodial management scenario within the same reporting year (control scenario against which all differences in habitat suitability were subtracted from). The most striking zone of habitat improvement in all reporting years was the ring around the ridge from Wheeler Peak to Lincoln Peak that included various aspen-conifer and subalpine conifer systems; however, improvement was smaller for the PRISM climate than the ACCESS1 and HadGEM-ES climates. Climate effects on bighorn sheep habitat suitability in future years were

counterintuitive because lower habitat suitability was found in the PRISM climate that showed highest fire frequencies, which should produce more palatable forage for bighorn sheep. Wildfire, however, was least frequent, even absent, at the alpine and subalpine elevations most inhabited by bighorn sheep. Climate effects on area burned would, therefore, be more pronounced lower in elevation in the zone of aspen-mixed conifer where escape habitat was also sparser (i.e., less suitable habitat). We found after thorough investigation that greater area of early-successional palatable vegetation was created by more frequent wildfire, but the young forage had matured to mid-successional pole-sized unpalatable aspen (i.e., lower suitability) by the 2035, 2047, and 2072 reporting years in greater amount in the PRISM climate than other climates. Additionally, the climate warming scenarios were predicted to reduce snow depth compared to historic climate, which would increase habitat suitability at higher elevations. Finally, the strongest explanation for the highest habitat suitability in the HadGEM-ES climate, slightly less in the ACCESS1 climate, and least in the PRISM climate was the greater avalanche frequency observed in the HadGEM-ES climate, slightly less in the ACCESS1, and lowest frequency in the PRISM climate. Avalanches frequency increased because it was modeled to increase with greater cool season precipitation extremes (i.e., greater severe drought to very wet year variability) that was higher in the HadGEM-ES and ACCESS1 climates than in the less variable PRISM climate. Increased precipitation variability associated with warmer ocean temperatures was generally predicted for Global Circulation Models for the western USA.

- Runoff and recharge estimated by USGS Basin Characterization Model
 - Large variation was observed among basins; for example, results for r ranged from <5mm of runoff in basin 10 (lowest part of Snake Creek drainage and small) to >110mm in basin 20 (part of southern Highland Ridge) for the custodial management scenario.
 - Basins with low or high runoff, respectively, showed low or high recharge. This was expected because the results are derived from water budgets for each grid cell, so basins with more precipitation had more water to distribute to recharge or runoff.
 - Both runoff and recharge were always highest in the HadGEM-ES climate, slightly less in ACCESS1 and least in the PRISM climate. These discrepancies were hard to explain as PRISM was the wettest climate and ACCESS1 the driest in our simulations; however, PRISM was obtained from statistically interpolated predictions of precipitation and temperatures from weather station time series whereas the ACCESS1 and HadGEM-ES climates (Localized Climate Analogs or LOCAs) were process-based and empirical models. All LOCAs start with a common value of precipitation and temperatures that is higher than the starting value for PRISM. Therefore, LOCAs predicted more precipitation than PRISM for initial and future conditions. This was not a problem for simulations because we used the SPEI, which

- was a statistically estimated value of departure in standard deviations from zero where initial conditions did not matter. In future projects, we will select LOCAs that are nearly identical to the historic climate (e.g., MRI for central eastern Nevada) to avoid the use of PRISM, unless the study does not involve Global Circulation Models.
- By basin, positive and negative basin differences between the preferred and custodial management scenarios (difference = preferred - custodial) were found in all years, although greater positive than negative amplitudes were found in the PRISM and ACCESS1 climates, whereas the opposite was found in the HadGEM-ES climate.
 - In general, recharge deviations were more dispersed from the zero line than observed with runoff differences. The PRISM climate showed the greatest positive differences, the HadGEM-ES presented the largest negative differences with obvious median negative values, whereas the ACCESS1 climate showed more negative differences in the first half of the simulation and more positive differences in the latter half.
 - The third type of hydrologic results was average annual runoff or recharge differences (Y axis) plotted against total area treated (X axis) in each basin. The treated area was dominated by shrubland treatments that would have increased sublimation as shading of snow was removed (negative differences in runoff and recharge as treatment size increases). Basins that received mostly shrubland treatments showed negative or weakly positive differences in runoff and recharge where values changed with climates.
 - Only a few basins received prescribed burning and tree thinning in various aspen types and conifers and subalpine shrublands at high elevations; however, prescribed burning would have temporarily increased sublimation due to lack of tree shading until growth of young canopies would have provided shade on snow and the reduction of sublimation. Small to moderate-sized basins generally showed positive differences in runoff and recharge due to high elevation treatments.
- *Fire effects on riparian health*
 - Vegetation treatments reduced the area on montane riparian burned in the HadGEM-ES and ACCESS1 climate, respectively by 2.1% and 1.0% of the total riparian area. These estimates amount to miles of streams. Vegetation treatments had no cumulative effect on the riparian area burned in the PRISM climate although treatments at least reduced burned area in the Pole Creek and Can Young Canyon and in the entire AOI. This would imply that the riparian area burned increased elsewhere as the PRISM climate experienced the largest area burned.
 - The index of riparian health was moderately high in 2022, but generally lower at lower elevations because of the proximity of roads. Distance from roads was the strongest determinant of the index in 2022 and 2047. In 2047, however, climate had multiple effects on area burned, cumulative runoff, and the area invaded by exotic

species. The strongest differences in 2047 were between the driest (ACCESS1) and wettest (PRISM) climates because less annual precipitation was modeled to cause fewer exotic species invasions, which reduced the index of riparian health in the ACCESS1 climate compared to the PRISM climate. This effect was stronger than that of future reduced runoff.

- *Single System Management.* Twenty-two systems were targeted for active management, although each in very different levels of intensity. The maximum number of systems The Nature Conservancy staff had considered for Landscape Conservation Forecasting was 13 for a landscape twice the size of the south Snake Range. Because the annual budget ceiling was fixed, the consequence of partitioning funding was that few systems received enough funding to appreciably change ecological departure or sufficiently reduce the area of undesirable vegetation classes.
 - Many shrublands on upland soils above the mixed salt desert zone that were highly departed from reference condition received limited but successful treatments that reduced undesirable vegetation classes; however, treatments that resulted in uncharacteristic introduced species seedings or recipient classes showed no improvement in ecological departure as one uncharacteristic class was exchanged for another. Therefore, increasing funding to treat more area will not generally reduce ecological departure but should greatly diminish undesirable vegetation classes. Cutting of young or old trees, sometimes followed by seeding, or replacing a non-native annual species dominated class with perennial species seedings were typical actions in this category. Illustrative systems were antelope bitterbrush-black sagebrush, black sagebrush, Wyoming big sagebrush on upland soils, and low sagebrush on semi-desert soil.
 - Many shrublands from the lower montane to lower subalpine zones responded to treatments that resulted in lower ecological departure compared to doing nothing, and by the decrease of undesirable vegetation classes. The ability to lower ecological departure was achieved using native species seeding or reduction of reference late successional classes. Also, increased investment in treatments often paid off with even lower ecological departure or greater reduction of undesirable vegetation classes. Tree lopping, cutting, mastication, and occasionally prescribed burning, were common actions in these systems often encroached by conifers and dominated by reference late successional classes. Examples were antelope bitterbrush-mountain big sagebrush, montane sagebrush steppe-upland soil, montane sagebrush steppe-mountain soil, mountain shrub, low sagebrush steppe, and littleleaf mountain mahogany.
 - A group of montane and subalpine forested systems were managed to increase bighorn sheep forage primarily through prescribed burning sometimes to the detriment of ecological departure by favoring too much recruitment of the reference early successional class, at least in the short term. In most cases, the

- increase of ecological departure by a few percentages points did not result in appreciable degradation of departure but did achieve the desired future condition of increasing bighorn sheep forage. Examples are aspen woodland, aspen-subalpine conifer, and limber-bristlecone pine-mesic; however, treatments in aspen-mixed conifer increased bighorn sheep forage and lowered the ecological departure compared to the custodial management scenario. It was also noted that treatments might not be needed at all in aspen woodland only for Great Basin National Park as they had no effect at the very low level of implementation, whereas newly understood aspen woodland gap regeneration might heal the system if herbivory is not too intense. Prescribed burning improved conditions on BLM-managed land because it was more substantial than in the Park. Both aspen-conifer systems also experienced noticeable wildfire and avalanche activity during the 50-year simulations. For this group of systems, the Park was the area of most extensive treatment and greatest wildfire and avalanche activities.
- At least two montane ecological systems (ponderosa pine and riparian ponderosa pine) were considered specialty systems because they were uncommon, even relicts, small patch systems whose fire dynamics would be driven by fire importation. Preservation of old trees was the management goal as high severity wildfire imported from adjacent systems kill the trees or convert the system to another system. Cutting and pile burning fuel ladders in closed canopies was the primary method of achieving the goal, which reduced and slightly increased, respectively, ecological departure in ponderosa pine and riparian ponderosa pine. Low levels of investment in these two systems paid off.
 - Montane riparian, dry wet meadow, and (wet) wet meadow shared the use of low areas of exotic forb and tree control, reconnection floodplains to creeks, and managing undesirable woody vegetation. In such systems, small areas corresponded to long linear distance. All treatments had desirable effects, albeit often indirect and delayed, that could not keep up very well with a deliberately high rate of exotic species invasion (authors believe the high rate while aggressive was realistic given central Nevada field observations conducted after the heavy snow years of 2023 and 2024). Ecological departure increased over 50 years, although exotic species control conducted early on reduced areas invaded compared to the custodial management scenario. This pointed out to the need for long-term maintenance management on non-native species.
 - Finally, Stansbury cliffrose was intended for active management but due to a simple coding error, encroaching conifers in the cliffrose were never cut using chainsaws. The unseen benefits were that no harm was achieved and no funding was spent.
- *Frequency Maps of Wildfire and Treatments.*
 - Wildfire predominantly occurred in past fire areas and on the eastern slope of the south Snake Range where non-native annual species were common. Future climates

- strongly affected future fire activity. The PRISM climate representing continuation of historic climate supported the most fire, whereas the HadGEM-ES climate showed slightly less wildfire activity and the ACCESS1 climate, the driest, had considerably less fire activity. Less wildfire caused greater preservation of shrub and tree classes.
- Maps of most treatments followed elevation zones around the south Snake Range because dominant vegetation classes targeted for management were also located in the same precipitation zones. Lower elevation montane shrublands above the mixed salt desert received treatments in a lower ring around the Park boundary, whereas these bathtub rings of treatments using more prescribed fire shrank to higher elevations pockets adjacent or within the Park and the Windy Peak area.
 - System specific treatments for exotic forb and tree control in wet systems, and specialized floodplain interventions followed the linear footprints of drainages. It was difficult to see many of these small and localized treatments on maps; however, even small areas could affect long distances in narrow systems.

1. Introduction

1.1. Background

In 2010, Great Basin National Park (hereafter GBNP) and The Nature Conservancy (hereafter TNC) entered into a Cooperative Agreement that resulted in (i) a high resolution (2.7-m) map layers of ecological systems and their vegetation classes, (ii) creation of non-spatial state-and-transition simulation models (STSM) to compare the effects of alternative management scenarios on a subset of focal ecological systems, and (iii) estimation of ecological departure from reference conditions, cost of restoration actions, and ecological return-on-investment among management scenarios (Provencher et al. 2010, 2013). As a result of mapping and forecasting the ecological outcomes of management scenarios with STSMs, GBNP completed and continues to propose restoration projects, and amended its Fire Management Plan.

The mapping and simulation software technology (Daniel et al. 2016), and ecological knowledge of some important systems have considerably advanced from 2010 (e.g., aspen woodland *versus* aspen-conifer) such that both questions and project area extent can, respectively, be more sophisticated and ambitious (Provencher et al. 2021a). By today's TNC landscape assessment standards, the 2010 project area at about 80,000 acres (77,180 acres for GBNP and additional area from the privately held Keyhole property) was relatively small within the larger Snake Range, considered a TNC Great Basin Foundational ecoregional portfolio site of exceptional biodiversity (Nachlinger et al. 2010). Ecological processes, such as fire, and wildlife species (bighorn sheep, elk, mule deer, mountain lion, and so on) spreads in and out of GBNP. The understanding that GBNP could increase achievement of management goals with neighbor land managers and that GBNP's concentrated Rocky Mountain bighorn sheep population could expand onto managed vegetation in other ownerships has forged the idea of a new project where GBNP, the Bureau of Land Management (BLM) Ely Bristlecone Pine Field Office, the USFS Ely Ranger District, and the Nevada Department of Wildlife collaborate while mapping, but not treating private lands. Common interests and funding criteria focused interest on fuels management while reducing ecological departure from reference conditions and improvement and expansion of high-quality bighorn sheep habitat.

Since 2010, at least three fires, severe droughts, avalanches, and restoration projects have occurred in GBNP and on BLM-managed lands such that the old non-spatial simulation outcomes designed in the absence of collaboration among land managers were outdated. To move ahead, the original vegetation map had to be updated, a compatible and new vegetation map covering the neighboring lands with a seamless interface was needed, and a modernized spatial state-and-transition simulation model database with management scenarios reflecting collaboration and incorporating climate change were necessary, and additional metrics were required to make the project relevant to multiple partners. For GBNP, this first reset might be considered the beginning of a possible long-term ecological study.

1.2. Objective

The focus of the project became the south Snake Range with at its center GBNP because of (i) the centrality of the bighorn sheep population that can be imagined spreading from Mt. Washington onto BLM-managed and USFS-managed lands and (ii) the greater likelihood of

wildfires initiating lower mid-slope elevations outside of GBNP and moving up into it. General project objectives were:

1. Update GBNP's 2010 vegetation map layers and create new high-resolution vegetation map layers for the rest of the south Snake Range managed by the BLM, USFS and private landowners;
2. Create a new spatial simulation database to collaboratively design new management scenarios with agency partners that will forecast financially constrained possibilities to:
 - a. Inform fuels management to reduce the risk of uncharacteristically large high-severity fires;
 - b. Improve Rocky Mountain bighorn sheep habitat suitability through fuels management;
 - c. Reduce the ecological departure of focal systems from reference conditions; and
 - d. Minimize detrimental fire effects on riparian health.

2. Methods

2.1. Study Area

The south Snake Range Area of Interest (AOI) of 399,075 acres (161,569 ha) is in central-eastern Nevada adjacent to the Utah border (Wheeler Peak at 38°59'25.80"N, 114°20'09.48"W; Fig. 2.1). The small town of Baker, NV is within the project area. The geology of the south Snake Range is fascinating (DeCourten and Biggar 2017). The Snake Range is one of a handful of Great Basin plutonic ranges where tremendous tectonic pressures pushed upward and exposed older rock formations (late Pre-Cambrian and Cambrian periods – about 500 million years ago) to elevations higher than average for the region. The southern half of the south Snake Range is mostly carbonate rocks (various limestone and dolomite types), whereas the northern part is largely metamorphic dominated by high-purity quartzite and plutonic granite on the eastern mid-elevation slopes around Sacramento Pass and the Kious Basin. Paleozoic limestone on the western slope where Highway 50 climbs to Sacramento Pass is also found in the northern half. The most remarkable and rare geologic feature of the Snake Range is the Great Detachment, a very low-angle slippage fault where the Paleozoic limestones slide east and over older Cambrian formations (e.g., plutonic granite) flowing west and underground; thus causing the relatively rapid widening of Spring Valley and, even, southern Steptoe Valley. Exposure of plutonic granite explained the distribution of antelope bitterbrush in the AOI. The Snake Range's famous Mexican free-tailed bat cave is in the Paleozoic limestone formation.

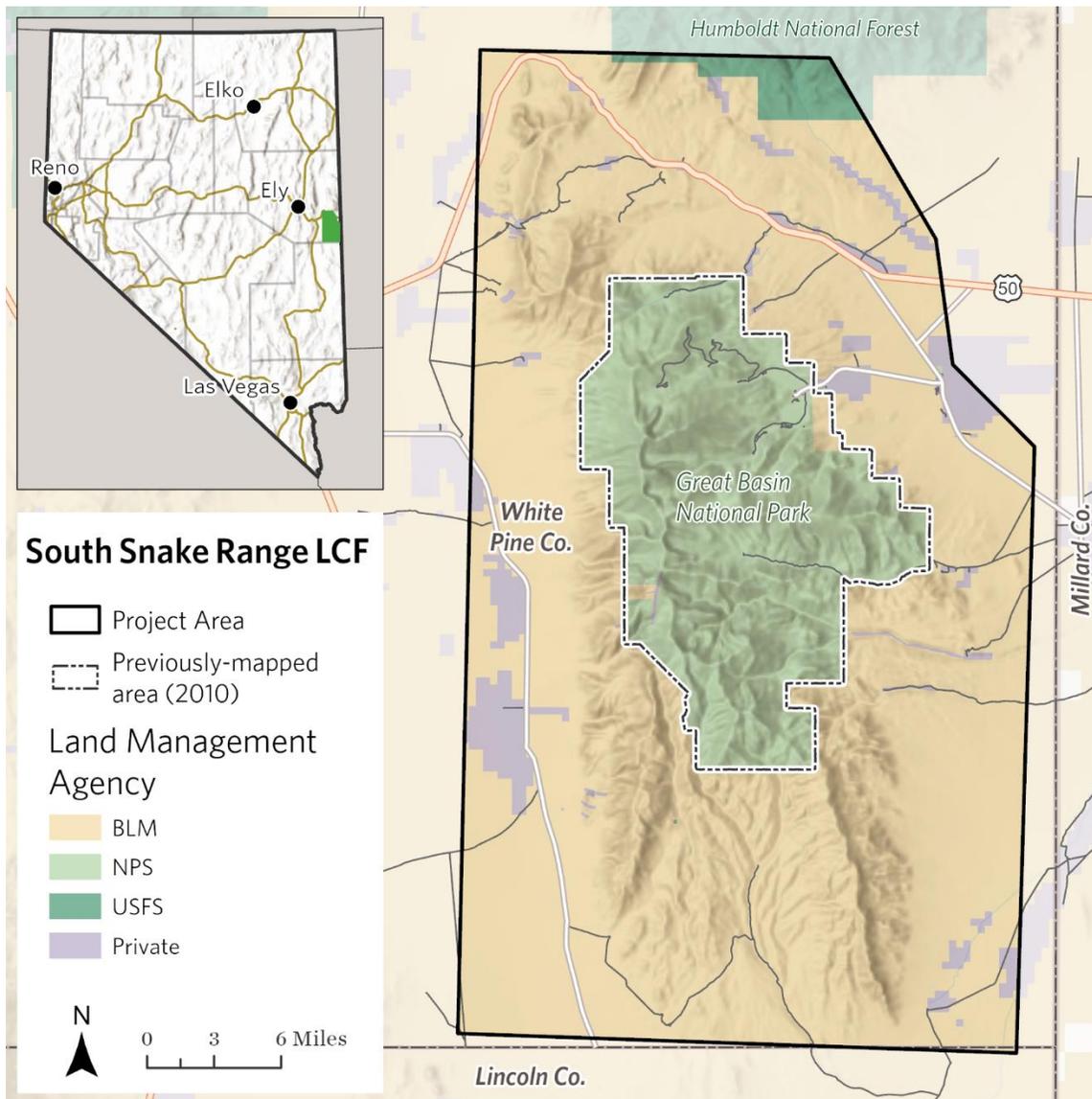


Figure 2.1 Area of Interest in the south Snake Range, NV. Great Basin National Park occupies the central portion of the map.

The Great Basin vegetation of the south Snake Range is highly diverse because (a) the elevation gradient is considerable from 4,000 to 13,000+ feet and (b) vegetation combines systems typical of the western Great Basin, such as most sagebrush systems, aspen, limber pine, pinyon-juniper woodlands, curl-leaf mountain mahogany, with ecological systems that occur with the North American monsoon (Hales 1973), such as ponderosa pine, Engelmann spruce, Douglas-fir, Rocky Mountain white fir, bristlecone pine, subalpine grassland, Stansbury cliffrose, littleleaf mountain mahogany, Rocky Mountain juniper, and desert almond (a Mojave Desert community). Moreover, perennial and intermittent streams dissect the Snake Range where flows are mostly found on metamorphic rock.

The BLM land peripheral to GBNP contains the classic mixed salt desert scrub communities, semi-desert grassland, greasewood flats, black and low sagebrush, various mountain shrub communities, swamps cedars (globally rare valley bottom groundwater dependent Rocky Mountain juniper woodlands) and lower elevations Wyoming big sagebrush. The higher elevations of BLM-managed land contain many ecological systems also found in GBNP, with the exception of alpine, such as three types of aspen communities, ponderosa pine, Engelmann spruce, patches of bristlecone pine dry and mesic, pure Rocky Mountain white fir, mixed conifers, pinyon-juniper woodlands, curl-leaf and littleleaf mountain mahogany, associations of antelope bitterbrush and three sagebrush species (black, mountain big, and Wyoming big sagebrush), low sagebrush steppe (subalpine low sagebrush), subalpine grassland, and montane sagebrush steppe.

2.2. Tasks

To achieve the main objective, a series of complex tasks were required:

- a) Map the ecological systems and current vegetation classes of the AOI;
- b) Build spatial STSMs of all ecological systems;
- c) Using collaborative workshops, define guiding management objectives for simulations, chose metrics to measure success, management scenarios, annual budgets, actions used to treat vegetation, their costs per unit area and success and failure rates; and
- d) Developed metric of success for non-spatial ecological departure, spatial ecological departure, bighorn sheep habitat suitability, and spatially modeled runoff and recharge per hydrologic basin.

2.2.1. Vegetation Mapping

The first step of all Landscape Conservation Forecasting (LCF) projects completed prior to any field work, mapping, or modeling was to write a “living” document describing all ecological systems and vegetation classes (Appendix 1). Such a vegetation description was written in 2010, which was greatly expanded and modernized here for GBNP and surrounding lands. This document also included non-vegetation “systems” such as roads, buildings, water bodies, and so on. The document included ecological systems and their vegetation classes that could be found but may not be detected during remote sensing.

Ecological systems were potential vegetation types expected in the physical environment under natural disturbance regimes usually named for the dominant upper-layer vegetation (e.g., black sagebrush, ponderosa pine; Provencher et al. 2016). Ecological systems were considered mostly permanent over centuries as they strongly correlate to soils. Vegetation class was the ecological system’s current state defined by coarse species composition, canopy structure, successional stage, and whether it was in reference or uncharacteristic condition. An uncharacteristic class was not a reference class and was caused by post-European settlement disturbances. While ecological systems rarely changed, vegetation classes could be changed by a single disturbance. The nested description of ecological systems (ecological and non-vegetated systems or agriculture) combined with vegetation classes resulted in >500 unique thematic combinations (Appendix 1) that were modeled and potentially mapped by remote sensing. The vegetation description document was primarily written for the remote sensing contractor, field work, and

modelers; therefore, description of classes included short descriptions of all systems and classes, including the naming and numerical codes as used in models. In the field, the remote sensing contractor used short-hand codes appropriate for fast observations that were later translated by TNC staff to the codes found in Appendix 1.

One image from WorldView 2-4 2 m resolution multispectral satellite imagery of about 399,075 acres (161,569 ha) was ordered in May 2022 and captured on June 22, 2022. (WorldView 2-4 spans multiple resolutions, including 65 cm and 2 m, such that the remote sensing contractor could switch among resolutions for analysis.) About 82,780 acres (65,413 ha) covered the 2010 area of interest, which was partitioned between 77,180 acres of Great Basin National Park and 5,600 acres Keyhole Property inserted sideway on the west-central slope of the Park (tan area within 2010 boundary in Fig 1.; Provencher et al. 2013), and 316,413 acres (128,055 ha) covered the remaining BLM-managed land, USFS-managed land, and private lands in the AOI. Remote sensing was conducted with the software ERDAS Imagine® from Hexagon AB applied to WorldView imagery. Moreover, freely available Google Earth imagery (www.earth.google.com/web/), especially historical imagery, was used to assist with interpretation after completion of the field work.

Two different methods were applied to the analysis of the WorldView imagery; 1) change detection measuring the spectral differences between the 2007 QuickBird (used to create the 2010 map) and the 2022 WorldView imagery for GBNP and the Keyhole Property and 2) traditional remote sensing analysis (i.e., new mapping) applied to the rest of the AOI. In the field, however, the acquisition of ground observations and local interpretation was the same for both methods.

Change detection. Imagery from 2010 (QuickBird) and 2022 (WorldView) were compared using a variety of standard algorithms of change detection analysis. These algorithms included image subtraction, vegetation index comparison, and principal components analysis (Lillesand and Kiefer 2000). Allowed cutoff variance for change detection varied among techniques and varied due to annual precipitation differences. While variance cutoffs were used, tools used were not allowed to be fully automated to detect differences and the final step of analysis were manually examined. Taken together, the image-to-image analysis and manual evaluation led to the development of a data layer indicating areas of spectral difference for further investigation in the field.

Field visits to all spectral differences were accomplished for the purposes of describing: 1) the potential agent of change (e.g., fire, restoration treatment, climatic/weather impact); and 2) current land cover classification ecological system and vegetation class. The land cover classification ecological system and vegetation class assignment was selected from the same discrete classification scheme employed in the original project area mapping effort but modified with the current descriptions (Appendix 1); (a) dry wet meadow had not been split from wet meadow in 2010 (Provencher et al. 2010) but both meadows types were separated in 2022 (Appendix 1); (b) the difference between wooded late-successional montane sagebrush steppe and pinyon-juniper woodland was reinterpreted in 2022 to allow montane sagebrush steppe on steeper slopes with loamy soil (first revised for Strawberry Creek valley slopes and then applied throughout the Park); c) the 2010 antelope bitterbrush description ignored the

underlying sagebrush species, however in 2022 bitterbrush was split into antelope bitterbrush-mountain big sagebrush, antelope bitterbrush-black sagebrush, and antelope bitterbrush-Wyoming big sagebrush at the request of agency specialists; and d) several very late-successional aspen-conifer patches that were originally mapped as aspen-mixed conifer or aspen-subalpine conifer were reinterpreted as true conifer forest in 2022 following field visits. In the field, seasonal and precipitation-caused spectral differences (not a transition change) needed to be distinguished from spectral differences caused by disturbance events and succession to other vegetation classes (true change). Areas with no spectral difference were assumed unchanged from 2010. Spatial Solutions and TNC visited 445 field locations for change detection in 2022.

Remote sensing for new mapping. The LCF mapping methodology has evolved over the past decade because of technology and innovations and has been previously described (Provencher et al. 2008, 2010, 2013, 2021a; Low et al. 2010). Following an unsupervised classification of imagery to identify unique spectral combinations of red, blue, green and near infrared and image texture to specific ecological systems and vegetation classes, field work was conducted from 8-24 July and 17-24 October 2022. In the remaining area on BLM, USFS, and private lands (accessed only if without “no trespassing” signs), 9,927 rapid observation points (9,043 on BLM, 285 on USFS, and 599 on private lands), obtained from 4WD exploration and hiking, were collected to ensure that a large percentage of the landscape was visited. At each rapid observation location, the ecological system, vegetation class, explanatory notes, and at least two georeferenced photographs were taken. Should change detection be conducted in the future, we highly recommend taking observations from a helicopter for at least two days as many areas were remote, in part because of wilderness areas, or rugged.

Spatial Solutions delivered the vegetation map of ecological systems and vegetation classes on September 20, 2023. The resolution of the delivered imagery was 2 m. This version of the map contains the contractor’s short-hand field codes (and not the codes in Appendix 1) that required quality control by TNC staff and translation from short-hand codes to 8-digit codes found in Appendix 1. Only class-level revisions were made to the vegetation map after review by GBNP, BLM, NDOW, and TNC during the first management workshop in November 2023.

The 2-m resolution system-class raster was resampled to 14 m for simulations to stay within computational limits. To avoid losing small, narrow, and ecologically important vegetation types, ecological systems and vegetation classes were resampled according to a user-defined hierarchy scripted in Python (Appendix 2). Small or linear ecological systems and vegetation classes, and systems critical to species success were given higher priority than common systems, which were resampled with a majority rule. This final vegetation class raster represented the “current condition” vegetation.

2.2.2. State-and-transition Simulation Modeling

STSMs are stochastic models of landscape change. The landscape in an STSM is represented by a discrete set of simulation cells classified into a discrete set of states. Simulation cells change over discrete timesteps according to a discrete set of possible transitions that are caused by either natural (e.g., wildfire) or anthropogenic (e.g., chainsaw thinning) processes (Daniel et al.

2016). All simulations were conducted using the ST-Sim package (version 3.3.11) in SyncroSim (Version 2.4.18; Daniel et al. 2016; www.apexrms.com).

STSMs were spatially simulated for 50 years (2023 to 2072). In ST-Sim each pixel was assigned an initial condition state (a state is the combination of an ecological system and a vegetation class) obtained from remote sensing that can either (a) age one timestep and stay in the same class, (b) age one timestep into an older class (i.e., succession), or (c) experience a probabilistic disturbance and transition to ≥ 1 other states, including the originating state. Additionally, land ownership, categorized as GBNP, BLM, US Forest Service, or private, was uploaded to constrain management actions.

Transitions are probabilistic (ecological disturbances and succession – in past projects succession was deterministic whereas we shifted to strictly and more realistic probabilistic succession). Land management actions were implemented using area targets (e.g., 1,000 acres·yr⁻¹ or 405 ha·yr⁻¹ seeded on average in designated vegetation classes). Probabilistic disturbances and management actions can be modified or constrained temporally or spatially to mimic real world processes such as climate variability, fire spread behavior, and equipment operation limits.

Fire is the dominant ecological disturbance in the south Snake Range, although fires have not been common or large in recent history. The Phillips Ranch Fire (2000 at 2,533 acres or 1,025 ha), Black Fire (2013 at 4,723 acres or 1,912 ha), and Strawberry Fire (2016 at 4,656 acres or 1,885 ha) have been the largest reported fires since federal fire reporting started in the 1980s. These numbers reflected fire suppression management. The observed fire size distribution for the AOI in Table 2.1 was very different than fire size distributions generally reported elsewhere in the Great Basin (Provencher et al. 2021a).

Table 2.1. Size distribution (acres or ha) of fire events for South Snake Range based on federal fire occurrence data from 1980 to 2016 and the Monitoring Trends in Burn Severity (MTBS) data from 1984 to 2016.

<u>Area of Disturbance</u> <u>Acres (ha)</u>	<u>South Snake Range</u> <u>Percent Occurrence</u>
>0 to 10 (>0 to 4)	7.5
>11 to 100 (>4 to 40)	12.5
>101 to 1,000 (>121 to 405)	36.25
>1,001 to 5,000 (>405 to 2,023)	43.75

To approximately match these numbers given that each system’s model was based on reference fire return intervals, the simulations suppressed fire return intervals of reference classes and other vegetation classes without non-native annual fuel by 90% (Provencher et al. 2021a); however, simulations that imitated reference conditions did not contain a suppression

factor. The modeling of the annual variability of wildfire (i.e., the high, average, and low fire years) is explained later in the section on temporal multipliers.

Fire spread was modeled using three principles: 1) prevailing winds elongated fire predominantly from the southwest to the northeast, while allowing other directions (Fig. 2.2); 2) fires spread more readily upslope than downslope relative to wind directions based on McArthur’s fire danger meter (Weise and Biging 1997; Table 2.2); and 3) natural fire ignition locations were spatially determined by observed lightning strikes and likely anthropogenic ignition locations near roads.

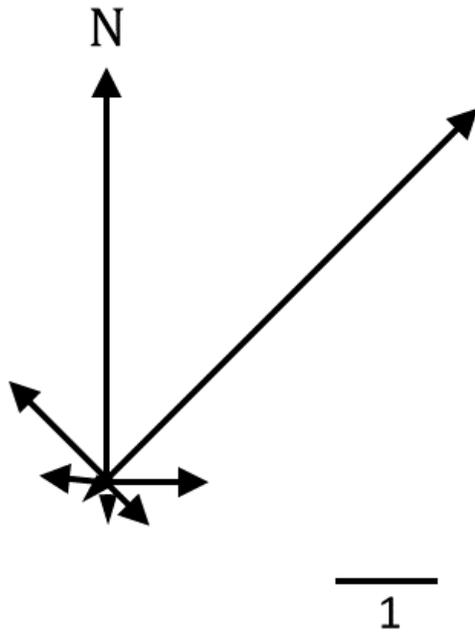


Figure 2.2 Wind directions that would “push” fire to elongate in the direction of the arrows. The longer the arrow, the higher probability of spread in that direction.

Table 2.2. Fire spread slope multipliers using McArthur’s fire danger meter.

Slope (%)	Multiplier
-16	0.4700
-8	1.1320
0	1.0000
8	0.5600
16	3.9620

Lightning strike locations obtained by GBNP from the Western Regional Climate Center in Reno NV were converted to a frequency map using a trial-and-error 12.5 km² moving window. The frequency values were standardized from 0 to 1 and converted into a 14 m resolution raster of lightning strike density to model natural fire starts. Pixels with values of 1 had the highest likelihood of fire starts via lightning. A second raster of human-caused ignitions was modelled using the distance from frequently used roads. Based on Morrison's (2007) ignition data, distances from roads were also standardized to values between 0 and 1 using the equation:

$$H_i = 1.0171 \cdot e^{-0.004 \cdot Dist} \quad (1)$$

where H_i = Probability of human ignition at pixel i and $Dist_i$ = Distance from pixel i to the nearest road with frequent use (the first pixel distance was calculated from $\frac{1}{2}$ pixel length). The maximum value between the two layers for each pixel was retained to create the final map of ignition likelihood. Once fire ignited in these locations, the fire spread based on underlying vegetation characteristics and prevailing wind directions (Fig. 2.2).

The other dominant process was herbivory expressed as livestock grazing on BLM-managed land, USFS-managed land, and private lands (primarily cattle, domestic sheep grazing mostly in the southern part of the AOI), wild horse grazing limited to the southeast corner of the AOI, and native herbivory by elk, mule deer, pronghorn, and lagomorphs present everywhere relevant. The four forms of herbivory were modeled separately. Moreover, we separated cattle grazing between the boot-stage phase (mid-May to late June), which is the most damaging to perennial grasses, and the rest of the year (July to early May). Because herbivory was present in nearly all classes, especially cattle grazing, it had the potential to considerably slow the speed of simulations depending on the approach used. We used area targets to set the level of grazing by allotments/pastures (for example, 300,000 acres [121,406 ha] grazed per year), whereas other layers below the more local and intensity of grazing by cattle, sheep, and horses.

The rate of cattle and sheep grazing varies among ecological systems according to their productivity in the boot stage versus the rest of the year, and when the forage is primary used. All grazing rates were set at 1.0 (grazed every year) in the models' vegetation classes but then adjusted with a transition multiplier number (in ST-Sim's Transition Multiplier's menu) between 0 and 1. A system's cattle grazing multiplier was obtained by dividing the season of use's productivity by the maximum season-adjusted annual productivity among systems (Table 2.3). The highest values were assigned to the most productive (i.e., most palatable) systems such as basin wildrye, dry wet meadow, subalpine and montane riparian, and wet meadow, based on actual forage production from NRCS ecological site descriptions prorated to the most likely season of use for a system (75% of total annual productivity grazed for upland systems and 25% of total for wet systems in the boot stage, respectively, and 25% of total annual productivity grazed for upland systems and 75% of total for wet systems during of the rest of the year – including the hot summer). Finally, all rates were multiplied by 0.1 to make sure that grazing rates do not accidentally dominate the probability space, although transition targets ultimately controlled overall implementation rates of grazing (different menu explained in previous paragraph). Similar ranking was conducted for domestic sheep and wild horses (Table 2.3).

Table 2.3. Relative cattle and sheep grazing preference ranking of ecological systems based on NRCS annual productivity.

Ecological System	15 May-30 June Cattle Grazing Probability Per Year	July to April Cattle Grazing Probability Per Year	Sheep Grazing Probability Per Year
Antelope Bitterbrush-Black Sagebrush	0.0017	0.0083	0.0017
Antelope Bitterbrush-Mountain Sagebrush	0.0035	0.0175	0.0035
Antelope Bitterbrush-Wyoming Sagebrush	0.0032	0.0158	0.0032
Aspen Woodland	0.0067	0.0333	0.0067
Aspen-Mixed Conifer	0.0067	0.0333	0.0067
Aspen-Subalpine Conifer	0.0017	0.0083	0.0017
Basin Wildrye	0.0167	0.0833	0.0167
Big Sagebrush semi-desert	0.0022	0.0108	0.0022
Black Sagebrush	0.0017	0.0083	0.0017
Desert Wash	0.0027	0.0133	0.0027
Dry Wet Meadow	0.0167	0.0833	0.1667
Four-Wing Saltbush	0.0013	0.0067	0.0013
Greasewood	0.0005	0.0025	0.0005
Little-leaf Mountain Mahogany	0.0017	0.0083	0.0083
Low Sagebrush Steppe	0.0035	0.0175	0.0035
Low Sagebrush-semi-desert	0.0028	0.0142	0.0028
Mixed Salt Desert	0.0007	0.0033	0.0007
Montane Riparian	0.0127	0.0633	0.0127
Montane Sagebrush Steppe-mountain	0.0035	0.0175	0.0035
Montane Sagebrush Steppe-upland	0.0035	0.0175	0.0035
Mountain Shrub	0.0035	0.0175	0.0035
Pinyon-Juniper	0.0015	0.0075	0.0015
Ponderosa Pine	0.0035	0.0175	0.0035
Riparian Ponderosa Pine	0.0035	0.0175	0.0035
Saline Meadow	0.0040	0.0200	0.0040
Semi-Desert Grassland	0.0027	0.0133	0.0027

Ecological System	15 May-30 June Cattle Grazing Probability Per Year	July to April Cattle Grazing Probability Per Year	Sheep Grazing Probability Per Year
Sodic Pools	0.0040	0.0200	0.0040
Stansbury Cliffrose	0.0017	0.0083	0.0017
Subalpine Riparian	0.0127	0.0633	0.0127
Swamp Cedars	0.0040	0.0200	0.0040
Wet Meadow-Montane	0.0090	0.0450	0.0090
Winterfat	0.0018	0.0092	0.0018
Wyoming Big Sagebrush-upland	0.0032	0.0158	0.0032

The probability of being grazed per year was one aspect of modeling herbivory. The other component was the proportional allocation of grazing effects to different vegetation classes. With proper grazing management, there generally was no change in vegetation composition or structure (i.e., the class does not change due to proper grazing). However, intense grazing transitioned a small proportion of pixels to a less desirable vegetation class, such as around water sources. Grazing that occurred from May to late June (i.e., the boot stage) was considered more physiologically damaging to grass species than grazing during the rest of the year (Tables 2.3 and 2.4; Provencher et al. 2021a).

If an ecological system was grazed during the boot stage, we represented proper grazing by a proportion of 0.999 (no change of class); consequently, the undesirable proportion was 0.001 (1-0.999) that led to often bare ground (U-A:Bare-Ground), annual species dominance (U-A:Annual-Species), or early shrub dominance (U-A:Early-Shrub) in upland systems and hummocked (U-A:Hummocked) or dominance by native unpalatable shrub and forb species (U-C:Shrb-Frb-Encroach) in wet systems (Appendix 3). Sometimes the 0.001 proportion was equally split among classes. If an ecological system was grazed outside of the boot stage, then the proper grazing was slightly higher at 0.9995; consequently, the undesirable proportion was 0.0005. In general, bare ground was not the outcome of transitions to less desirable classes during the non-boot stage seasons of uses. These proportions were the results of a decade trail-and-error calibration from several projects where we found that higher harmful proportions led to dominance of uncharacteristic classes never observed at such levels even after a century of grazing with proper management.

Wild horse grazing effects were modeled as boot stage transitions because wild horses access systems during all seasons of use; therefore, their damage was equivalent to cattle grazing during the boot stage (same proportions; Appendix 3). Domestic sheep were also modeled as boot stage grazing because of the way they utilize the whole herbaceous plant (closer to the soil) and the concentration of animals in any one location (Appendix 3).

Native herbivory (grazing and browsing) was tricky to model because mule deer, bighorn sheep, elk, pronghorn, and lagomorphs annually forage in most ecological systems (probability per year = 1). We only included native grazing in ecological systems where it was known to be important to the ecology (Table 2.4). For examples, different antelope bitterbrush, mountain shrub, curl-leaf mountain mahogany, and aspen systems can be greatly affected by native browsing; therefore, we modeled native herbivory in those. However, black sagebrush and mountain big sagebrush are browsed and frequently grazed by different native mammals, but their effects are considered minor compared to domestic sheep; therefore, we did not model native herbivory in those latter systems. It was assumed that native herbivory did not cause transitions to uncharacteristic classes under more intense herbivory pressure but did cause a one-year reversal of woody succession in shrublands through browse and acceleration of woody succession by one year in herbaceous systems through grazing (Table 2.4). The differential preference among systems by native herbivores as a generalized group was the relative annual plant productivity with a value of one given to the most productive systems (Table 2.4).

Table 2.4. Proportional allocation of seasonal native browsing and native grazing outcomes into no class change and transition to undesirable classes.

Ecological System	Relative Preference Based on NRCS Ecological Site Annual Productivity	Native Herbivory Probability Per Year	
		Dominant herbivory Proportion (no change in class)	Less Undesirable Proportion (change in succession in same class)
Antelope Bitterbrush-Black Sagebrush	0.1	0.999	0.001
Antelope Bitterbrush-Mountain Sagebrush	0.21	0.999	0.001
Antelope Bitterbrush-Wyoming Sagebrush	0.19	0.999	0.001
Aspen Woodland	0.4	0.95	0.05
Aspen-Mixed Conifer	0.4	0.95	0.05
Aspen-Subalpine Conifer	0.1	0.95	0.05
Curl-leaf Mountain Mahogany	0.19	0.95/0.999	0.05/0.001

Ecological System	Relative Preference Based on NRCS Ecological Site Annual Productivity	Native Herbivory Probability Per Year	
		Dominant herbivory Proportion (no change in class)	Less Undesirable Proportion (change in succession in same class)
Dry Wet Meadow	1	0.999	0.001
Four-Wing Saltbush	0.08	0.999	0.001
Little-leaf Mountain Mahogany	0.1	0.999	0.001
Low Sagebrush Steppe	0.21	0.999	0.001
Montane Riparian	0.76	0.999/0.9999	0.001/0.0001
Montane-Subalpine Grassland	0.25	0.999	0.001
Mountain Shrub	0.21	0.999	0.001
Semi-Desert Grassland	0.16	0.999	0.001
Stansbury Cliffrose	0.1	0.999	0.001
Subalpine Riparian	0.76	0.9999	0.0001
Wet Meadow - montane	0.54	0.999	0.001
Winterfat	0.11	0.999	0.001

Cattle and sheep grazing were spatially constrained as defined by BLM and USFS grazing permits. For cattle, each year was partitioned by the late spring grazing season (May 15-June 30) and rest of the year (July 1 to May 14 next year); therefore, two rasters were created for cattle (Fig. 2.3). For sheep grazing, we did not partition by season of use although we retained the more undesirable effects of late-spring use (Table 3); therefore, only one raster was deployed (Fig. 2.4). We attributed each allotment-pasture combination's pixels with relative grazing intensity using the actual active Animal Unit Months (AUM; permitted maximum the pasture can support), the realized AUM, seasons of use, and the duration of use. To obtain grazing intensity each pasture's actual active AUM was divided by the realized AUM, and multiplied by the relative duration of the permit's grazing period (number of days grazing divide by 365 days) for each season of use. Rested pastures were assigned a stocking rate of 0 in their respective seasons/years.

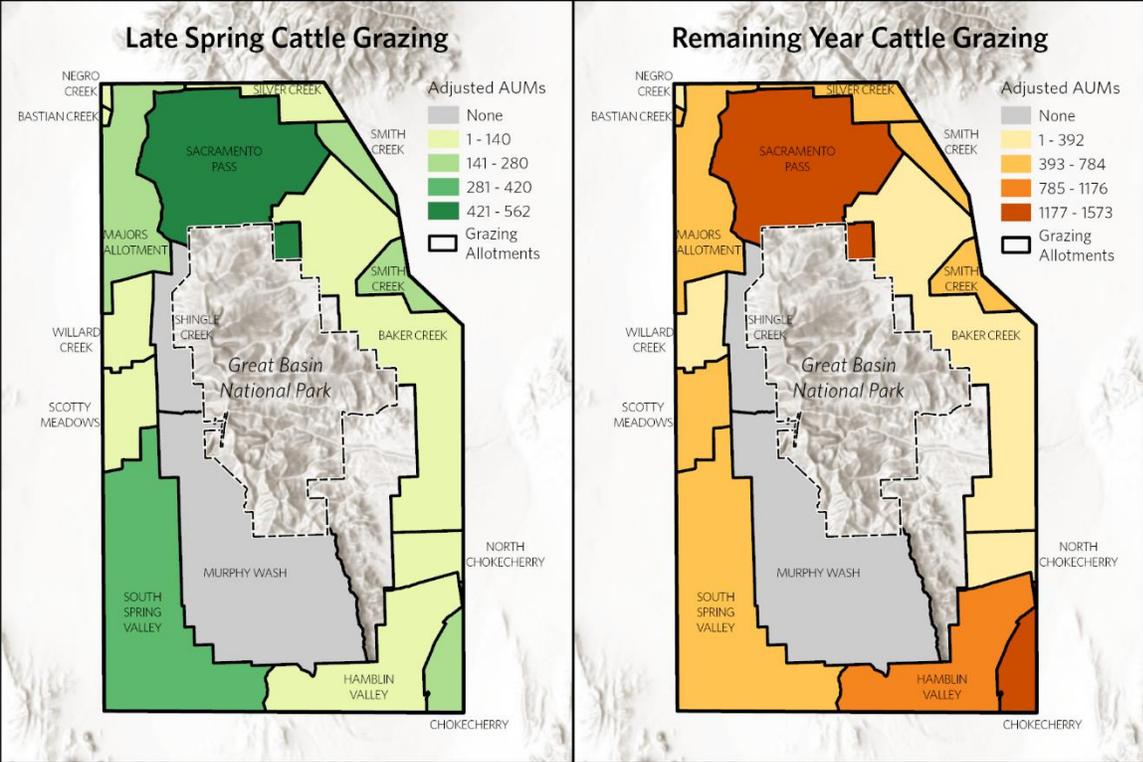


Figure 2.3. Cattle season of use allotments and pastures in the south Snake Range.

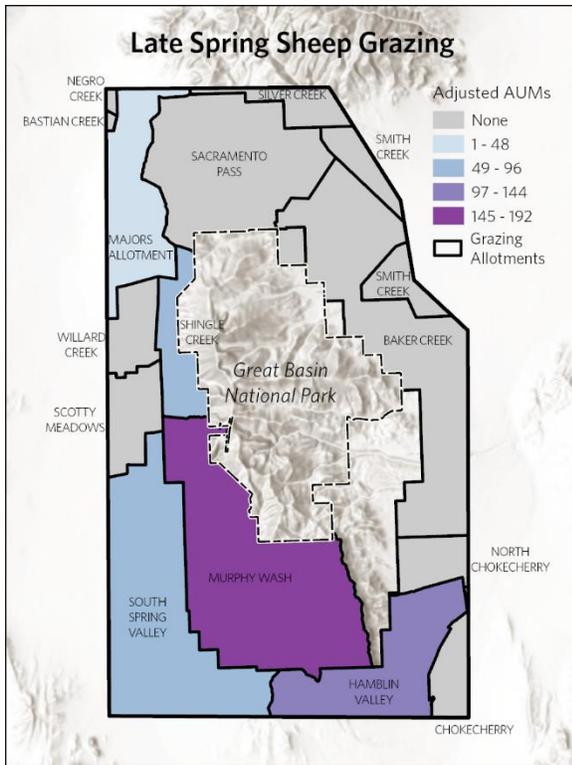


Figure 2.4. Sheep allotments and pastures in the south Snake Range.

Disturbances other than fire and herbivory included severe drought, shorter droughts, avalanches, native conifer invasion of shrublands, stream flooding, non-native annual species invasion, exotic forb invasion, insect and disease outbreaks, wet years, very wet years, aspen clone loss, natural recovery of degraded vegetation, and succession (Appendix 3).

Management Scenarios. A management scenario was a group of land management actions and specific climate effects that define a simulation theme. Scenario development was determined by the general guiding objectives of GBNP, BLM, and NDOW. Guiding objectives set the tone for land managers' priorities corresponding to a period of future management of about 10-15 years. During the first and second workshops, partners established the following guiding objectives (Table 2.5):

Table 2.5. Joint agency guiding management objectives established by GBNP, BLM, and NDOW during the first and second management workshops for south Snake Range's (NV) natural resources.

Guiding Objectives
Map potential and current vegetation, and ecological condition as expressed by ecological departure from reference conditions (formerly Fire Regime Condition Class).
Maintain overall condition of and restore degraded native upland and wetted ecological systems to reference conditions or desired future conditions given climate change.

Maintain and enhance bighorn sheep habitat given climate change.
Treat Wildland-Urban Interface (WUI) areas and reduce fuel loads to help protect human settlements and cultural resources in and around the project area from wildfire.
Meet wilderness area objective of maintaining or enhancing wilderness characteristics using wildland fire for resource benefit and/or targeted prescribed fire.
Help NPS and BLM, and other partners, meet objectives specified in management plans.

Six management scenarios were simulated for 50 years: two levels of management were factorially crossed with three forecasted 50-year climate scenarios. Two management scenarios determined management levels and were (1) a status-quo scenario (named custodial management) that included the maintenance of current fire-suppression activities and, where applicable, livestock grazing practices but did not use any mechanical or prescribed burning actions (this scenario was a control) and (2) preferred management that represented an ambitious level of vegetation treatment implementation. While \$0 per year was spent on the custodial management scenario, the preferred management scenario was limited to a maximum average annual expenditure level of about \$200,000 on GBNP lands and \$400,000-\$600,000 on BLM lands from year 2025 (first year after NEPA, with one earlier exception) to 2039, with low level maintenance management thereafter. Due to the stochasticity of simulations, total cost was expected to vary widely as implementation rates also varied around mean maximum values. If simulated treatments could not find enough areas to treat, realized expenditures were less than the maximum allowed. A list of management actions was selected by agency experts per ecological system. Each action was assigned a cost per area (Table 2.6) and other implementation attributes were imbedded in the simulation library: success and failure proportions, vegetation class outcomes for success and failures, and slope constraints (described below).

Three climate scenarios were statistically forecasted from time series of minimum and maximum temperatures and precipitation from 1945 to 2022 climate data obtained from the Parameter-elevation Relationships on Independent Slopes Model (PRISM; continuation of historic climate with a slight climate change trend; Daly et al. 2008) and LOcalized Climate Analogs (LOCAs) for ACCESS1 (hotter and drier) and HadGEM-ES (hotter and wetter spring and drier winter) Global Circulation Models (Pierce et al. 2014; WRCC 2022) downloaded at location 38°56'46.2"N 114°15'26.8"W. The methods of statistical forecasting of replicated climate data and translation to Standard Precipitation-Evapotranspiration Index time series used in simulations were described in Provencher et al. (2021a). The six simulated scenarios were: custodial and PRISM, preferred and PRISM, custodial and ACCESS1, preferred and ACCESS1, custodial and HagGEM-ES, preferred and HagGEM-ES. In each of the six scenarios the same actions were implementation at the same planned rates; however, planned rates were not equal to the rates realized as climate replicates and stochasticity caused sometimes substantial differences of implementation among scenarios and replicates within scenario.

Table 2.6. Cost per acre of management actions and per agency. Blank entries imply that the actions were not used in that system and agency.

Action/Ecological System	Agency Cost	
	BLM	GBNP
Chainsaw+Chip+Herbicide+Native-Seed		
Basin Wildrye		\$650
Chainsaw+Lop-Scatter+NativeSeed		
Montane Sagebrush Steppe-upland		\$430 (\$365-\$500)#
Chainsaw+Pile+Native-Seed contract		
Antelope Bitterbrush-Mountain Sagebrush		\$1183 (\$1,000 -\$1,250)
Chainsaw+PileBurning		
Littleleaf Mountain Mahogany	\$500	
Montane Riparian	\$500	\$4,000
Ponderosa Pine	\$500	\$4,000
Riparian Ponderosa Pine	\$500	\$4,000
Chainsaw+PileBurning+Seed		
Basin Wildrye	\$637	
Chainsaw-Thinning contract		
Black Sagebrush	\$1,000	
Mountain Shrub	\$1,000	
Stansbury Cliffrose	\$1,000	
Exotic-Control		
Dry Wet Meadow	\$200	\$225
Montane Riparian	\$200	\$225
Riparian Ponderosa Pine	\$200	\$225
Saline Meadow	\$200	
Wet Meadow-Montane	\$200	\$225
Exotic-Control+Native-Seed		
Basin Wildrye	\$400	\$400
Fence		
Aspen Woodland	\$6,100 (\$2,200-\$10,000)	
Aspen-Mixed Conifer	\$10,000	
Herbicide-Plateau+Seed		
Black Sagebrush	\$237	
Wyoming Big Sagebrush-upland	\$237	
Lop+Scatter		
Little-leaf Mountain Mahogany	\$80	
Lop+Scatter+RxAviation		
Aspen-Mixed Conifer	\$750	\$750

Masticate+Native-Seed		
Antelope Bitterbrush-Black Sagebrush	\$577	
Black Sagebrush	\$577	
Montane Sagebrush Steppe-upland		\$1,083 (\$1,015-\$1,150)
Masticate+Seed		
Antelope Bitterbrush-Black Sagebrush	\$577	
Antelope Bitterbrush-Mountain Sagebrush	\$577	
Black Sagebrush	\$577	
Montane Sagebrush Steppe-upland	\$577	
Wyoming Big Sagebrush-upland	\$577	
Mow+Seed		
Black Sagebrush	180 (\$170-\$185)	
Pine-Cone-Collection		
Ponderosa Pine	\$1	\$1
Riparian Ponderosa Pine	\$1	\$1
RxFire-Aviation		
Aspen Woodland	\$600	\$600
Aspen-Mixed Conifer	\$600	\$600
Aspen-Subalpine Conifer	\$600	\$600
Dry Wet Meadow	\$600	\$600
Limber-Bristlecone Pine-mesic		\$600
Low Sagebrush Steppe	\$600	\$600
Montane Sagebrush Steppe-mountain		\$600
Mountain Shrub	\$600	\$600
Wet Meadow-Montane	\$600	\$600
RxFire-Ground		
Dry Wet Meadow	\$250	\$1,134
Montane Riparian		\$1,134
Montane Sagebrush Steppe-upland		\$1,134
Mountain Shrub	\$250	
Wet Meadow-Montane	\$250	\$1,134
Small-Tree-Lopping		
Antelope Bitterbrush-Black Sagebrush	\$80 (\$65-\$95)	\$250
Antelope Bitterbrush-Mountain Sagebrush		\$250
Black Sagebrush	\$80 (\$65-\$95)	
Low Sagebrush-semi-desert	\$80 (\$65-\$95)	
Montane Sagebrush Steppe-upland	\$80 (\$65-\$95)	
Stansbury Cliffrose	\$80 (\$65-\$95)	
Thin+Herbicide+Native-Seed		
Basin Wildrye	\$350	\$350

Water-Table-Uplift		
Montane Riparian	\$800 (\$400-\$1,200)	\$800 (\$400-\$1,200)
Wet Meadow-Montane	\$800 (\$400-\$1,200)	\$800 (\$400-\$1,200)
Weed-Inventory+Treat		
Basin Wildrye	\$115	\$115
Dry Wet Meadow	\$115	\$115
Montane Riparian	\$115	\$115
Riparian Ponderosa Pine	\$115	\$115
Saline Meadow	\$115	
Wet Meadow-Montane	\$115	\$115

The range between minimum and maximum cost was sampled with a uniform distribution by ST-Sim.

Constraints on Management Actions. Rasters that spatially constrain implementation of management actions were uploaded to ST-Sim. Based on the experience of agency machinery operators, all actions that used tractors pulling seeders, mowers, or harrows were limited to slopes less than 15% in a raster calculated from the US Geological Survey Digital Elevation Model. Similarly, masticators could be used on slopes up to 30% whereas chainsaw operations could be used on even steeper slopes. Prescribed fire was not limited by slopes. Another group of constraints were the zones where some or any machinery could not be used because they were wilderness areas, and around known ferruginous hawk nesting trees (no actions that result in trees dying with 100m radius) and one greater sage-grouse lek (no actions that mow sagebrush within 1 mile of lek, but tree cutting is allowed). The ferruginous hawk nest and lek constraints are not shown to protect the locations of these sites. BLM staff indicated that chainsaw and mastication work could be applied to the Big Springs Wash area south of the Highland Ridge Wilderness Area (brown triangle in Fig. 2.5).

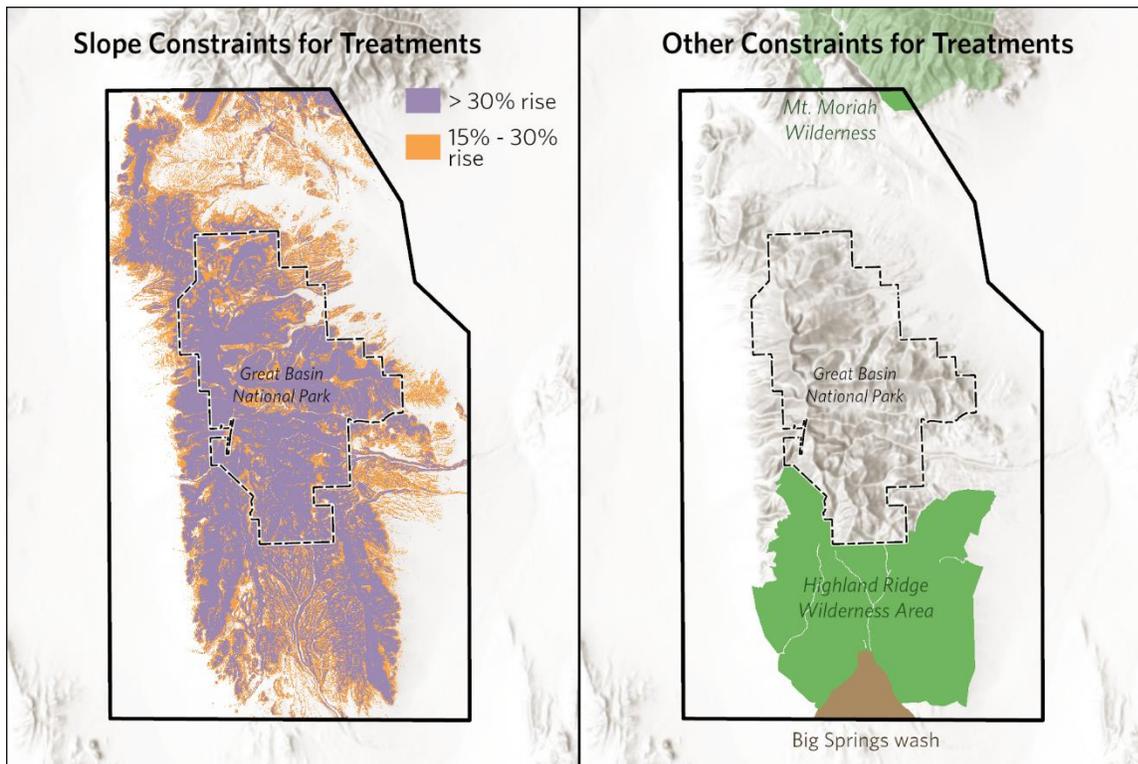


Figure 2.5. Map of spatial constraints areas in the south Snake Range.

Replication and Climate Variability. Each management scenario (custodial and preferred) used the same replicated climate time series to introduce temporal variability into the expression of ecological disturbances. Monthly precipitation and monthly minimum and maximum temperatures were the same downloaded ones for PRISM and the two LOCAs (i.e., ACCESS1 and HadGEM-ES) in scenario building. A stochastic weather generator (SWG; Verdin et al. 2014) was used to statistically replicate the three (precipitation, minimum temperature, and maximum temperature) climate time series 10 times over 50 years.

The purpose of simulating future climate was to introduce temporal variability in dominant ecological processes (Provencher et al. 2016). Variability directly affects processes through temperature and precipitation, or indirectly mediates processes through the Standard Precipitation-Evapotranspiration Index (SPEI; SPI initially published by Hayes et al. 1999). SPEI is a standardized drought index that, as the name implies, includes both precipitation and evapotranspiration, and is expressed in positive (wet) and negative (dry) standard deviations from the mean (Hayes et al. 1999). Unlike the Palmer's Drought Index fixed at a 12-month lag at the beginning of the hydrologic year, SPEI is calculated over user defined time lags. SPEI was calculated from PRISM's replicated time series of monthly precipitation and minimum and maximum temperatures using the "spei" function in R package 'SPEI' (Begueria and Vicente-Serrano 2017). Each of the 10 climate replicates containing three climate time series (precipitation and minimum and maximum temperatures) resulted in one SPEI time series

expressed each year as a matrix organized by month of reporting (for example, September) and backward lag of drought values expressed in months (for example, 9 months prior).

Temperature, precipitation or SPEI time series were transformed into transition multipliers in ST-Sim (Provencher et al. 2016, 2021a). Transition multipliers are a quantitative method to determine how climate variations influence ecological processes. Transition multipliers are traditionally determined by dividing each yearly value of the time series (for example, area burned) by the temporal average of the time series, thus creating a non-dimensional time series with an average of one. A transition multiplier is a varying unitless number ≥ 0 in an annual time series that multiplies a base disturbance rate in the STSM. For example, a transition multiplier of 1 implies no change in the annual probability for fire, a transition of 0 is a complete suppression of fire, and a transition of 3 triples the annual probability of fire. Patterns of climate variability can therefore be used to reproduce patterns in fire activity over periods of years that were statistically replicated by the SWG.

Often, however, we do not have access to time series of data from which to calculate even a single replicate; therefore, we theoretically generated the transition multipliers using different SPEI and curve-fitting equations based on the theorized relationships, sometimes documented in the scientific literature, between an ecological process and different standard deviations of SPEI (Table 2.7).

Table 2.7. The transition multiplier (TM) as a function of climate variables or rare events sampled from a distribution. A TM multiplied the model's transition base rate. The symbol "x" indicates multiplication of the two temporal multipliers as performed by the ST-Sim software.

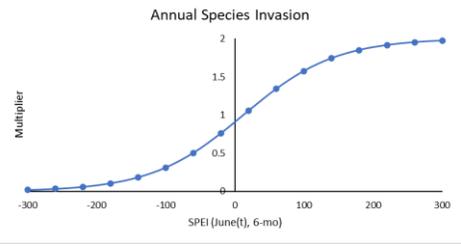
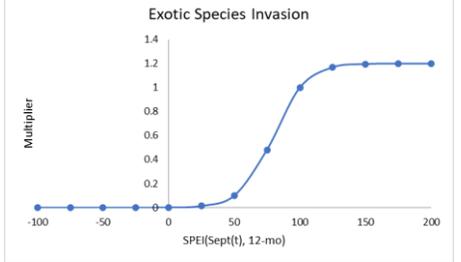
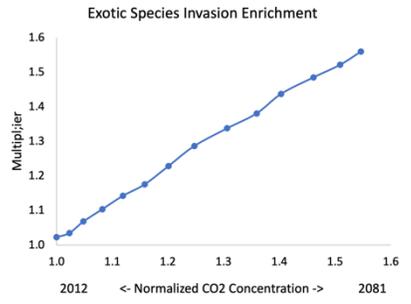
Ecological Process Affected	First factor	Second Factor
<p>Annual Species Invasion[#]: TM corresponding to the 6-month SPEI of that year's June.</p>		
<p>Exotic Species Invasion^a: TM corresponding to the 12-month SPEI of that year (regressed to represent annual flows in riparian corridor). This first component was multiplied by the normalized atmospheric CO₂ from the IPCC report.</p>		

Table 2.7. The transition multiplier (TM) as a function of climate variables or rare events sampled from a distribution. A TM multiplied the model's transition base rate. The symbol "x" indicates multiplication of the two temporal multipliers as performed by the ST-Sim software.

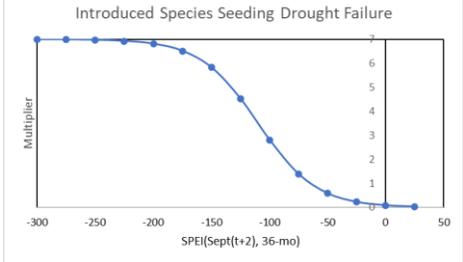
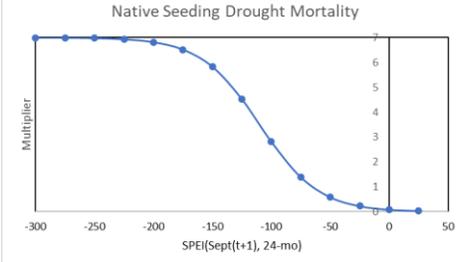
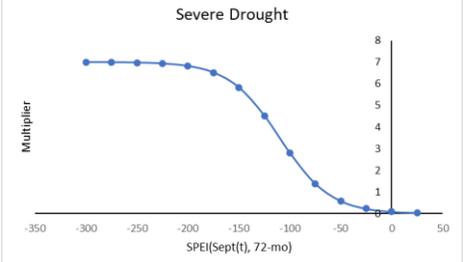
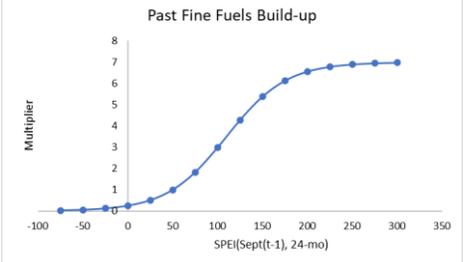
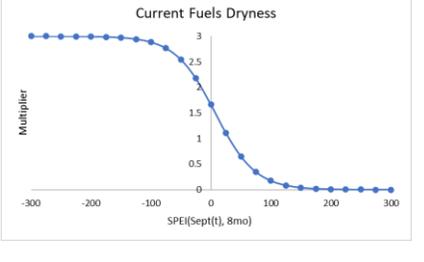
Ecological Process Affected	First factor	Second Factor
<p>May Hard Freeze: TM obtained by multiplying the resampled Beta density functions for episodic rare events of early spring thaw in April causing Gamble oak bud breaks <u>followed</u> by bud kill during hard May freeze.</p>	<p>April Thaw: Beta Distribution Mean = 4.75 Standard Deviation = 4.50 Minimum value = 0.001 Maximum value = 100.00</p>	<p>May Hard Freeze: Beta Distribution Mean = 4.75 Standard Deviation = 3.54 Minimum value = 0.001 Maximum value = 100.00</p>
<p>36-month drought mortality%: Three-year drought one year prior and two years into the future will cause introduced species failure.</p>		
<p>24-month drought mortality@: Two-year drought one year prior and one year into the future will cause native species failure.</p>		
<p>Severe Drought+: Five-year drought for the current and past four years will cause shrub and tree thinning, and affect woody succession in wet systems. This curve also applies to Insect/Disease Outbreak.</p>		
<p>Fire Activity*: 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.</p>		

Table 2.7. The transition multiplier (TM) as a function of climate variables or rare events sampled from a distribution. A TM multiplied the model's transition base rate. The symbol "x" indicates multiplication of the two temporal multipliers as performed by the ST-Sim software.

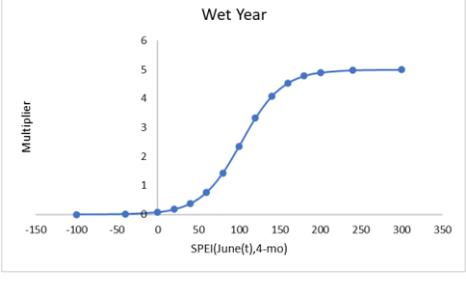
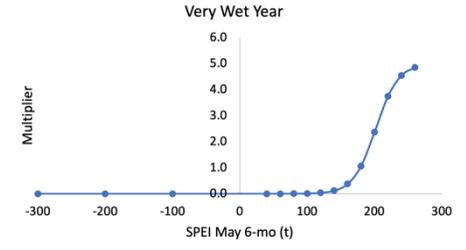
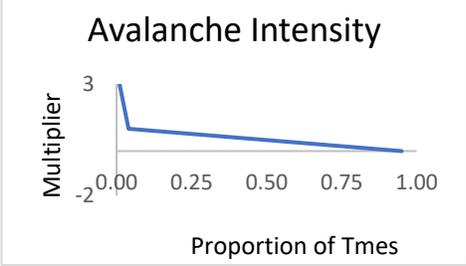
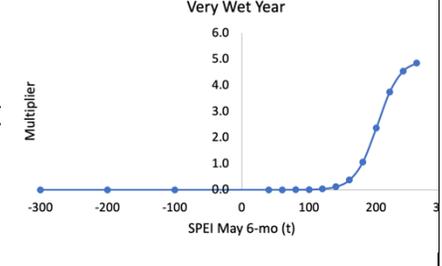
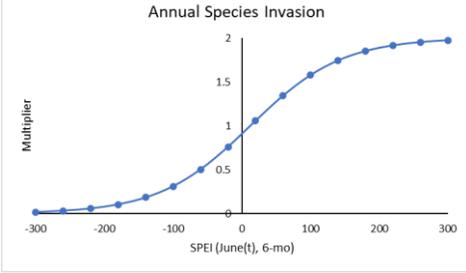
Ecological Process Affected	First factor	Second Factor
<p>Wet Year⁸: A wet year is equal to one standard deviation more moisture than the mean; TM = 2.3 when SPEI = 100. Wet years primarily fertilize cheatgrass cover-increase in upland systems, and slightly reverse woody succession in saline and wet meadows.</p>		
<p>Very-Wet year⁴: A very-wet year is equal to two standard deviations more moisture than the mean; TM = 16 when SPI = 200. Very wet year was only used as a stand replacing event in salt desert communities through root rot.</p>		
<p>Avalanche: TM is obtained by multiplying the Very Wet Year Multiplier with an avalanche intensity multiplier obtained from simple resampling of avalanche events (no avalanche 95% of times, multiplier of 1 4% of times, and multiplier of 3 x average at 1% of times).</p>		
<p>Annual Species Invasion⁵: Non-native annual species can invade even during droughts: Invasion is enhanced at SPEI > -0.42 StDEV from mean.</p>		

Table 2.7. The transition multiplier (TM) as a function of climate variables or rare events sampled from a distribution. A TM multiplied the model's transition base rate. The symbol "x" indicates multiplication of the two temporal multipliers as performed by the ST-Sim software.

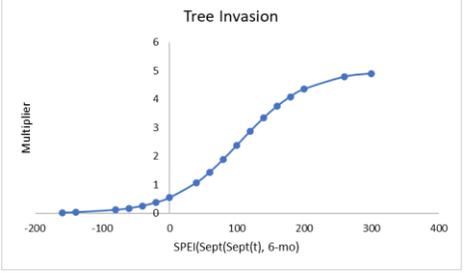
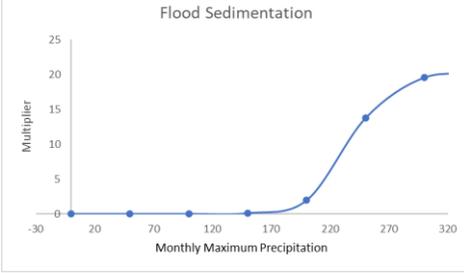
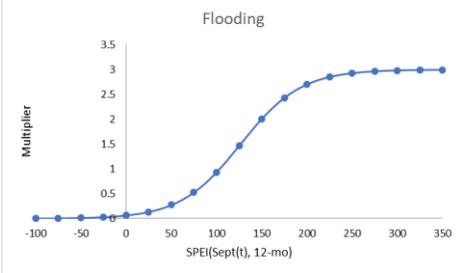
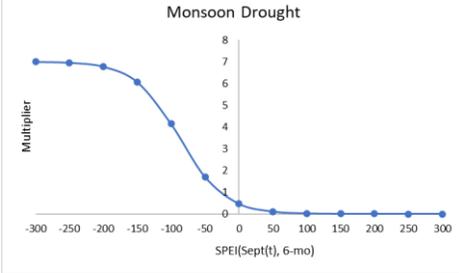
Ecological Process Affected	First factor	Second Factor
<p>Tree (Native) Invasion[†]: Conifer species (primarily pinyon and juniper) germinate and establish during wet years: Invasion is enhanced at SPI>+1 STDEV from mean.</p>		
<p>Flash Flood: The flash flood intensity multiplier obtained from simple resampling of rare flash flood events (no flash flood 98% of times (I.e., multiplier = 0), multiplier of 99 about 2% of times).</p>	<p>Multiplier = 0, 98% of events Multiplier = 99, 2% of events</p>	
<p>Flood Sedimentation^b: Monthly maximum precipitation (mm) causing TM sedimentation in montane riparian of 1 at +1 STDEV from the mean and increasing to about a 20-year flood event by +3 STDEV from the mean.</p>		
<p>Flooding^c: The total TM for annual flooding in riparian systems combined the precipitation for the hydrologic year (Sept[t], 12-mo) as a surrogate for the snowpack thickness and rare events of sudden snowmelt sampled from a Beta distribution due to warm temperature. The precipitation TM for Sept(t, 12-mo) corresponded to 1 at +1 STDEV from the mean and 3 at +3 STDEV from the mean SPEI.</p>		<p>Snowmelt Temperature Beta Distribution Mean = 4.7620 Standard Deviation = 4.54 Minimum value = 0.001 Maximum value = 100.00</p>

Table 2.7. The transition multiplier (TM) as a function of climate variables or rare events sampled from a distribution. A TM multiplied the model's transition base rate. The symbol "x" indicates multiplication of the two temporal multipliers as performed by the ST-Sim software.

Ecological Process Affected	First factor	Second Factor
<p>Monsoonal Drought^d: Only applies to Rocky Mountain juniper seed germination and sapling mortality in Swamp Cedars. Failure of precipitation from March to September combines late winter precipitation and summer monsoonal storms. TM of 7 at -3 STDEV from the mean and TM of 3.7 at -1 STDEV of the mean. TM is generally zero for a +0.5 STDEV greater than mean.</p>		

Footnotes for Table 7 are listed below:

$$\# \text{Annual Species Invasion} = 2 \cdot e^{1.5 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{June}(t), 6\text{mo}} + 80))} / (4 + e^{1.5 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{June}(t), 6\text{mo}} + 80))})$$

$$^a \text{Exotic Species Invasion} = 1.2 \cdot e^{8 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t), 12\text{mo}} - 80))} / (1.5 + e^{8 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t), 12\text{mo}} - 80))})$$

$$\# \text{Annual Flow}_t = 49.9158 + 0.1421 \cdot \text{SPEI}_{\text{Sept}(t)} + 0.000085259 \cdot \text{SPEI}_{\text{Sept}(t)}^2$$

$$\% \text{36-month introduced seeding drought mortality} = 7 \cdot (1 - e^{-4 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t+2), 36\text{mo}} + 195))}) / (30 + e^{-4 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t+2), 36\text{mo}} + 195))})$$

$$@ \text{24-month native seeding drought mortality} = 7 \cdot (1 - e^{-4 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t+1), 24\text{mo}} + 195))}) / (30 + e^{-4 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t+1), 24\text{mo}} + 195))})$$

$$^+ \text{Severe Drought}_t \text{ variability factor} = 7 \cdot (1 - e^{-4 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t), 72\text{mo}} + 195))}) / (30 + e^{-4 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t), 72\text{mo}} + 195))})$$

*Shrubland Area Burned_t variability factor = Past Fine Fuels Buildup · Current Fuels Dryness, where

$$\text{Past Fine Fuels Buildup}_t = 7 \cdot e^{3 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t-1), 24\text{mo}} - 110))} / (1 + e^{3 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t-1), 24\text{mo}} - 110))}), \text{ and}$$

$$\text{Current Fuels Dryness}_t = 3 \cdot (1 - e^{3 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t), 8\text{mo}} + 100))}) / (25 + e^{3 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t), 8\text{mo}} + 100))})$$

$$\& \text{Wet Year}_t \text{ variability factor} = 5 \cdot e^{4 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{June}(t), 4\text{mo}} - 80))} / (2.5 + e^{4 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{June}(t), 4\text{mo}} - 80))})$$

$$\wedge \text{Very-Wet Year}_t \text{ variability factor} = 5 \cdot e^{6 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{May}(t), 6\text{mo}} - 150))} / (5 + e^{6 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{May}(t), 6\text{mo}} - 150))})$$

$$^s \text{Non-Native Annual Species Invasion}_t \text{ variability factor} = 2 \cdot e^{1.5 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{June}(t), 9\text{-mo}} + 80))} / (4 + e^{1.5 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{June}(t), 9\text{-mo}} + 80))})$$

$$^\ddagger \text{Tree (Native) Invasion}_t \text{ variability factor} = 5 \cdot e^{2 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t), 6\text{-mo}} - 50))} / (3 + e^{2 \cdot (0.01 \cdot (100 \times \text{SPEI}_{\text{Sept}(t), 6\text{-mo}} - 50))})$$

$$^b \text{Flood Sedimentation} = 20 \cdot e^{6 \cdot (0.01 \cdot (\text{MonthlyMaximumPrecipitation} - 210))} / (5 + e^{6 \cdot (0.01 \cdot (\text{MonthlyMaximumPrecipitation} - 210))})$$

$$^c \text{Flooding} = 3 \cdot e^{3 \cdot (0.01 \cdot (L268 - 90))} / (3 + e^{3 \cdot (0.01 \cdot (L268 - 90))})$$

$$^d \text{Monsoonal Drought} = 7 \cdot (1 - e^{3 \cdot (0.01 \cdot (L289 + 195))}) / (25 + e^{3 \cdot (0.01 \cdot (L289 + 195))})$$

2.2.3. Measures of Ecological Departure

We calculated three measures of ecological departure from reference conditions: (a) ecological departure (ED) per ecological system (Provencher et al. 2013, 2021a), (b) spatially explicit and stochastic ED by ecological system (Provencher et al. 2024), and (c) spatially explicit and stochastic ED for all ecological systems (Provencher et al. 2024). In 2010, Provencher et al.

(2010, 2013) only presented the traditional ED metric for GBNP that was the Fire Regime Condition metric from LANDFIRE, now termed Vegetation Departure Condition by LANDFIRE (Eq. 2; Blankenship et al. 2021). Traditional ED is the dissimilarity between the *observed* (O) distribution of vegetation class percentages, likely from remote sensing, and the *expected* (E) distribution of vegetation class percentages in the reference condition (i.e., most often assumed to be pre-European settlement condition; Hann and Strom 2003; Shlisky and Hann 2003; Rollins 2009; Blankenship et al. 2021; Swaty et al. 2022):

$$ED = 100 - \sum_{i=1}^N \min(O_i, E_i) \quad (\text{Eq. 2})$$

where $i = 1, \dots, N$ classes (Provencher et al. 2008; for an example see Low et al. 2010). Lower values indicate that vegetation was closer to the reference condition and may not require management interventions.

Spatially explicit and stochastic ED was based on Eq. 2 but modified to make the estimation of departure more local from the perspective of an observer (animal or human) assessing condition standing in each of all pixels on the map and with a limited field of perception. Therefore, a pixel located well within the boundary of GBNP would have an ED value not dependent on the vegetation classes beyond GBNP's boundary or even beyond a perception distance set by managers. The percentages in Equation 2 were obtained from tabular data calculated in a Geographic Information System (GIS), were not spatially explicit, and the value of ED for any ecological system applied equally to all pixels. In spatially explicit estimation, the percentages of vegetation classes and the reference conditions are uniquely calculated for each pixel within a search radius from the focal pixel.

We used a radius of daily perception of 1,400 m to estimate spatially explicit ED based on independent GBNP staff observation and a graduate student Master's thesis research from Oregon State University of GPS-collared bighorn sheep. The Master research showed that the averaged maximum daily displacement for a female with more than 2 points per day was 729 m. It was assumed that an equal distance beyond that was also "perceivable," therefore, doubling the value to about 1,458 m. Even accounting for unequal data among the females and taking the average displacement per female and average across all females, the maximum displacement was about 700 m that doubled to 1,400 m for the perceived distance. Some observations suggested that bighorn sheep reacted to predators about 1 km away; therefore, doubling the value to estimate a perceivable range was likely reasonable.

The equation for exponential decay imitating bighorn sheep perception of surrounding vegetation from a pixel assumed that a pixel at 1,400 m had a weight of 0.01 (1%); therefore, Eq. 3 was:

$$\text{Weight of ED perception}(m,n) = W_{m,n} = e^{-0.00329 \cdot \text{distance}(m,n)} \quad (\text{Eq. 3})$$

where $\text{distance}(m,n)$ is the distance in meters between the middle focal pixel m and the middle of pixel n within the search radius (Fig. 2.6). The value of -0.00329 was derived from $\ln(0.01/1400)$.

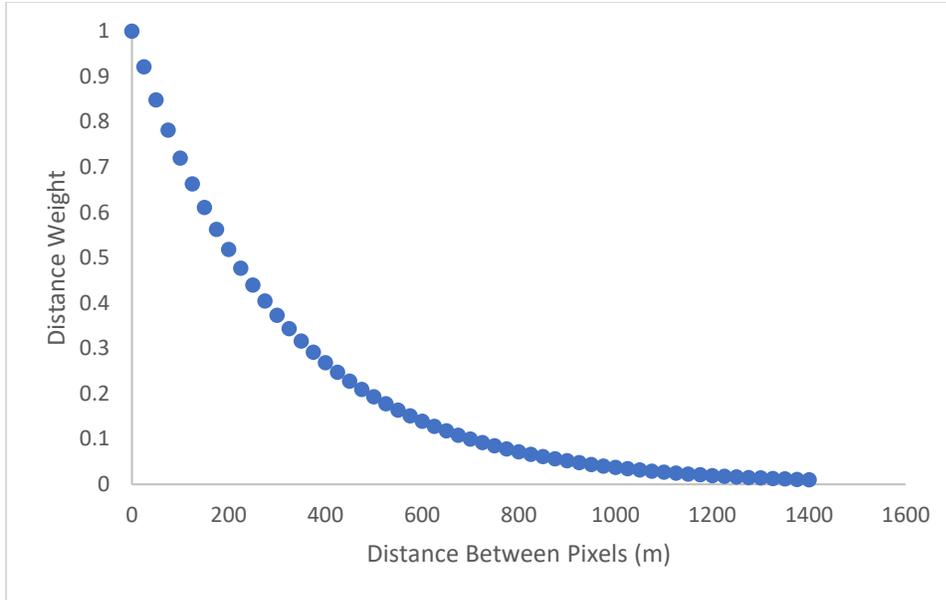


Figure 2.6. Distance decay weight representing the relative value of vegetation of a distance pixel as perceived by an average female bighorn sheep as a function of the distance (meter) between the focal pixel n and another pixel m within the 1,400m search radius. Weight of ED perception(m,n) = $W_{m,n} = e^{-0.00329 \cdot distance(m,n)}$

For spatially explicit ED estimation, the value of a pixel of the same vegetation class as the focal pixel was “1” multiplied by the pixel distance weight (Eq. 3; henceforth the value of 1 can be dropped) as the distance effect from the focal pixel; therefore, the proportion of each vegetation class i of the focal pixel at location $[k, p]$, where k and p were column and row positions, was obtained by summing the weights per same class type and dividing the sum of weights among all classes per ecological system:

$$\text{Proportion of class } (i, k, p) = \frac{\sum_{n=1}^R \sum_{m=1}^C W(i, m, n)}{\sum_{n=1}^R \sum_{m=1}^C \sum_{j=1}^N W(j, m, n)} \quad (\text{Eq. 4})$$

where i and j coded for the vegetation class i or j ($i, j = 1, 2, \dots, N$ maximum number of classes); m and n coded for column and row position; C and R , respectively, were the maximum number of columns and rows in the raster. The proportion of class _{i} can be either for E_i or O_i in Eq. 2 for ED.

The multiple-system ED used the same Eqs. 2-4 as before but proportions obtained from Eq. 5 were prorated by the proportion of the ecological system to which they belong relative to all systems within the moving window of Eq. 3 and the sum of all prorated proportions was 1:

$$M(i, r, k, p) = \text{Proportion of class } (i, k, p) \times \text{Proportion of system}(r, k, p) \quad (\text{Eq. 5})$$

where M is the multiple system proportion for the system by class combination, i , k , and p had the same meaning as in Eq. 3, whereas r was ecological system r ($r = 1$ to Q , where Q was the maximum number of ecological systems in the landscape). The proportion of each ecological system among all was estimated in the moving window; therefore, small systems at the landscape level will always have more equal representation than large systems within a moving

window. Eq. 4 was applied to observed and reference condition vegetation classes, and Eq.1 was used to estimate ED.

One important component of ED is the value of E_i , the reference condition for ecological system i , that was stochastically and spatially simulated. Eqs. 2-4 applied to the reference condition as they did for the observed vegetation to obtain the expected proportions of vegetation classes. The reference condition was created in a few steps. First, we replaced all non-reference vegetation classes and infrastructure in the initial conditions map with the most similar successional reference vegetation classes for non-infrastructure systems or with the most likely ecological system and vegetation for areas covered with infrastructure. These substitutions created an initial condition map that would transition with natural disturbances simulated for 700 years (i.e., the initial vegetation classes will be replaced several times over).

Second, only disturbances found during pre-settlement were simulated. Fire was perhaps the dominant disturbance in the AOI. Fire greatly determined the spatial variation in the reference condition that resulted in either early-successional vegetation classes if fire found a path around natural fuel breaks or late-successional vegetation classes if fire was stopped by natural fuel breaks. We captured this spatial variation using the moving window estimation previously discussed. As explained above, fire directionally spreads following prevailing winds and the speed of spread among pixels was influenced by slopes facing or opposing prevailing winds shaped the distribution of vegetation classes (Provencher et al. 2021a).

Third, the reference condition scenario simulated for 700 years was replicated 10 times. Replicates were obtained from different time series of minimum and maximum temperatures, and precipitation that were estimated with a stochastic weather generator (Verdin et al. 2015) applied to PRISM climate data (Daly *et al.* 2008) from 1950 to 2018 (see Provencher et al. 2021a). The time series were used to estimate the Standard Precipitation and Evapotranspiration Index (SPEI; Hayes et al. 1999) specified for different months and lags that are relevant to different ecological processes. The SPEI values were used to introduced real variability around the fixed parameter value of each disturbance in the ST-Sim model pathways as explained in Provencher et al. (2016, 2021a). For infrequent events not related to climate, such as flash floods and rain-on-snow events, we sampled from a built-in ST-Sim statistical distribution that sampled events of a certain value (multiplier) at a user-specified frequency (e.g., 2 flash floods per 100 years).

Fourth, the proportion of each reference vegetation class per ecological system (i.e., the expected proportion) was estimated for each replicate at year 700 only. A replicate was defined by a distinct climate time series (i.e., distinct SPEI time series) from which we only retained the vegetation classes at year 700 (we verified that values were at equilibrium). The pixel-by-pixel moving window was applied to each reference replicate raster on year 700 using the same search radius and distance-decay weight function that was used to estimate observed pixels (Eq. 3). The last step of ED estimation was to apply Eq. 2 to each pixel location using the observed and reference condition proportions in the moving window. A raster map of variance was also estimated by pixel, although any statistical measure of variability would work.

2.2.4. Bighorn Sheep Habitat Suitability Index

The habitat suitability index for GBNP's Rocky Mountain bighorn sheep was designed during two stakeholder workshops supplemented with literature (Comer et al. 2016) and follow-up expert consultation. Nine covariates were considered to build resource selection functions (RSF) partitioned among a) summer habitat and b) winter habitat. Two covariates of distance to escape terrain and distance to roads were used in both the summer and winter habitat estimates. All calculations were conducted in R version 4.3.1 (R Core Team 2023).

To measure the effect of human road use on bighorn sheep, roads were identified in the project boundary (hiking trails were not included). Distance from the nearest classified road pixel was then measured, using the distance function in the 'terra' package (Hijmans 2023). We used a positive, sigmoid relationship to create the RSF, generally distances greater than a quarter mile (400 m) were given a value of 1.0:

$$RSF_{Road} = e^{25*(distance-0.3)} / (0.1 + e^{25*(distance-0.3)}) \quad (\text{Eq. 6})$$

where *distance* = distance to the nearest classified road pixel in kilometers.

To calculate the distance from escape RSF, first escape terrain was identified. Escape terrain was defined by steep terrain, above 30° (60% slope; Dunn 1996). Slope was calculated using the terrain function with an 8-pixel neighbor window in the 'terra' package (Hijmans 2023). Then, pixels above 30° were retained and distance to those pixels was estimated, using the distance function in 'terra' (Hijmans 2023). Distances within 250 m (~ 820 feet) were considered optimal. The following equation was used to describe the final RSF:

$$RSF_{Escape} = 1 - e^{25*(distance-0.4)} / (1 + e^{25*(distance-0.3)}) \quad (\text{Eq. 7})$$

where, *distance* ≥ 30° slope in kilometers.

Summer habitat was defined by summer forage, topographic roughness, and elevation. Summer forage was based on the ecological systems and vegetation classes. Ecological systems used by bighorn sheep were identified by partners within the workshops. Vegetation classes were assigned either a value of 1.0 (highest forage value for bighorn sheep), 0.75 (some forage value), or 0.0 (no forage value). Early seral classes generally had the highest forage value (for a full list see Appendix 4). Topographic Roughness Index (TRI) was calculated using the terrain function in the 'terra' package (Hijmans 2023). To transform the TRI to an RSF, the following equation was used:

$$RSF_{TRI} = e^{25*(\frac{TRI}{100}-0.15)} / (4.5 + e^{25*(\frac{TRI}{100}-0.15)}) \quad (\text{Eq. 8})$$

where, *TRI* = topographic roughness index.

Elevation was used to constrain summer habitat, where elevations above 8,000 ft. (2,438 m) were most preferred. The sigmoid equation used was:

$$RSF_{ElevS} = e^{17*(elev-2.4)} / (0.1 + e^{17*(elev-2.4)}) \quad (\text{Eq. 9})$$

where, *elev* = the elevation in kilometers.

Summer habitat was estimated using the mean of the three seasonal RSFs:

$$Habitat_S = \frac{RSF_{ForageS} + RSF_{TRI} + RSF_{ElevS}}{n} \quad (\text{Eq. 10})$$

where, $RSF_{ForageS}$ = the summer forage value at a given pixel, RSF_{TRI} = the value of the topographic roughness RSF at a given pixel, and RSF_{ElevS} = the value of the summer elevation RSF at a given pixel.

The final summer habitat suitability index was found averaging the summer habitat value ($Habitat_S$) with the escape terrain RSF and distance from road RSF:

$$HSI_S = \frac{Habitat_S + RSF_{Road} + RSF_{Escape}}{n} \quad (\text{Eq. 11})$$

Winter habitat was estimated using four parameters: 1) aspect, 2) elevation, 3) winter forage, and 4) average snow depth. Aspect was used to identify areas where winter forage are more readily available and thermal conditions are preferred. The highest values for the aspect RSF were southerly facing. Using the terrain function in the 'terra' package (Hijmans 2023), aspect was determined. Then the RSF was calculated as:

$$RSF_{Aspect} = 1.25 \times e^{-1 \times \frac{(Aspect - 180)^2}{2 \times 60^2}} \quad (\text{Eq. 12})$$

where, $aspect$ = the aspect at a pixel. This equation creates values above 1.0, which were then set to a value of 1.0.

The winter elevation RSF was characterized by the toe slopes of the project area with areas above ~1,830 m (6,000 ft.) being preferred. The positive, asymptotic relationship used was:

$$RSF_{ElevW} = e^{17 \cdot (elev - 1.9)} / (0.1 + e^{17 \cdot (elev - 1.9)}) \quad (\text{Eq. 13})$$

where, $elev$ = the elevation at a pixel in kilometers.

Winter forage RSF was created in a similar process as the summer forage RSF. Forage value was assigned to each vegetation type: 1.0 (for highest forage value), 0.75 (for moderate forage value), and 0.0 (for no forage value). Snow depth RSF was used to estimated where snow tends to accumulate about roughly 3 feet. This depth was identified as an important barrier for sheep to forage. Average winter snow depth data were gathered for between 2004 to 2022. A negative, sigmoid relationship was then applied to the raster create the RSF:

$$RSF_{Snow} = 1 - e^{5 \cdot (snow - 3)} / (1 + e^{5 \cdot (snow - 3)}) \quad (\text{Eq. 14})$$

where $snow$ = mean winter snow depth in feet.

As with the summer habitat, winter habitat was then calculated taking the average of the four winter seasonal covariates and then the final winter habitat suitability index was found by averaging the winter habitat value, distance to road RSF, and distance to escape terrain:

$$HSI_W = \frac{Habitat_W + RSF_{Road} + RSF_{Escape}}{n} \quad (\text{Eq. 15})$$

2.2.5. Fire Effects on Riparian Health

Two metrics measured fire effects on riparian health. The first was a direct measure of fire burning the montane riparian, which included some inhabited by Bonneville cutthroat trout. The metric was the area of montane riparian burned when fire burned outside and inside the montane riparian as we could not ascertain fire direction from results. This metric assumed that the risk of stream sedimentation from upland debris flow increased when the floodplain's lacked the unburned vegetation to stop or moderate sedimentation. Simply having upland systems burn but not the montane riparian would contribute zero area to the metric.

The second more complicated metric was inspired by proper functioning condition, which could be a surrogate for Bonneville cutthroat trout habitat suitability. Six covariates formed the metric of proper functioning condition: basin-level runoff, channel degradation, vegetation diversity, percent of exotic vegetation classes in the riparian buffer, erosion risk, and distance from nearest roads (Table 2.8). Vegetation diversity was estimated using the new spatially explicit and stochastic full-system ED metric that evaluated diversity relative to the potential maximum ecological system diversity a site can achieve (Table 2.8).

Table 2.8. Covariates of stream proper functioning condition.

Covariate	How
Hydrology - Relative index of runoff/recharge	Estimated total runoff and recharge by basin (Fig. 2.7) using the USGS Basin Characterization Model. All riparian sections within their basin received the same runoff and recharge values.
Hydrology - Channel degradation	Calculate percentage of pixels classified in one of the degraded classes (e.g., desertified, inset floodplain, inset floodplain with exotic species, hummocked)
Vegetation diversity	Estimated the spatially explicit and stochastic full-system ED of each riparian pixels using the current and simulated vegetation rasters
Vegetation - Percent of exotic classes in riparian buffer	Proportion of exotic species classes estimating from the current and simulated vegetation rasters
Erosion - Percent of bare ground or recently burned in riparian buffer	Proportion of bare ground, hummocked, and charred vegetation classes in riparian system
Distance to nearest road for each pixel	Distance of riparian pixel from nearest road as surrogates for sedimentation into streams and probability of exotic aquatic animal species (threat to BCT)

For the hydrology wetness index, the ratio of the yearly recharge to overall mean was calculated for each mean. The ratio was then translated to a RSF type relationship such that values near or above 1 were the highest value, using:

$$Wet = e^{7*(year:mean-0.85)} / (1 + e^{7*(year:mean-0.85)}) \quad (\text{Eq. 16})$$

where, *year* = the recharge for a given subbasin in a given year *and mean* = the average recharge across all years for a given subbasin.

To estimate channel degradation, the proportion of classes that had physical channel degradation was found within each riparian corridor per subbasin. These includes any mesic system-class combination that had U-A: Bare Ground, U-A:Hummocked, U-X:Inset, U-X:Desertified, or U-X:Incised. For the vegetation diversity, the inverse of the spatial ED score was used (i.e., 1- spatial ED so that high values indicated higher integrity). For the exotic variable, we found the proportion of exotic classes (U-X:Exotic Forb, U-X:EFT, U-X: Inset EFT, or U-X:Incised EFT) within the riparian buffer for each subbasin. To approximate risk of sedimentation, two variables were developed. The first was the proportion of burned, bare ground, or hummocked classes in the riparian buffer. Next the distance from each pixel to the nearest road was measured. In addition to a pathway for sedimentation (Megahan and King 2001), distance to nearest road served as a proxy for the likelihood of invasive flora and fauna introduction (Mortensen et al. 2009; Deeley and Petrovskaya 2022). To convert the distance to road between 0-1, the following sigmoid equation was used:

$$Road = e^{20*(distance-0.3)} / (1 + e^{20*(distance-0.3)}) \quad (\text{Eq. 17})$$

Where, *distance* = the distance to nearest road pixel in kilometers.

The final riparian health index was found by averaging across each of the six variables for each subbasin. Note, that while the calculations were often only calculated at the riparian buffer, the index value was assigned to the whole subbasin.

2.2.6. BCM Description

The Basin Characterization Model (BCM) is a raster-based model that uses climate, vegetation, geology and soils inputs for a study area to calculate a water balance according to the water balance equation (i.e., a description of water inputs and outputs of watersheds in the model) under natural conditions (Flint et al. 2021; Fig. 2.7). It can also be used to simulate possible scenarios to consider alternative management and climate conditions, which was done here.

Flint HydroScience calibrated BCM with a spatial resolution of 270m using the same snow, climate, and flow data used to calibrate a BCM for the AOI in Provencher et al. (2021b). The calibrated model was then run at 14 m resolution after GIS resampling of vegetation to enable better correspondence with vegetation output from ST-Sim for Water Years 2018-2072 to consider future climate impacts that aligned with the ACCESS1 and HadGEM-ES LOCAs.

2.2.6.1. Basin determination and setup

Flows were estimated for GBNP, the Keyhole Property, and the BLM “donut” around the Park (Figs. 2.1, 2.8). US Geological Survey (USGS) gage data for GBNP and vicinity were obtained from the National Water Information System (NWIS) of the USGS (Table 2.9). Gage data

maintained by the National Park Service and additional data from Prudic et al. (2015) were also obtained. A Basin File was initially created using a Digital Elevation Model (DEM) for the region and gage locations. Additional basins of interest were determined manually with the DEM. Basin identification numbers (ID) were randomly assigned (Fig. 2.8). Basin areas were calculated as the number of cells in the 270-m BCM for each basin times 270 m by 270 m (Table 2.9).

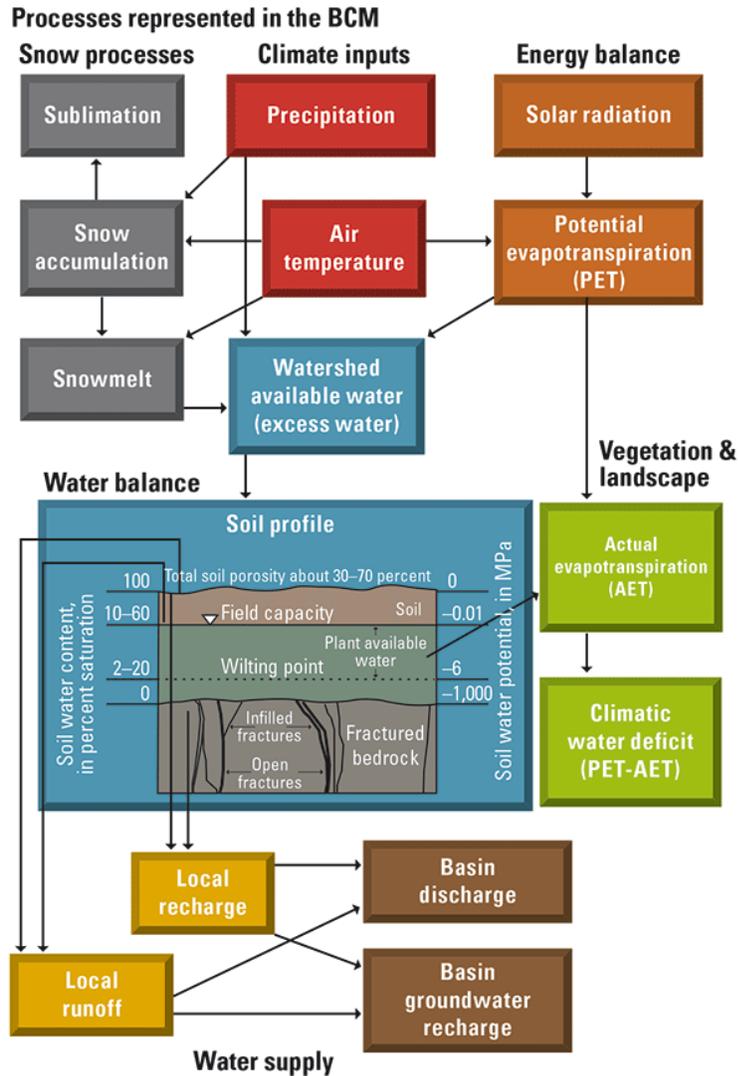


Figure 2.7. Schematic of Basin Characterization Model (BCM). Source: <https://www.usgs.gov/media/images/basin-characterization-model>.

2.2.6.2. Climate and potential evapotranspiration

For calibration, Flint HydroScience used a dataset from the Parameter-Elevation Regressions on Independent Slopes Model (PRISM; <https://prism.oregonstate.edu/>) for water year (WY) 1940 to 2019 that included monthly maximum air temperature, monthly minimum air temperature,

and monthly precipitation across the western United States. That dataset was clipped to the BCM domain shown in Fig. 2.8.

Once the model was calibrated, we developed PRISM, ACCESS1 and Had-GEM-ES datasets for calendar years 2021 to 2079 that included monthly maximum air temperature, monthly minimum air temperature and monthly precipitation for the AOI. We then calculated potential evapotranspiration using a pre-processing program developed by Flint HydroScience.

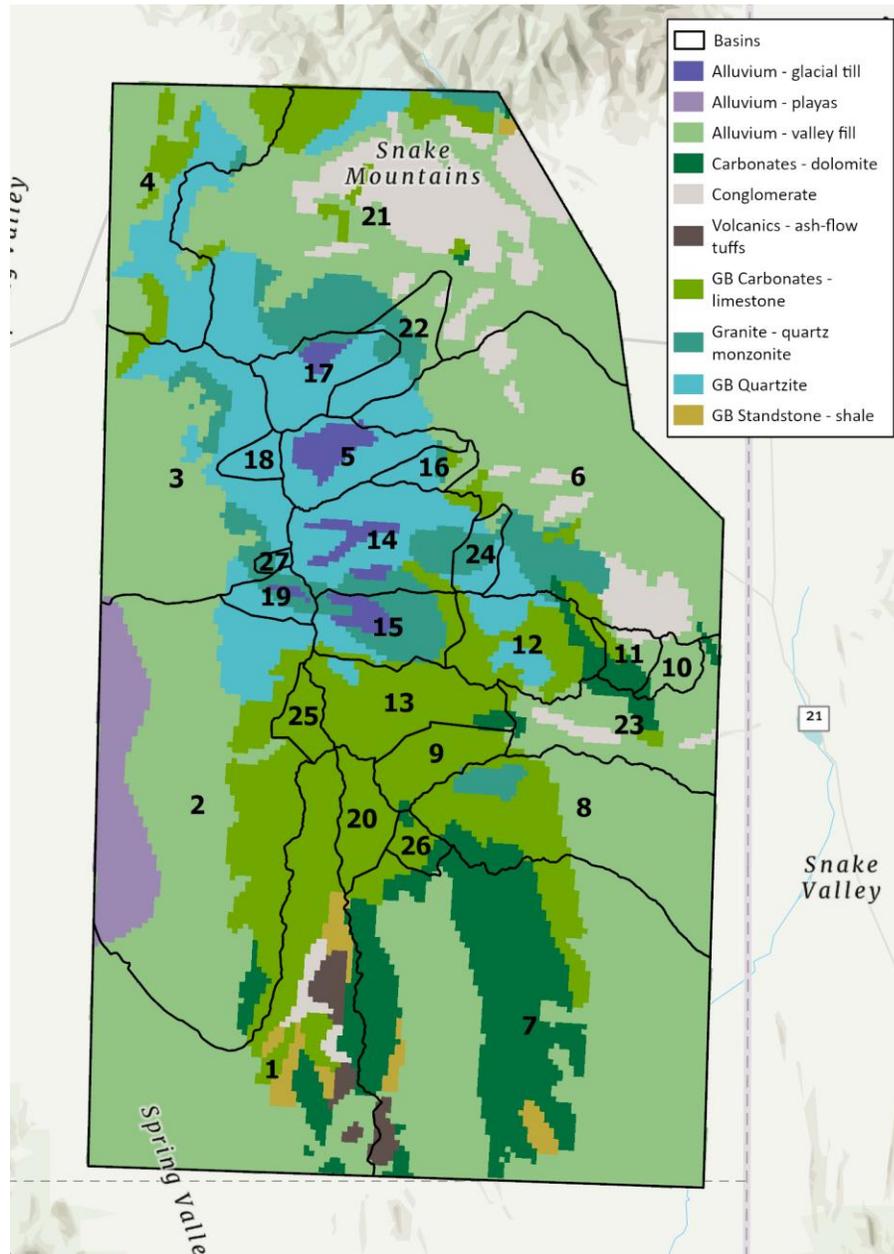


Figure 2.8. Watershed sub-basins with underlying geology where total runoff and recharge were estimated by the USGS Basin characterization Model for riparian health and treatment effects on hydrology. Black numbers indicated basin identification numbers.

Table 2.9. USGS gaging stations used with the BCT BCM 270-m model and corresponding basins. Basin areas were determined from the Basin File in ArcGIS and the outfile generated by BCM. Asterisk(*) indicates gages that did not have complete data during the calibration period. Hatch (#) indicates Basins that were not calibrated. WY = water year.

Basin ID	USGS Gage No.	Station Name	Data dates	Calib. WYs	Area (10 ⁶ m ²)
1#	None	No station – SW corner of model			154.8396
2#	None	No station – west basin Minerva			203.6826
3#	None	No station – west basin Shingle Creek			103.7367
4#	None	No station – NW corner of model			73.1187
5	10243260	Lehman Ck nr Baker, NV (also GBNP LHM1)	10/1947-8/2/2020*	2002-2019	23.6925
6#	None	No station – east basin d/s of Baker Ck and Lehman Ck			156.1518
7#	None	No station – SE corner of model			273.3750
8#	None	No station – E side of model; Lexington Ck			84.5640
9#	None	No station – North Fk Big Wash			17.0586
10#	None	No station – d/s Snake Creek			6.3423
11	10243233	Snake Ck blw Spring Ck nr Garrison, UT	1/2003-9/2004	2004	8.2377
12	10243232	Snake Ck at Great Bsn Nat Pk Bndy nr Baker, NV	9/2002-10/2019*	2003-2019	33.3882
13	10243228	S Fk Big Wash abv Great Bsn Nat Pk nr Baker, NV	10/2002-9/2004	2003-2004	34.1172
14	10243240	Baker Ck at Narrows nr Baker, NV	10/1947-10/2019*	2003-2019	44.3961
15	10243230	Snake Ck abv Pipeline nr Baker, NV	9/2002-10/2019*	2003-2019	25.0776
16	10243265	Rowland Spgs at Great Basin Nat Pk nr Baker, NV	10/2002-9/2010	2003-2010	7.2171
17	10243280	Strawberry Ck abv Great Bsn Nat Pk Bdy nr Baker, NV	10/2002-8/2016*	2003-2016	20.8494
18#	10243640	Shingle Ck nr Great Bsn Nat Pk Bdy nr Osceola, NV	9/2002-9/2004	2003-2004	5.4675
19	10243630	Williams Cyn abv Aqueduct nr Minerva, NV	10/2002-9/2004	2003-2004	8.8209
20#	10243223	Decathon Cyn blw Great Bsn Nat Pk Bdy nr Minerva	10/2002-9/2004*	2003-2004	13.9968
21#	None	No station – NE corner of model			219.2832
22#	None	No station – d/s of Strawberry Creek			18.2979
23#	None	No station – d/s Big Wash			42.5736
24#	None	No station – Can Young Canyon			8.1648
25#	None	No station – Lincoln Canyon			8.0919
26#	None	No station – Big Spring Wash			6.3423
27#	None	No station – Spring Creek			1.7496

2.2.6.3. Vegetation and k-factors

Vegetation maps for the BCT BCM domain were obtained from change detection remote sensing for GBNP and the keyhole property and new 2022 remote sensing mapping by Spatial Solutions that completed the AOI (i.e., BLM-managed land, USFS-managed land, and private lands). We consolidated vegetation classes by considering those that had common ecology, occur at common elevations, and tended to have ecologically similar spectral signatures. Finally, the whole 2-meter vegetation layer was resampled to 270-meters. This resulted in 29 vegetation types that are mapped for the 270-m model (Table 2.10). Flint HydroScience used the 270-m vegetation maps to estimate k-factors for each vegetation class by calibrating to 30-m actual evapotranspiration (ET_a) grids from OpenET (<https://etdata.org/>) for the model domain.

Table 2.10. Vegetation types, corresponding VegIDs, for each vegetation type for the south Snake Range BCM model

VegID	Vegetation Type
1	Barren-Rock-Mud
2	Developed
3	Roads-Paved
5	Aspen:Herbaceous
6	Aspen:TreeClosed
7	Aspen:TreeOpen
9	Sagebrush:ShrubClosed
11	SubXericWoodland:Shrub
12	SubXericWoodland:TreeOpen
13	SubalpineConifer:Herbaceous
14	SubalpineConifer:TreeOpen
15	SubalpineConifer:TreeClosed
16	MontaneConifer:Herbaceous
18	MontaneConifer:TreeOpen
19	SubXericWoodland:TreeClosed
20	Sagebrush:ShrubOpen
21	Sagebrush:TreeClosed
22	Sagebrush:Herbaceous
23	Mountain
24	Mountain
28	SaltDesertScrub:Herbaceous
29	SaltDesertScrub:Shrub
31	Mountain
36	Greasewood:Herbaceous
37	Greasewood:ShrubOpen

40	Wetland:Herbaceous
41	Wetland:Shrub
42	Riparian:Shrub

BCM was used to generate cumulative runoff and recharge with each basin for the riparian health index. Because of funding and time limitations, we only ran BCM for iteration 4 (randomly chosen) for each climate projection (i.e., PRISM, ACCESS1 and Had-GEM-ES) and for Custodial and Preferred scenarios.

3. Outcomes

To better inform managers, outcomes were present in three general parts: a) landscape-wide condition results from 2022 to 2072, b) simulated results of vegetation and treatments by focal ecological system, and c) landscape-wide raster results of fire and treatment implementation frequency. Within the simulation section, focal systems were presented in alphabetical order where content generically followed this pattern:

- Description of mapped ecological system’s vegetation class problems relative to ED as obtained from remote sensing and future sources of problems obtained from Custodial management simulations; and
- Prescriptions for management by focal ecological systems based on vegetation classes that contribute most to ED, bighorn sheep habitat suitability, or reduction of undesirable vegetation classes without a change in ED.

3.1. Landscape-wide Results

3.1.1. 2022 Vegetation Map

Fifty-two “systems” were mapped but six were not vegetated ecological systems or were highly manipulated, such as agriculture, barren-rock-mud, developed, unpaved and paved roads, and water (Fig. 3.1). The five most common ecological systems across all ownerships were (Table 3.1): black sagebrush (116,802 acres), montane sagebrush steppe on upland soils (36,790 acres), pinyon-juniper woodland (25,524 acres), mixed salt desert (23,806 acres), and curl-leaf mountain mahogany (20,248 acres). The five smallest ecological systems across all ownerships were (Table 3.1): badland (0.2 acres), subalpine riparian (5.5 acres), four-wing saltbush (8.9 acres), antelope bitterbrush-Wyoming big sagebrush (20.9 acres), and montane-subalpine grassland (47.8 acres). The list of most and least common systems were substantially different among ownerships (Table 3.1). For example, black sagebrush was a small system in GBNP, but the dominant one on BLM-managed land.

Table 3.1. Area (acres) of ecological systems mapped with WorldView 2/3 imagery captured in 2022 by ownership. BLM = Bureau of Land management, NPS = National Park Service, and USFS = US Forest Service.

Ecological Systems	BLM	NPS	Private	USFS	Total
Black Sagebrush	109,611.5	2,050.3	1,524.1	3,616.1	116,802.0
Montane Sagebrush Steppe-upland soils	24,051.1	12,061.6	562.7	115.1	36,790.5
Pinyon-Juniper Woodland	22,299.3	2,422.1	135.9	667.3	25,524.5
Mixed Salt Desert	22,389.3	0.1	1,174.2	242.2	23,805.9
Curl-leaf Mountain Mahogany	12,824.4	7,407.8	3.7	12.5	20,248.4

Greasewood	15,319.7	22.1	2,714.0	13.4	18,069.2
Barren-Rock-Mud	2,526.1	14,181.3	82.2	70.4	16,859.9
Wyoming big sagebrush-upland	14,725.8	0.6	1,261.7	1.5	15,989.7
Little-leaf Mountain Mahogany	13,127.4	831.6	62.3	375.3	14,396.6
Mixed Conifer	10,548.0	1,724.3	11.2	13.6	12,297.1
Aspen-Mixed Conifer	1,838.0	9,899.0	4.9		11,741.9
Antelope Bitterbrush-Black sagebrush	10,995.5	302.8	119.0	141.0	11,558.4
Aspen-Subalpine Conifer	300.5	10,756.9	0.8		11,058.2
Engelmann Spruce	2,259.5	4,618.0	9.5		6,887.1
Limber-Bristlecone Pine-mesic	2,522.1	3,057.0	59.7		5,638.7
Saline Meadow	1,902.9	0.3	2,723.7	0.9	4,627.7
Big Sagebrush-semidesert	4,344.6	40.3	206.5	1.1	4,592.5
Antelope Bitterbrush-mountain big sagebrush	3,586.2	730.4	62.4	0.4	4,379.5
Winterfat	4,105.9	2.0	43.7	0.7	4,152.4
Mountain Shrub	3,847.4	111.3	6.9	115.9	4,081.6
Agriculture	84.0		2,628.1	5.3	2,717.5
Limber-Bristlecone Pine-dry	398.3	2,060.0	21.8		2,480.1
Low Sagebrush Steppe	1,437.1	801.0		42.5	2,280.7
Basin Wildrye-montane	1,285.3	202.4	690.8	26.7	2,205.3
Roads-Local	1,546.9	8.4	376.6	19.7	1,951.6
Montane Riparian	650.1	663.9	568.5	58.8	1,941.2
Swamp Cedars	1,015.7		879.3		1,895.0
Wet Meadow-montane	210.9	191.1	1,473.0	0.1	1,875.2
Developed	624.2	17.8	728.7		1,370.7
Alpine	4.9	940.6	5.6		951.1
Stansbury Cliffrose	399.5		0.5	402.0	801.9
Sparsely Vegetated	756.4	2.8	14.0	1.8	775.0
Aspen Woodland	216.7	520.6			737.3

Desert Wash	656.0		21.4	18.8	696.2
Montane Sagebrush Steppe- mountain soils	78.3	580.2			658.5
Ponderosa Pine-mesic	308.4	218.6	2.6		529.6
Riparian Ponderosa Pine	240.3	213.6			454.0
Roads-Paved	25.9	380.9	6.3		413.1
Low Sagebrush-semidesert	370.8		0.4		371.2
Dry Wet Meadow	205.5	35.6	120.5	0.7	362.4
Pickleweed	270.5				270.5
Water	78.9	17.6	94.5		191.1
Sodic Pools	53.0		67.0		120.0
Basin Big Sagebrush-Greasewood	54.2		55.8		110.0
Semi-Desert Grassland	90.9				90.9
Pygmy Sagebrush	66.2				66.2
Seep	31.8	8.4	10.3		50.5
Montane-Subalpine Grassland		47.8			47.8
Antelope Bitterbrush-Wyoming big sagebrush	17.5		3.3		20.9
Four-Wing Saltbush	8.9				8.9
Subalpine Riparian	1.0	4.5			5.5
Badland	0.2				0.2

The vegetation map from 2010 of GBNP and the Keyhole property was compared to the new map of 2022. The comparison was not between the 2007 QuickBird and WorldView 2/3 satellite imaged as conducted by the remote sensing contractor, but between the interpreted maps created by TNC in 2010 and 2022 as Spatial Solutions was not tasked to produce a difference map and confusion matrix. We eliminated many changes due only to scientific renaming, splitting, and reinterpretation of systems, and focused on all changes at the class level that were possible in the STSMs. This map-derived change detection was shown in Fig. 3.2 where class-only change indicated that only the class changed within possible model changes, and the system name remained the same. In addition, System and Class changes indicated two changes:

the system changed because the name was scientifically reclassified, and the class changed regardless of the system name but within allowable model transitions.

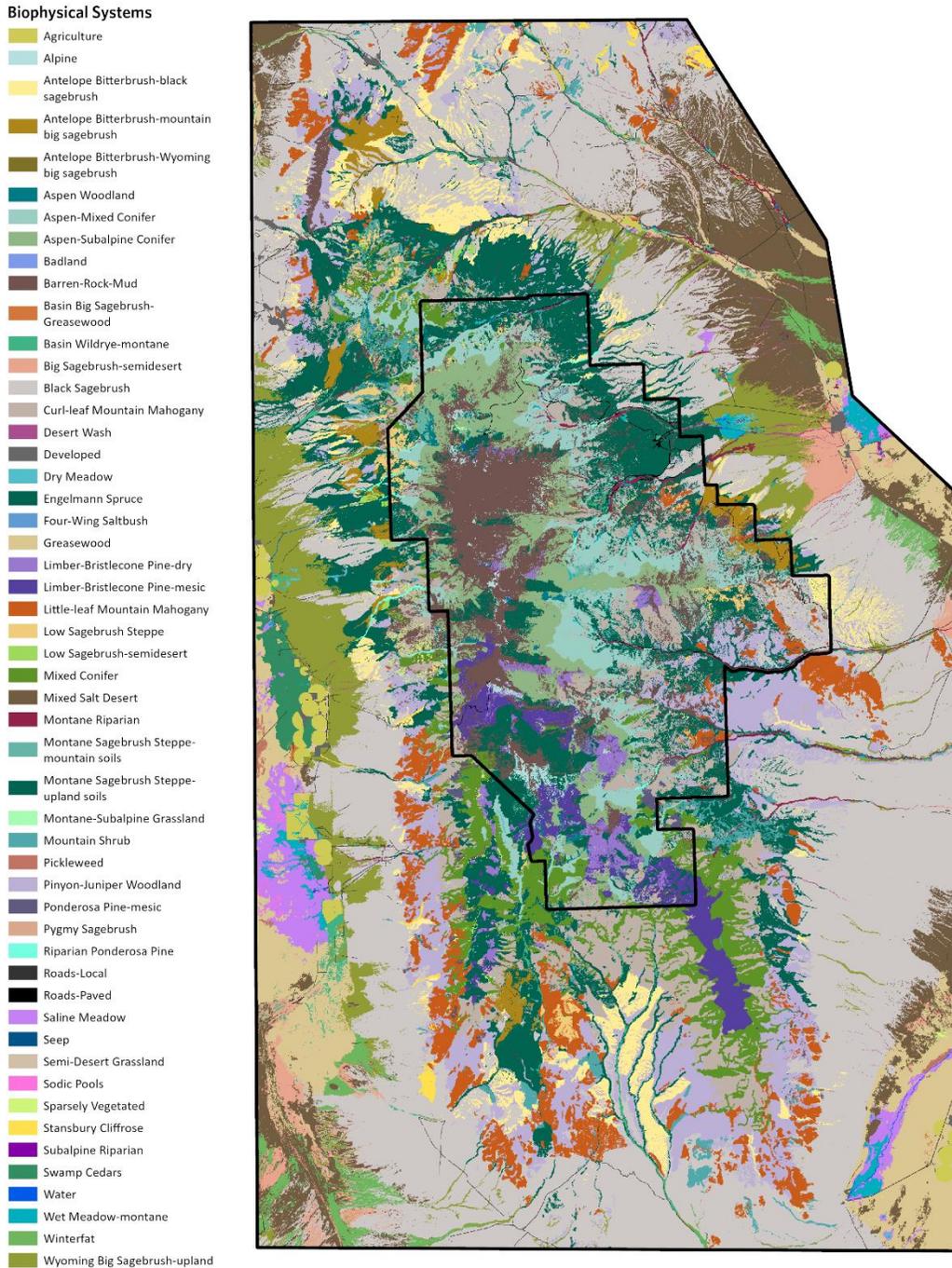


Figure 3.1. Ecological systems of the South Snake Range AOI based on 2022 WorldView 2/3 satellite imagery. GBNP and the Keyhole private property (within inside boundary) was remapped using change

detection remote sensing, whereas the area outside of the inner boundary required new remote sensing mapping.

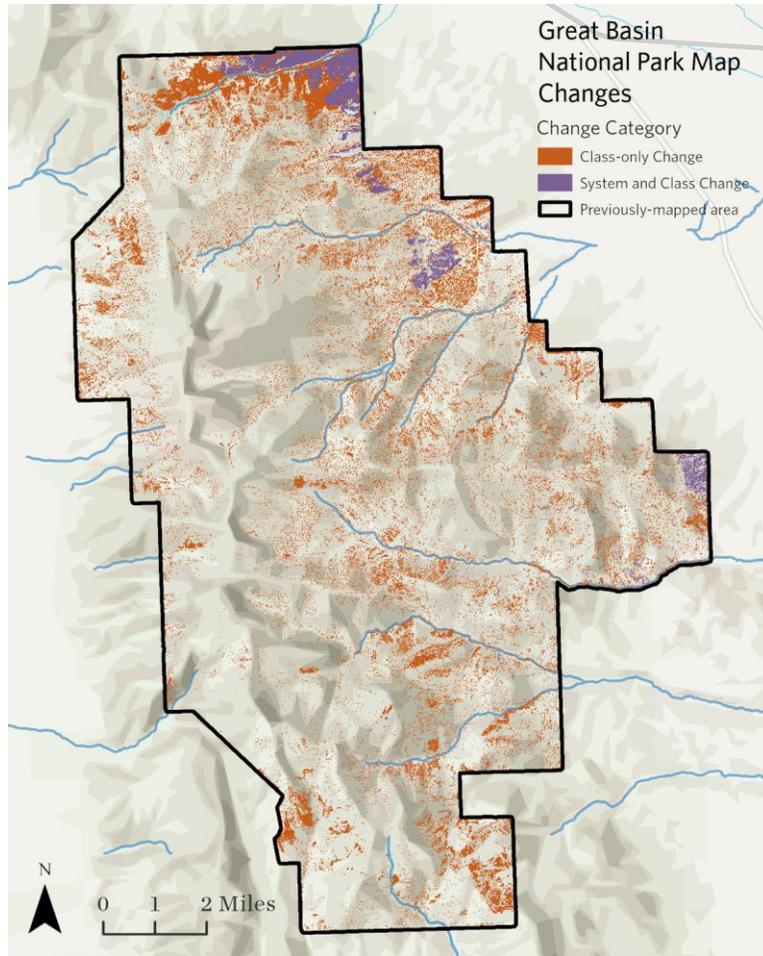


Fig. 3.2. Change detected between TNC’s interpreted vegetation maps of 2010 and 2022 due to change detection remote sensing. Class-only change indicated that only the class changed within possible model transitions and the system name remained unchanged. System and Class changes indicated two changes: the system changed because the name was scientifically reclassified, and the class changed regardless of the system name but within possible model transitions.

3.1.2. Non-spatial Ecological Departure

The measures of non-spatial ED were estimated by system from the entire landscape and not by ownership as per the definition of LANDFIRE (Hann and Strom 2003; Rollins 2009, Swaty et al. 2022; Provencher et al. 2024). Of the 46 ecological systems, 4 were <16%, 5 were between 17% to 33% departed from reference conditions (low departure), 15 were moderately departed (34% to 66% departure), and 21 were highly departed from reference conditions (>66%

departure; Table 3.2). Among the 22 *focal* systems (bold letters in Table 3.2), 3 were at low departure, 11 were moderately departed, and 8 were highly departed from reference conditions. The low departure systems were noteworthy because land managers would usually leave them untreated; however, limber-bristlecone pine-mesic and Stansbury cliffrose were designated for special management to recruit of younger vegetation classes for bighorn sheep foraging, whereas montane riparian continues to be treated for exotic species and entrenchment. Also noteworthy was aspen-subalpine conifer at the low end of moderate departure (39%), however it was also treated to increase the proportion of young classes that bighorn sheep would feed on for decades.

Table 3.2. Non-spatial ED in 2022 (initial conditions) of all vegetated ecological systems for all land ownerships in the South Snake Range. The systems in bold letters were the focal systems receiving treatments. Darkest green numbers indicate that ED <17%, lighter green indicates ED >16% and ED <34%, brick orange is for ED >33% and <67%, and red is >66%.

Ecological System	Non-spatial ED
Alpine	2
Antelope Bitterbrush-Black Sagebrush	99
Antelope Bitterbrush-Mountain Sagebrush	73
Antelope Bitterbrush-Wyoming Sagebrush	100
Aspen Woodland	62
Aspen-Mixed Conifer	84
Aspen-Subalpine Conifer	36
Basin Big Sagebrush-Greasewood	100
Basin Wildrye	98
Big Sagebrush semi-desert	99
Black Sagebrush	69
Chaparral	100
Curl-leaf Mountain Mahogany	43
Desert Wash	94
Dry Wet Meadow	53
Engelmann Spruce	39
Four-Wing Saltbush	100
Greasewood	17

Limber-Bristlecone Pine	16
Limber-Bristlecone Pine-mesic	18
Little-leaf Mountain Mahogany	64
Low Sagebrush Steppe	63
Low Sagebrush-semi-desert	71
Mixed Conifer	31
Mixed Salt Desert	78
Montane Riparian	32
Montane Sagebrush Steppe-mountain	41
Montane Sagebrush Steppe-upland	74
Montane-Subalpine Grassland	46
Mountain Shrub	59
Pickleweed	0
Pinyon-Juniper	33
Ponderosa Pine	51
Pygmy Sagebrush	96
Riparian Ponderosa Pine	39
Saline Meadow	47
Seep	0
Semi-Desert Grassland	98
Sodic Pools	95
Stansbury Cliffrose	25
Subalpine Riparian	58
Swamp Cedars	98
Wet Meadow-Montane	51
Winterfat	89
Wyoming Big Sagebrush-upland	99

3.1.3. 2022 Spatially Explicit and Stochastic Ecological Departure

Single-System Spatially Explicit Ecological Departure. While the non-spatial ED encompassed the whole AOI, spatially explicit and stochastic ED was highly local within ownerships. Assessment of spatially explicit ED was still limited to each system in the single-system version, where departure was adjusted by that system's relative presence in a window. The full-system version takes all systems' departure within the surrounding window into account. The radius of the moving window around each pixel was 1,400 m, based on bighorn sheep perception. Spatial departure was calculated for all vegetated pixels using the 2022 map, and for 10 simulated vegetation maps meant to represent possible reference conditions. The 2022 (initial conditions) map was compared to all 10 reference maps to generate an average spatial departure map and variance map. In 2022, GBNP and USFS-managed land were less departed than BLM-managed and private lands (Fig. 3.3).

The different single-system departure map (Fig. 3.3) showed that many areas were moderately departed (green) and patchily distributed among low departure areas (blue) for aspen-mixed conifer, aspen subalpine conifer, and montane sagebrush steppe. Parts of GBNP with higher departure (orange to red) were found in Strawberry Creek, around Lehman's cave visitor center (anthropogenic modifications), the western end of the Snake Creek road, the north slope above the southern headwaters of Pole Creek, the Lexington Arch area, and small areas at the NPS boundary south of Kious Basin down to Clay Springs (Fig. 3.3). These more departed areas often matched fires from the last 10 years. The area of lowest departure was the barren rock around Wheeler Peak surrounded by smaller patches of alpine and limber-bristlecone pine woodland. Areas of lower departure (blue and darker green) were patchily scattered at all elevations within GBNP in different ecological systems.

The most extensive areas of higher departure formed a lower elevation ring around the Snake Range on BLM-managed lands. In these areas, non-native annual species were either dominant after fires or occupied the understory of shrublands (Fig. 3.3). Depleted sagebrush was also common at middle elevations. Areas of low departure were around Windy Peak in all three types of aspen forests, the area north of the Keyhole Property with a diverse group of mixed conifers, curl-leaf mountain mahogany, aspen-mixed conifer, and aspen woodland, and the subalpine ridge west of Murphy Creek and John's Wash where various subalpine conifers (both dry and mesic limber and bristlecone pine forest and Engelman's spruce) and mountain shrublands were common. Interestingly, areas of low departure were found in the southwest and southeast corners of the AOI where larger wet meadow complexes, winterfat (west side), semi-desert grassland (west side), and greasewood were mapped.

Variance of spatially explicit departure was greatest for the lowest and highest departure areas, indicating that stand-replacing disturbances, such as fire and severe drought, were very unevenly present in time and space among the 10 spatial replicates of the reference conditions.

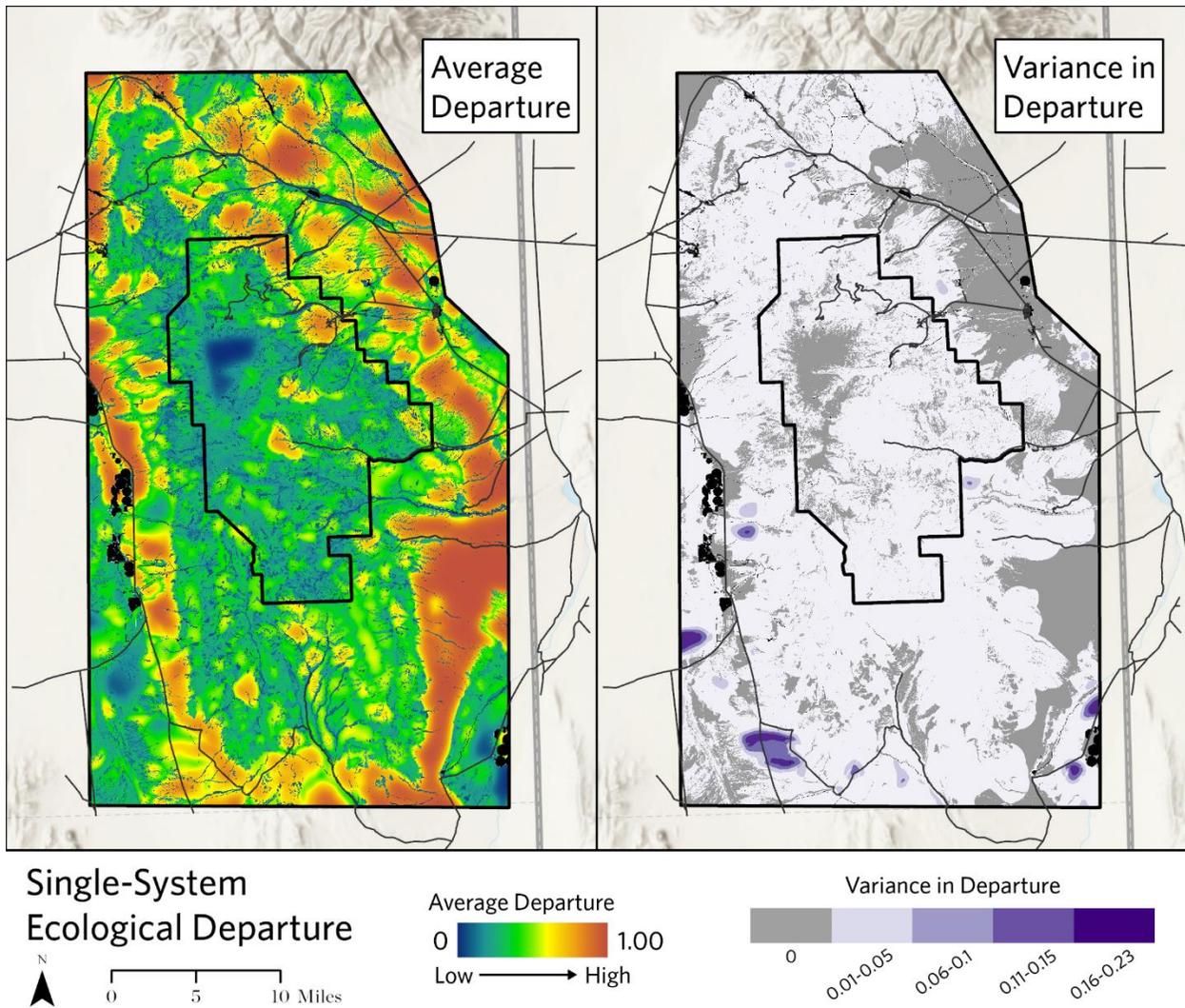


Figure 3.3. Average single-system departure (%) and variance for year 2022 (initial conditions) on the South Snake Range. N = 10.

Full-system Spatially Explicit Ecological Departure measures the dissimilarity between the current proportions and reference proportions of all systems for which the classes per system were pro-rated to the relative sizes of each system in the 1,400-m radius moving window (Provencher et al. 2024). The 2022 *full-system* departure showed substantially more departure than the single-system ED (Fig. 3.3 *versus* Fig. 3.4). In the single-system spatial departure, there was a fine patchwork of low departure and moderate departure systems distributed everywhere in GBNP. Because the moderate departure was well distributed, the *full-system* departure’s moving window was repeatedly capable of including the vegetation classes responsible for moderate departure, such as aspen dominated by either mixed conifers or subalpine conifers and montane sagebrush steppe dominated by pinyon and juniper. This appears to be the reason for high full-system departure up the eastern and middle slope of the

Snake Range. Only the subalpine and alpine elevations that have long fire return intervals, where systems were also less departed in the single-system departure, did *full-system* departure consistently show low levels of departure (Fig. 3.4).

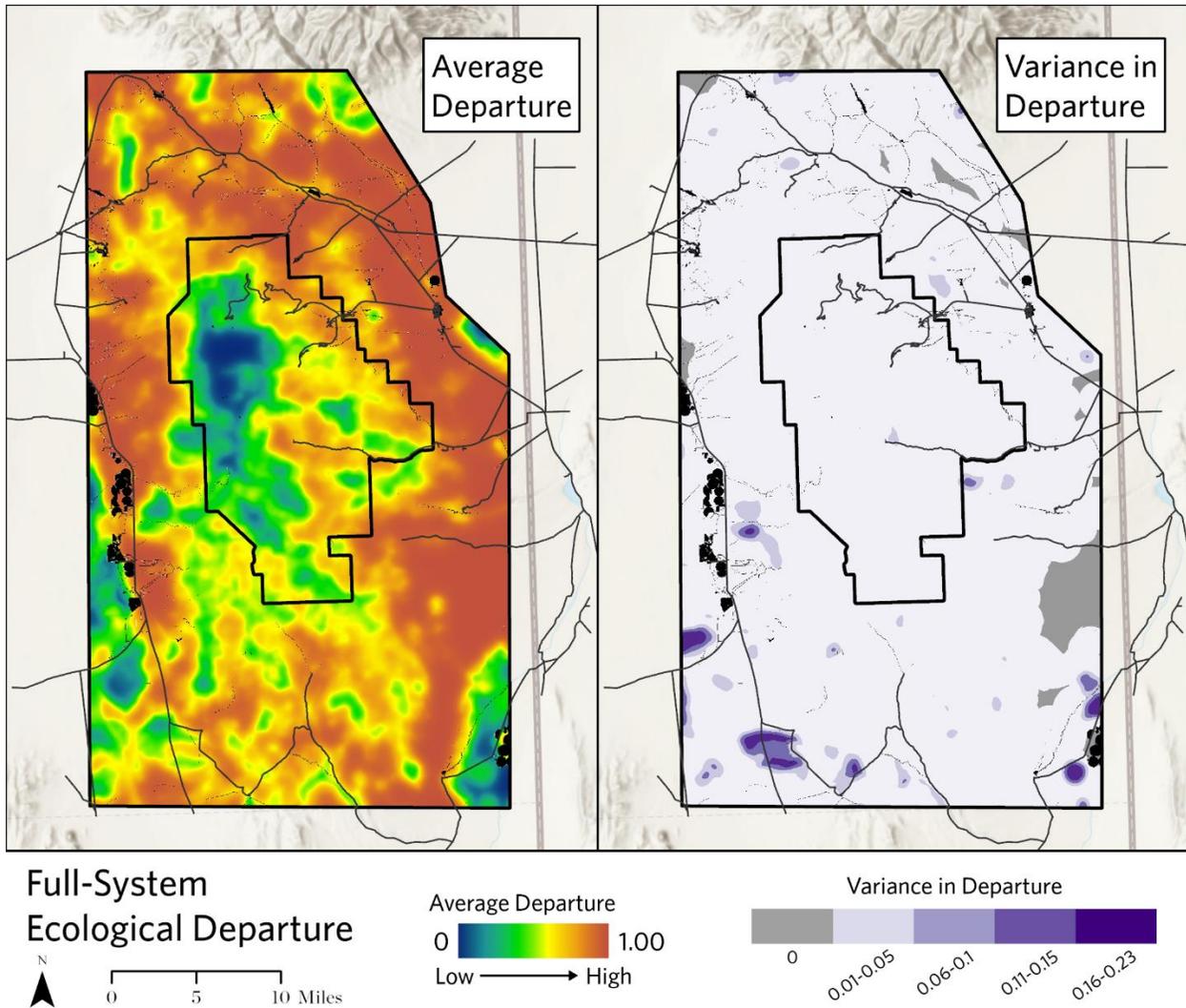


Figure 3.4. Average full-system departure (%) and variance for year 2022 (initial conditions) on the South Snake Range. N = 10.

On all other land ownerships, full-system departure was highly departed, except in the subalpine vegetation, in steep areas, and, again, in the southeast and southwest corners where both types of wet meadows, greasewood, and semi-desert grasslands provide reference classes in proportions not too dissimilar from the reference conditions. Also, at those middle to lower elevations, non-native annual grasses would commonly be dominant or present within a

moving window with a 1,400 m radius in the understory of all shrubland from mixed salt desert to montane sagebrush steppe, and bitterbrush, increasing the departure in those areas.

3.1.4. Future Spatially Explicit and Stochastic Ecological Departure

Single- and full-system spatially-explicit ecological departure were calculated for all scenarios (management and climates) in year 2047 because it was the best year to evaluate cumulative and recent change without a period of no management as in 2072 and estimation required weeks to months to perform on a server per year. In general, spatially-explicit departure slightly improved (decreased) from 2022 to 2047, especially locally north and south of the western part of Snake Creek and on the southeastern ridge (follow green strands; Figs. 3.5-3.7). In 2047, preferred management further and marginally improved those same areas in all climates compared to custodial management, although least obvious in the PRISM climate (Fig. 3.5 vs. Figs. 3.6-3.7).

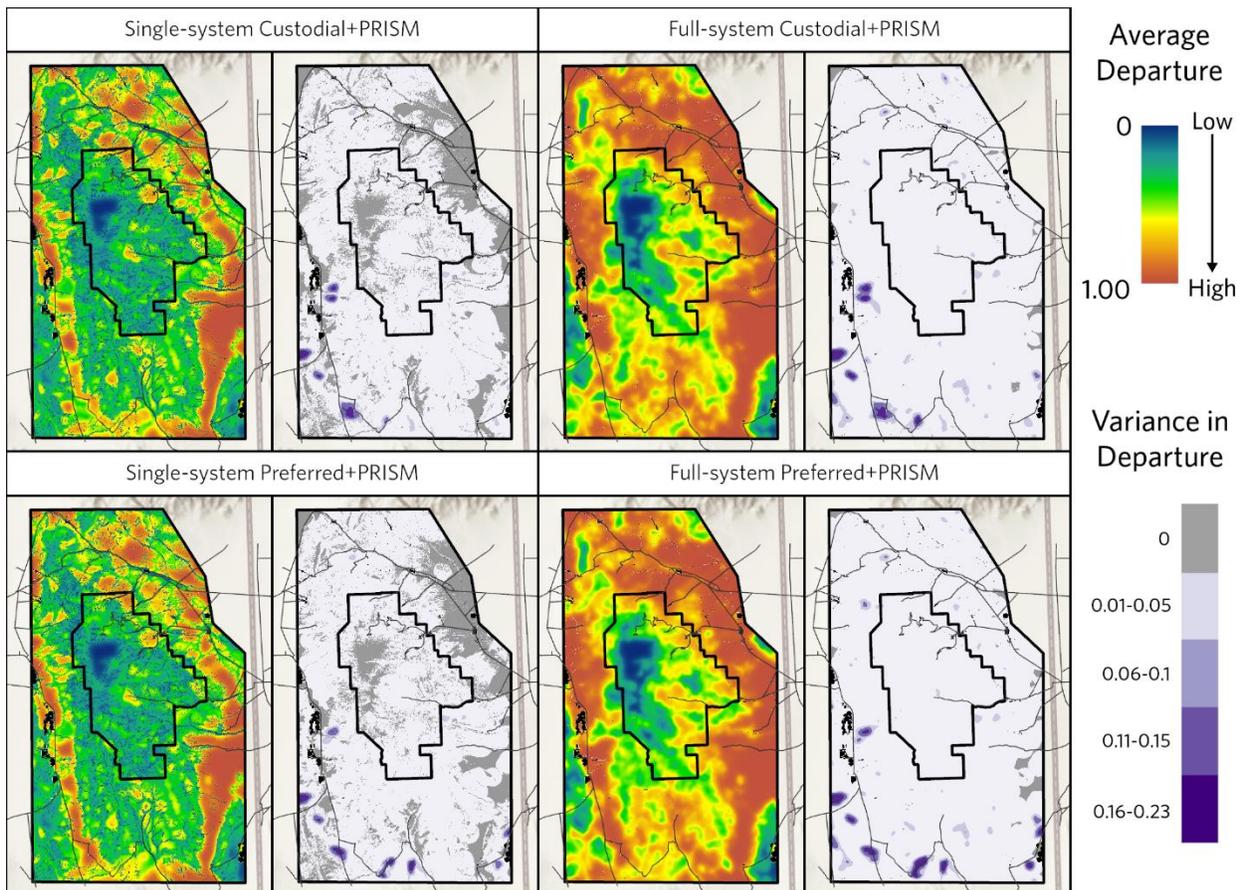


Figure 3.5. Average single-system (upper row) and full-system (lower row) spatially explicit ED (%) and variance in the custodial management (upper panel) and preferred management (lower panel) scenarios

year 2047 in the future PRISM climate on the South Snake Range. The inside black boundary marked the 2010 mapping area.

While spatial variance was mostly low or absent, small patches of greater variance were situated in a “U”-shape distribution in the southern half of the AOI generally in the same places (Figs. 3.5-3.7). Many were found in black sagebrush and greasewood at the bottom of valleys. The same patches were co-located with low (better) single- and full-system spatially-explicit departure. The uneven presence of recent and infrequent stand-replacing floods or fires among very few of the 10 replicates would cause this pattern.

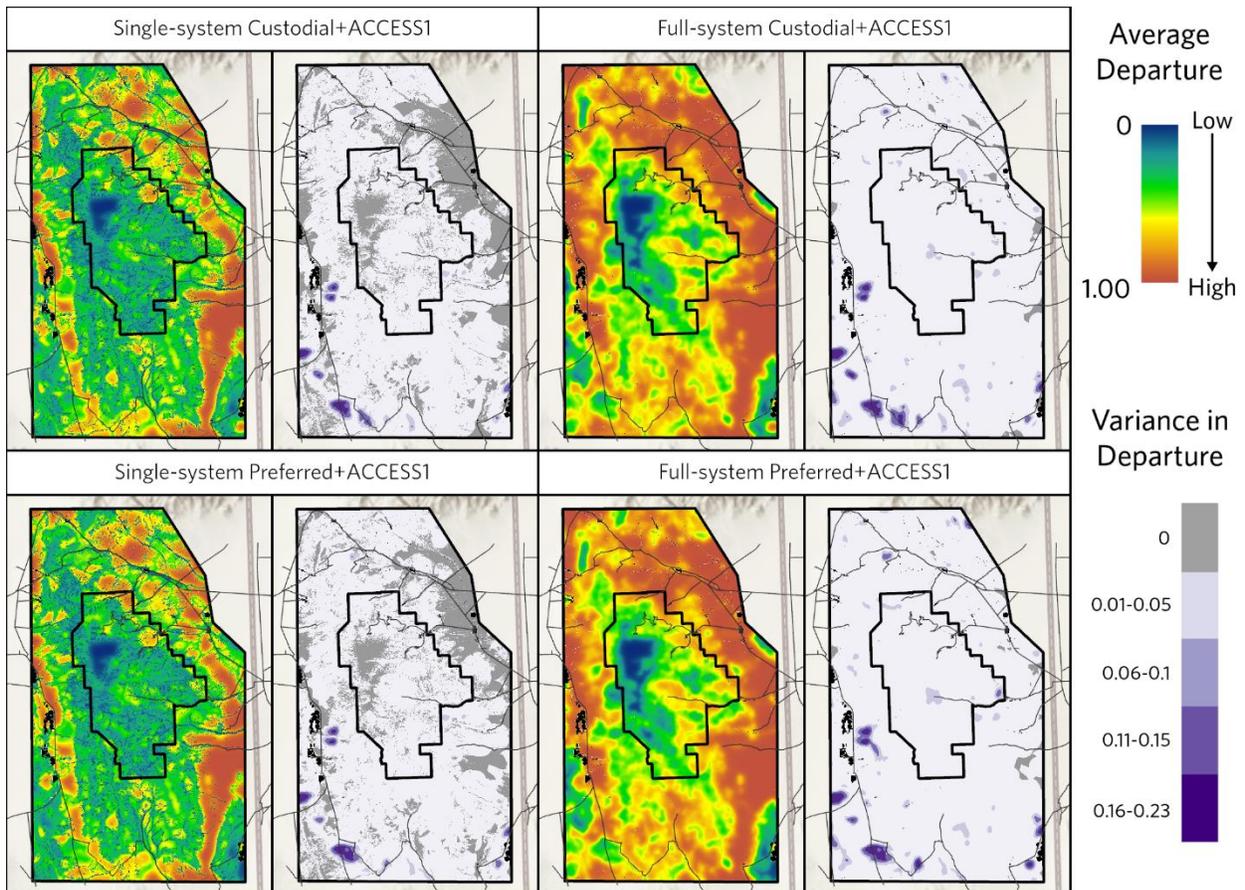


Figure 3.5. Average single-system (upper row) and full-system (lower row) spatially explicit ED (%) and variance in the custodial management (upper panel) and preferred management (lower panel) scenarios year 2047 in the future ACCESS1 climate on the South Snake Range. The inside black boundary marked the 2010 mapping area.

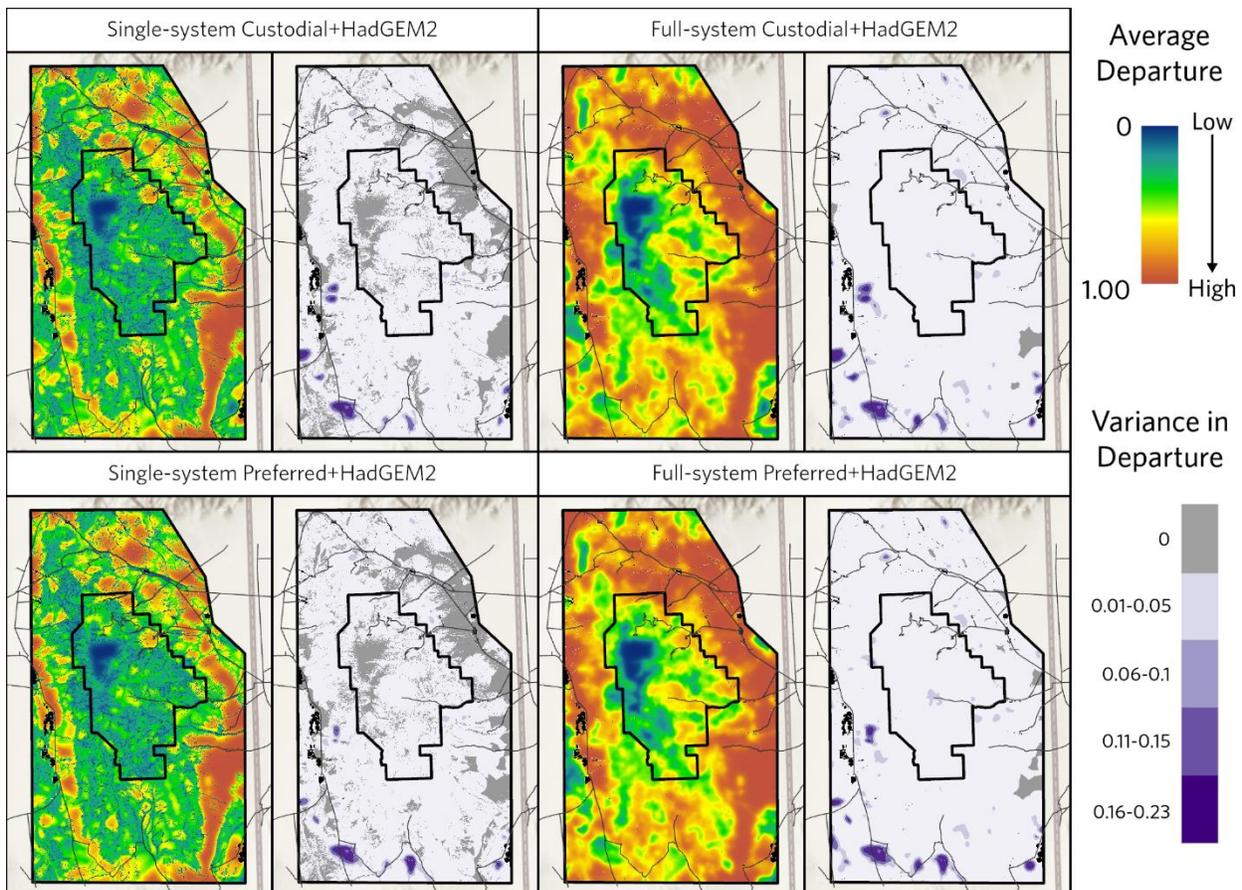


Figure 3.6. Average single-system (upper row) and full-system (lower row) spatially explicit ED (%) and variance in the custodial management (upper panel) and preferred management (lower panel) scenarios year 2047 in the future HadGEM-ES climate on the South Snake Range. The inside black boundary marked the 2010 mapping area.

3.1.5. Bighorn Sheep Habitat Suitability

Bighorn sheep habitat suitability was greater at the highest elevations on rocky or exposed ridges and near escape habitat during the growing season (Fig 3.7). While not zero, suitability was very low downslope from the break between the toe of mountains to the bottom of alluvial fans. Suitability was zero in the valley bottoms. Also noteworthy was the high suitability in areas that bighorn sheep do not currently occupy despite easy access as a function of distance. The very high elevations in the southeast portion ending at Big Spring Ranch, the area north of Windy Peak along the western limestone ridge (containing the Mexican freetail bat cave), and the ridge extending east from Pyramid Peak towards the Horse Heaven ridge paralleling north of Snake Creek were three large examples (Comer et al. 20016).

In all reporting years (2035, 2047, and 2072) and all climates, bighorn sheep growing season and winter habitat suitability consistently improved (increased) or degraded (decreased) in the

same parts of the landscape compared to the custodial management scenario combined with PRISM climate within the same reporting year (control scenario against which all differences in habitat suitability were subtracted from; Figs. 3.8-3.13). The most striking zone of habitat improvement in all reporting years was the ring around the ridge from Wheeler Peak to Lincoln Peak that includes various aspen-conifer and subalpine conifer systems; however, improvement was smaller for the PRISM climate than the ACCESS1 and HadGEM-ES climates. This counter-intuitive climate result was explained in Discussion.

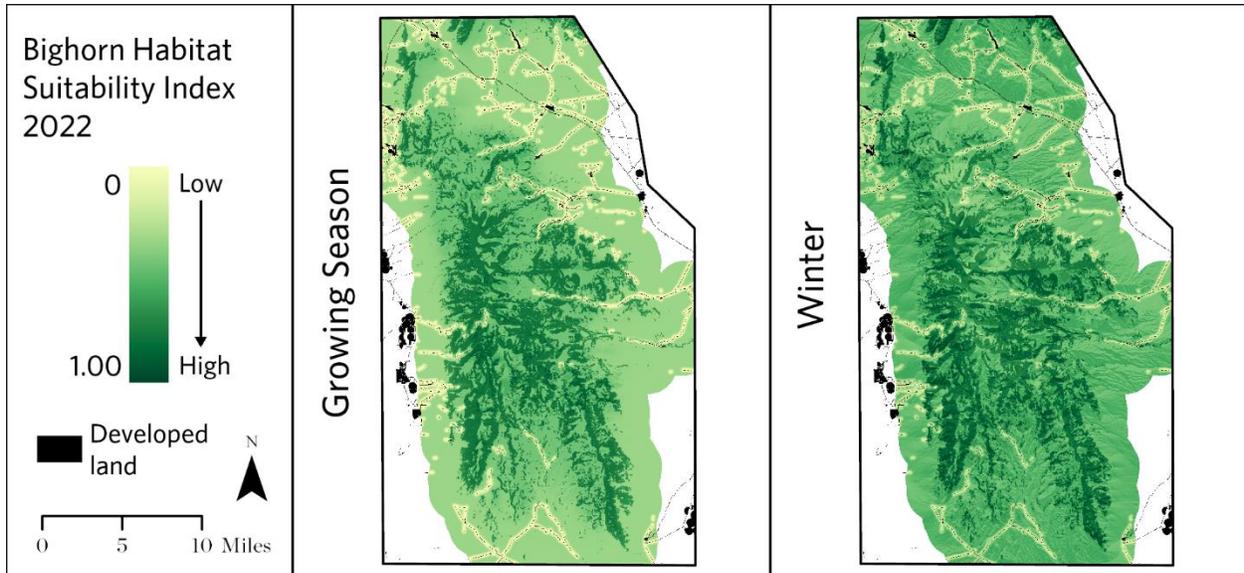


Figure 3.7. Bighorn sheep growing season and winter habitat suitability index (0% to 100%) for year 2022 (initial conditions) on the South Snake Range.

While climate-driven fire appeared to explain most results, subtle treatment effects were visible in the preferred management scenario *versus* custodial management scenario in the Windy Peak area, which was an intense management area, especially in 2047 and 2072 for the HadGEM-ES and PRISM climates for both growing season and winter habitat suitability (Figs. 3.10-3.13). This area, however, involves more human to animal interactions that bighorn sheep avoid (Comer et al. 2016).

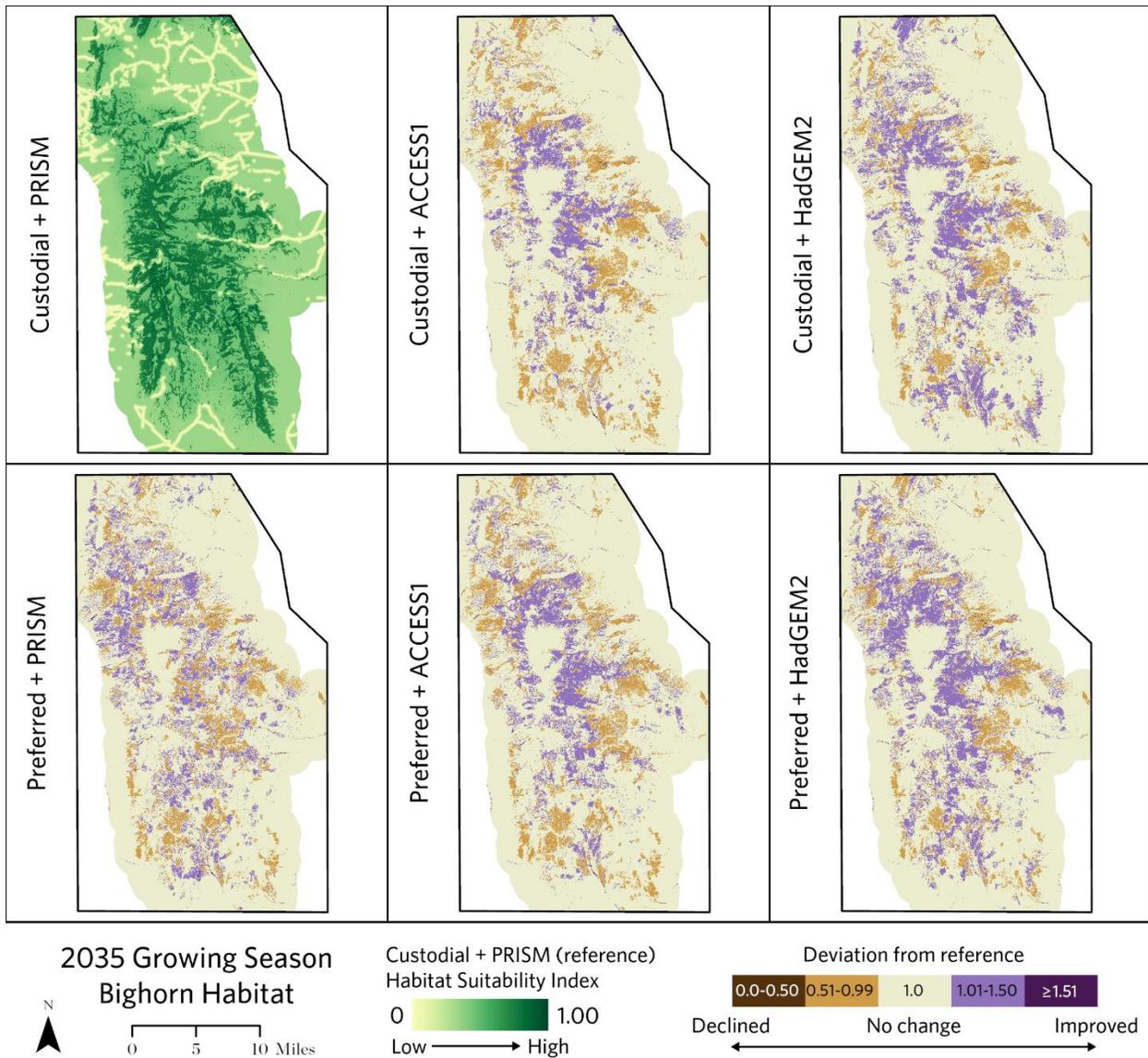


Figure 3.8. Average bighorn sheep growing season habitat suitability index (n = 10) presented in absolute value for the Custodial-PRISM management scenario and as differences from it for all other scenario combinations for year 2035 on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and Preferred (active management) combined with each of same future climates.

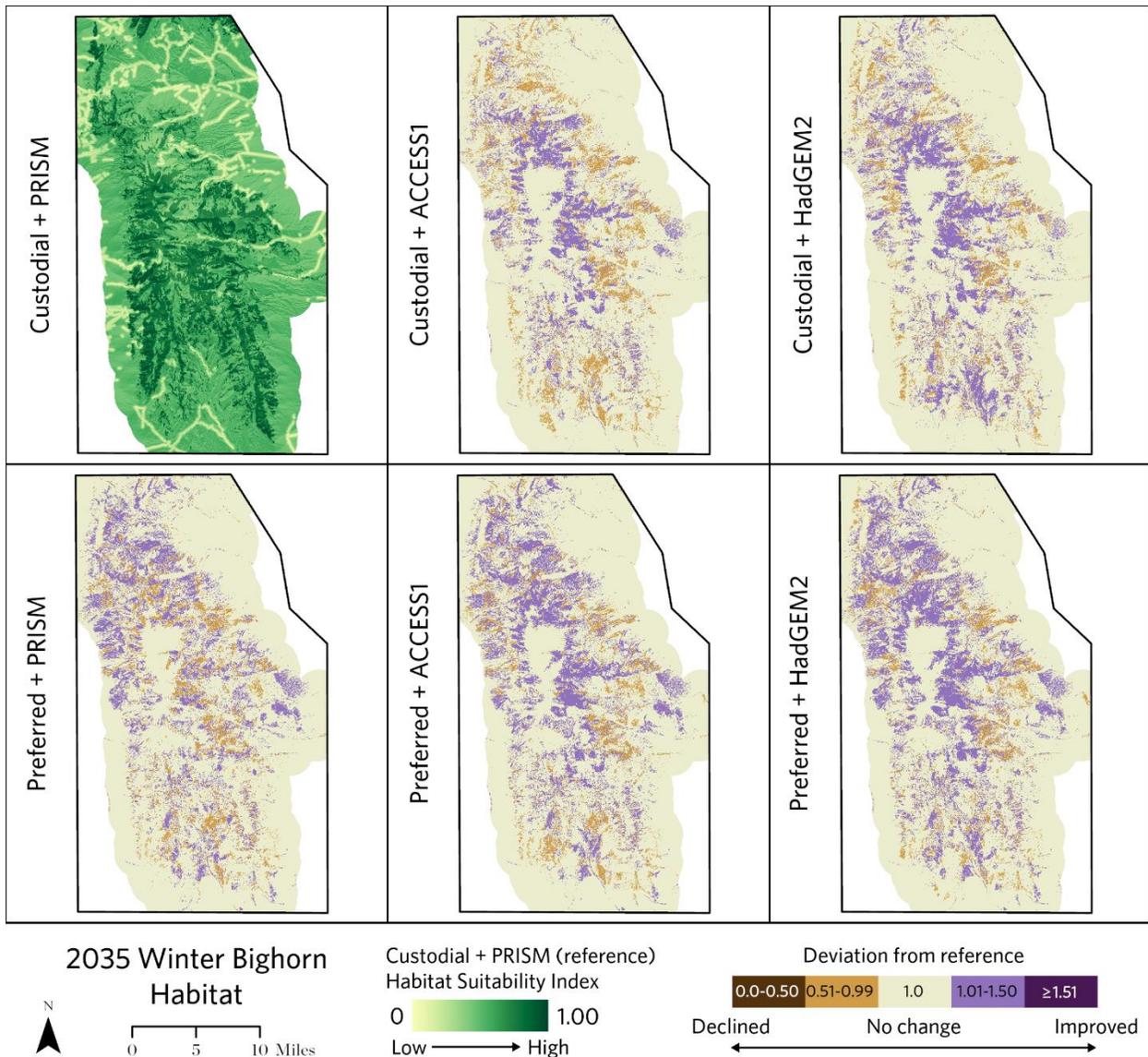


Figure 3.9. Average bighorn sheep winter habitat suitability index (n = 10) presented in absolute value for the Custodial-PRISM management scenario and as differences from it for all other scenario combinations for year 2035 on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and Preferred (active management) combined with each of same future climates.

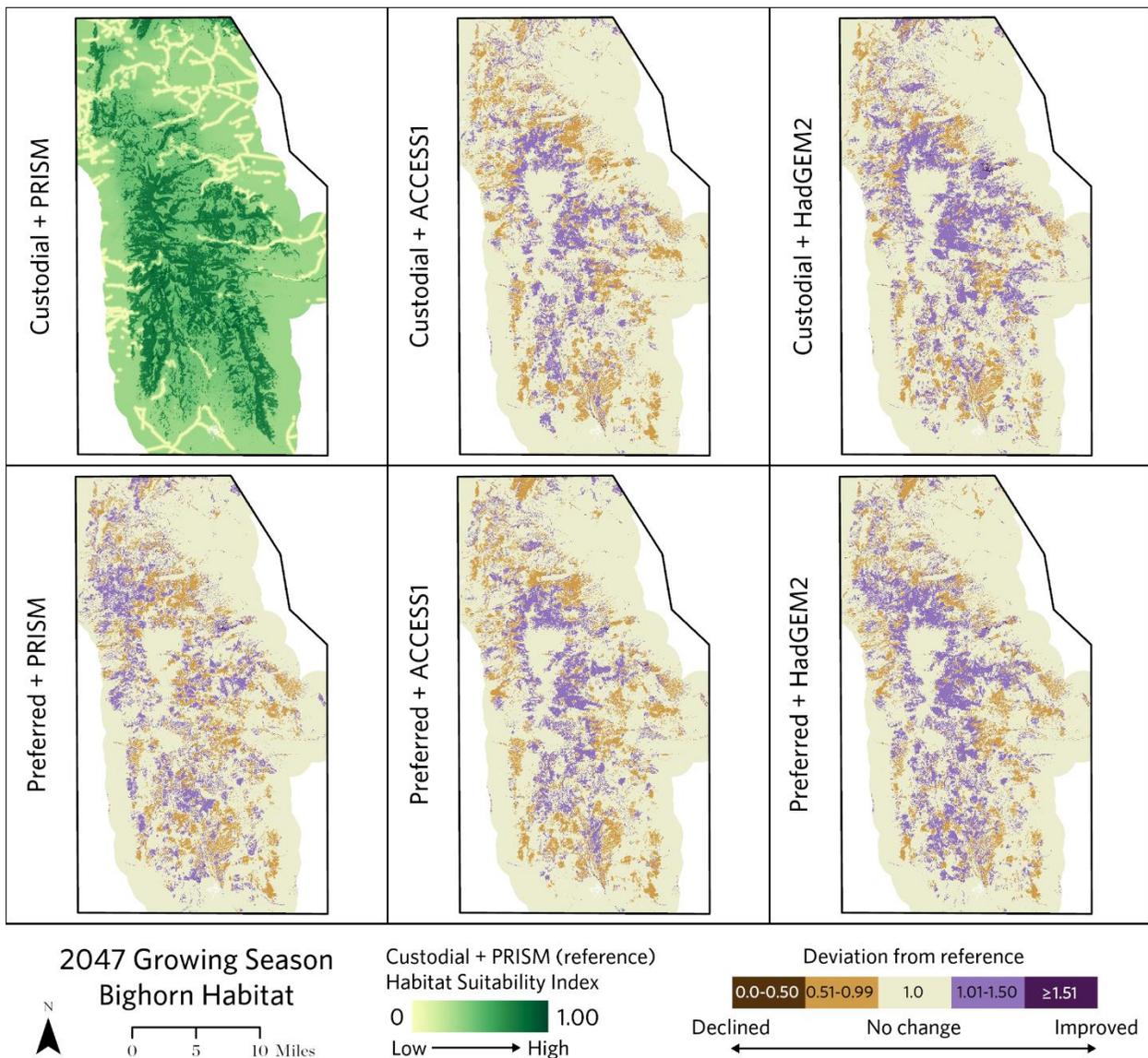


Figure 3.10. Average bighorn sheep growing season habitat suitability index (n = 10) presented in absolute value for the Custodial-PRISM management scenario and as differences from it for all other scenario combinations for year 2047 on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and Preferred (active management) combined with each of same future climates.

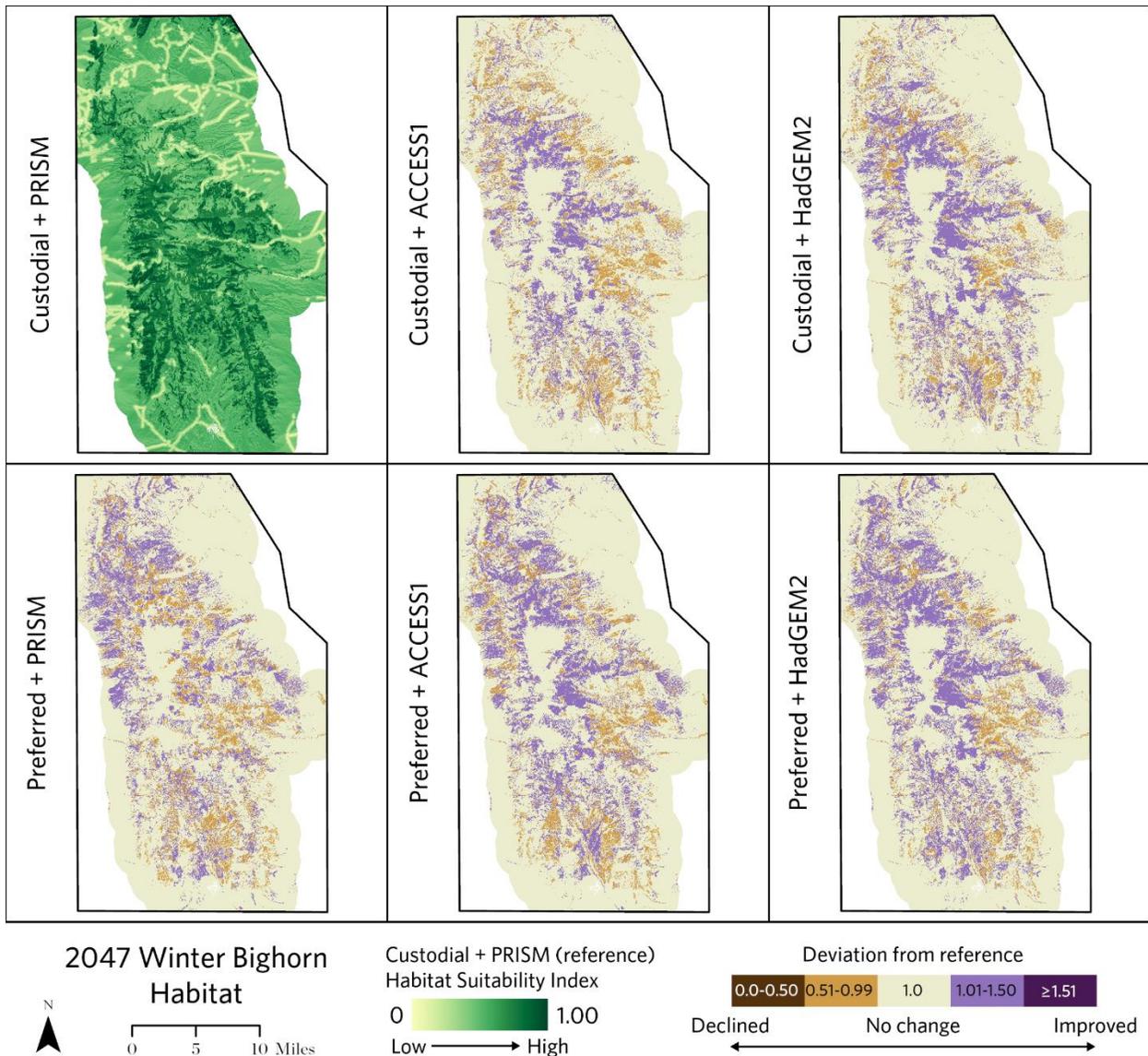


Figure 3.11. Average bighorn sheep winter habitat suitability index (n = 10) presented in absolute value for the Custodial-PRISM management scenario and as differences from it for all other scenario combinations for year 2047 on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and Preferred (active management) combined with each of same future climates.

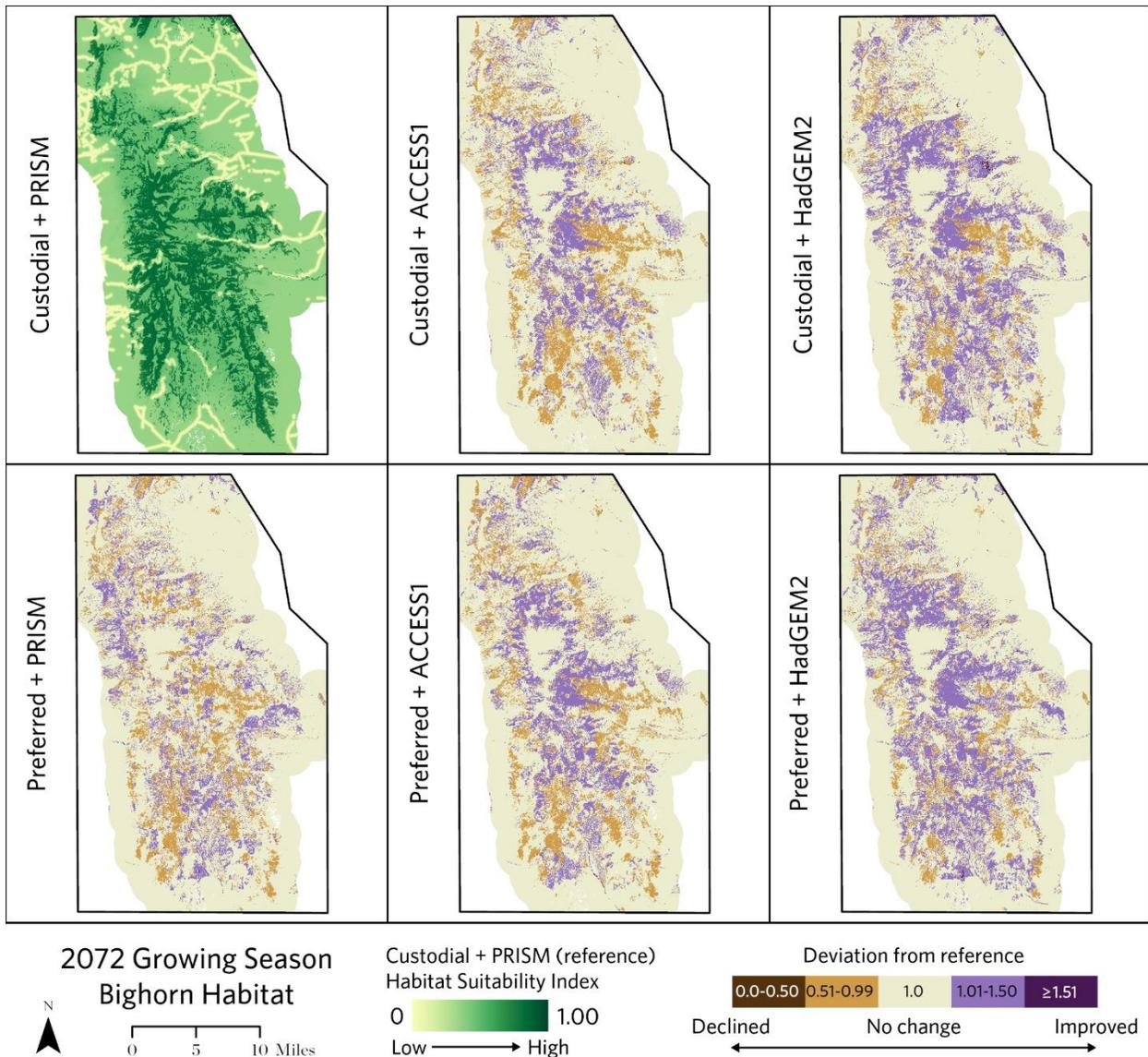


Figure 3.12 Average bighorn sheep growing season habitat suitability index (n = 10) presented in absolute value for the Custodial-PRISM management scenario and as differences from it for all other scenario combinations for year 2072 on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and Preferred (active management) combined with each of same future climates.

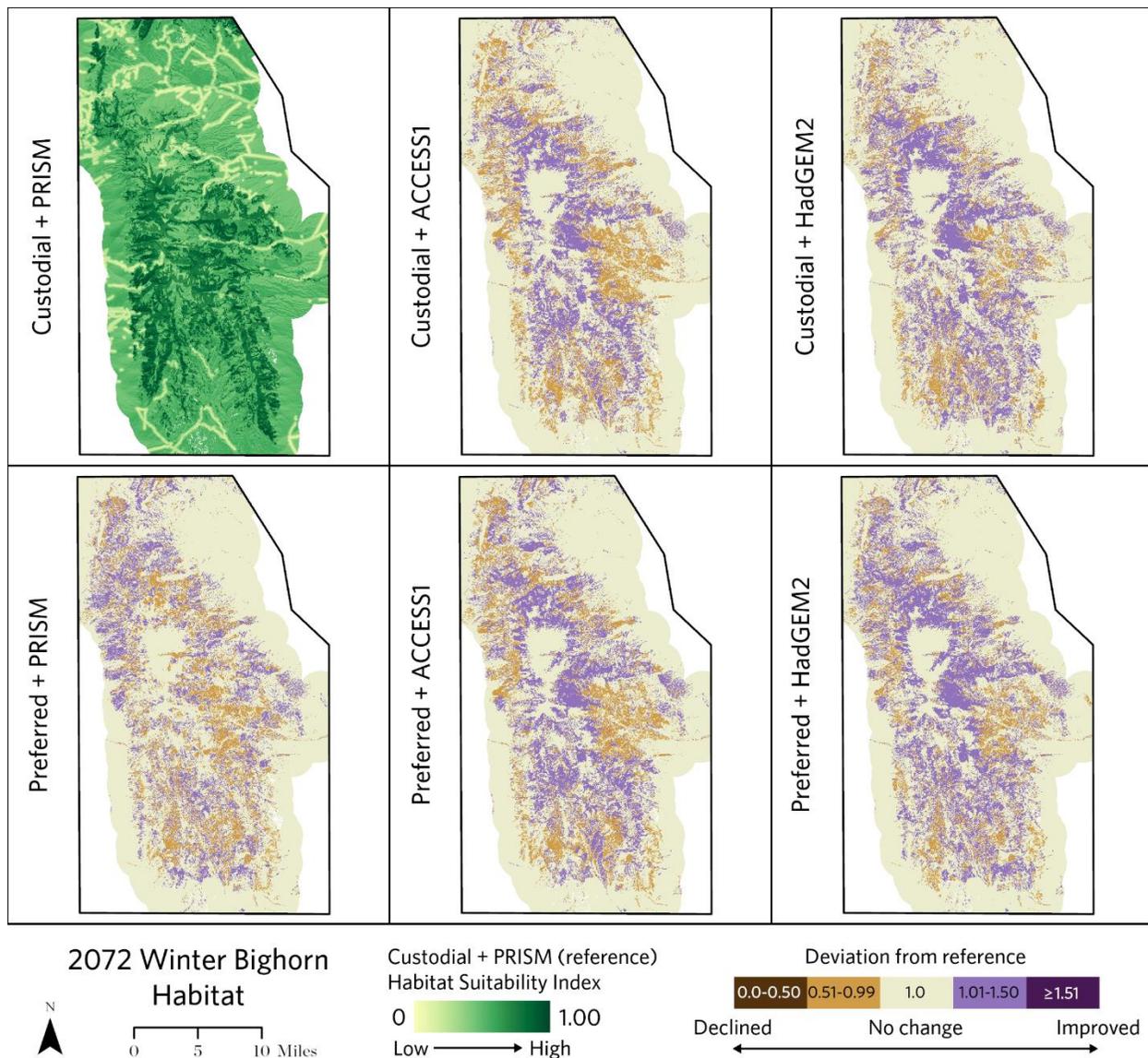


Figure 3.13. Average bighorn sheep winter habitat suitability index (n = 10) presented in absolute value for the Custodial-PRISM management scenario and as differences from it for all other scenario combinations for year 2072 on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and Preferred (active management) combined with each of same future climates.

3.1.6. Runoff and Recharge by Climate and Hydrologic Basins

Hydrologic results were reported as sums of runoff or recharge across all grid cells within each hydrologic basin (Fig. 2.8) and only for iteration 4 for each modeling scenario (i.e., custodial and preferred treatments for PRISM, ACCESS1 and HadGEM-ES climate conditions). Only one iteration of each scenario was run to help manage large memory constraints and storage, and cost of this study. Reported runoff or recharge did not include any contributions from upstream

basins. The first observation was the large variation among basins. For example, results for runoff ranged from <5mm in basin 10 (lowest part of Snake Creek drainage and small) to >110 mm in basin 20 (part of southern Highland Ridge) for the custodial management scenario (Fig. 3.14). For simplicity, only the results of the custodial management scenario are shown in Fig. 3.14.

Second, basins with low or high runoff, respectively, showed low or high recharge (Fig. 3.14). This was expected because the results are derived from water budgets for each grid cell, so basins with more precipitation had more water to distribute to recharge or runoff. Third, both runoff and recharge were always highest in the HadGEM-ES climate, slightly less in ACCESS1 and least in the PRISM climate (Fig. 3.14). These differences were hard to explain as PRISM was the wettest climate and ACCESS1 the driest in our simulations; however, PRISM was obtained from statistically interpolated predictions of precipitation and temperatures from weather station time series (Daly et al. 2007), whereas the LOCAs are process-based and empirical models (Pierce et al. 2014). All LOCAs start with a common value of precipitation and temperatures that was higher for precipitation than the initial values for PRISM (*personal communications, Lorrie Flint – Flint Hydroscience and Christine Albano – DRI*). Therefore, LOCAs predicted more precipitation than PRISM in initial and future conditions. This was not a problem for simulations because we used the SPEI (Hayes et al. 1999), which was a statistically estimated value of departure in standard deviations from zero where initial conditions do not matter. In future climate change projects, we will select LOCAs that are nearly identical to the historic climate (e.g., MRI for our AOI) to avoid the use of PRISM, unless the study does not involve Global Circulation Models.

Runoff and recharge were expressed as the difference (Δ) between the preferred management scenario and custodial management scenario per basin (i.e., $\Delta = P-C$ for each basin) over the simulation's 50 years where a positive or negative difference respectively indicated that treatments increased or decreased runoff and recharge (Fig. 3.15). In addition to the difference, the median difference among basins was plotted with a dark full circle. In these results, the runoff and recharge discrepancies in absolute values among climate (Fig. 3.14) did not matter because differences are independent of absolute values (as with SPEI).

Positive and negative basin differences for runoff were found in all years, although greater positive than negative amplitudes were found in the PRISM and ACCESS1 climates, whereas the opposite was found in the HadGEM-ES climate (Fig. 3.15). While the median was generally on or very close to the no-difference zero line, the median moved only slightly from zero in the same direction as the largest differences.

In general, recharge deviations were more dispersed from the zero line than observed with runoff differences (Fig. 3.16), although the largest difference between the treatment scenarios was observed for runoff for the PRISM climate (Fig. 3.15). The PRISM climate showed the greatest positive differences, the HadGEM-ES presented the largest negative differences with obvious median negative values, whereas the ACCESS1 climate showed more negative differences in the first half of the simulation and more positive differences in the latter half.

The third type of hydrologic results was average annual runoff or recharge differences (Y axis) plotted against total area treated (X axis) in each basin (Figs. 3.17-3.18). We did not have any expectation of change in runoff or recharge as a function of treatment area because restoration included opposing contributors to runoff and recharge: 1) tree cutting and seedings in shrublands, which should not contribute much runoff and recharge because they were generally found at lower and mid-elevation precipitation zones and prone to high snow sublimation, and 2) prescribed burning and tree thinning in high elevation forests of aspen and conifer that could contribute more than shrublands to runoff and recharge due to higher snowfall and less sublimation in forested canopies, until the canopy was completely cut or burned.

In this project, the treated area was dominated by shrubland treatments that would have increased sublimation as shading of snow by the short shrub canopy was removed (negative differences in runoff and recharge as treatment size increases). For examples, basins 2, 3, 6, 7, and 21 and had the largest treated areas that were also primarily in shrublands with upland soils (Figs. 2.8, 3.17-3.18). Basin 21, however, also received high elevation prescribed burning in aspen types in the upper Strawberry Creek drainage. These basins showed negative or weakly positive differences in runoff and recharge as climates changed (Figs. 3.16-3.18). For example, the basin differences shifted, respectively from weakly positive to negative and vice versa in PRISM and HadGEM-ES climates.

Only a few basins received prescribed burning and tree thinning in various aspen types and conifers and subalpine shrublands at high elevations; however, prescribed burning would have temporarily increased sublimation due to lack of tree shading during snowmelt until growth of young canopies would have provided shade on snow and the reduction of sublimation. Basins 5, 12, 16, 17, 18, and 22 were small to moderate-sized basins that generally experienced small to moderate-sized treatments (however, disproportionately large in a small basin) at high elevations with high snowfall (Figs. 2.8, 3.17-3.18). Those basins generally showed positive differences in runoff and recharge due to high elevation treatments.

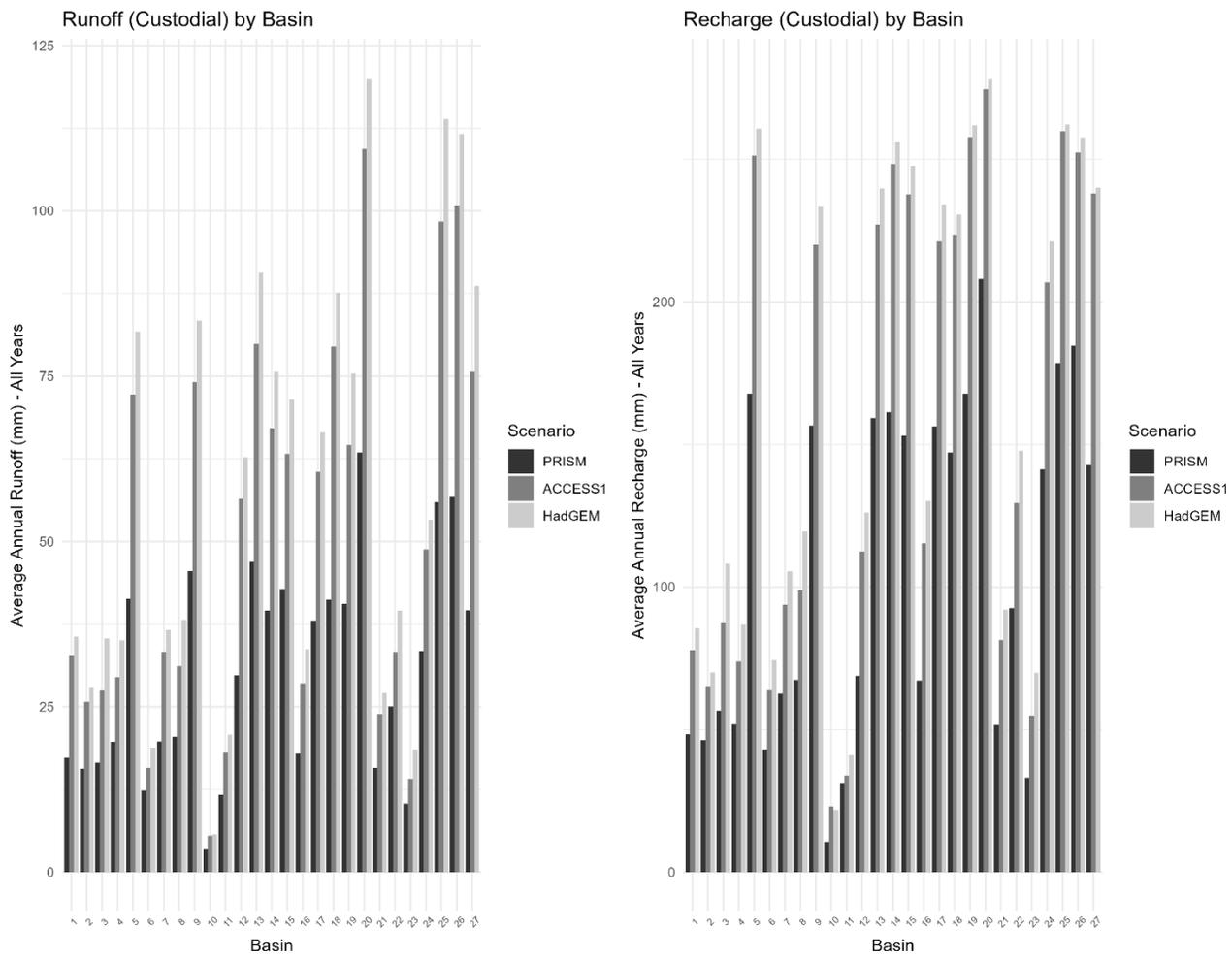


Figure 3.14. Average annual runoff (left panel) and recharge (right panel; mm) by hydrologic basin and climate only in the custodial management scenario on the South Snake Range. The three future climates were the PRISM, ACCESS1, and HadGEM-ES LOCAs presented as adjacent bars.

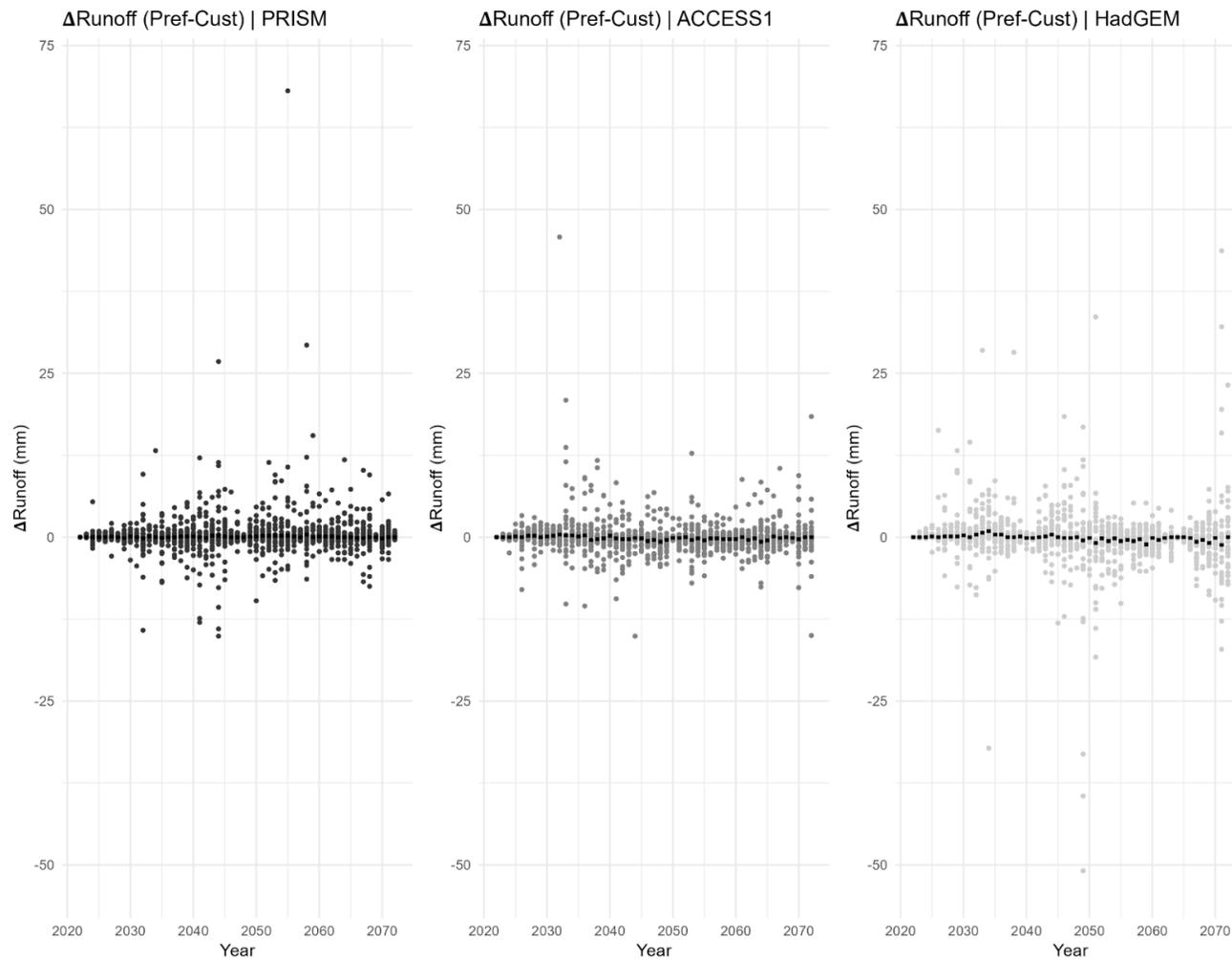


Figure 3.15. Annual runoff difference (Δ ; mm) between the preferred management and custodial management scenarios (P - C) by hydrologic basin and climate from 2023 to 2072 in iteration 4 on the South Snake Range. The three future climates were the PRISM (left panel), ACCESS1 (middle panel), and HadGEM-ES (right panel) LOCAs. Black circles indicate median differences in all basins in each year.

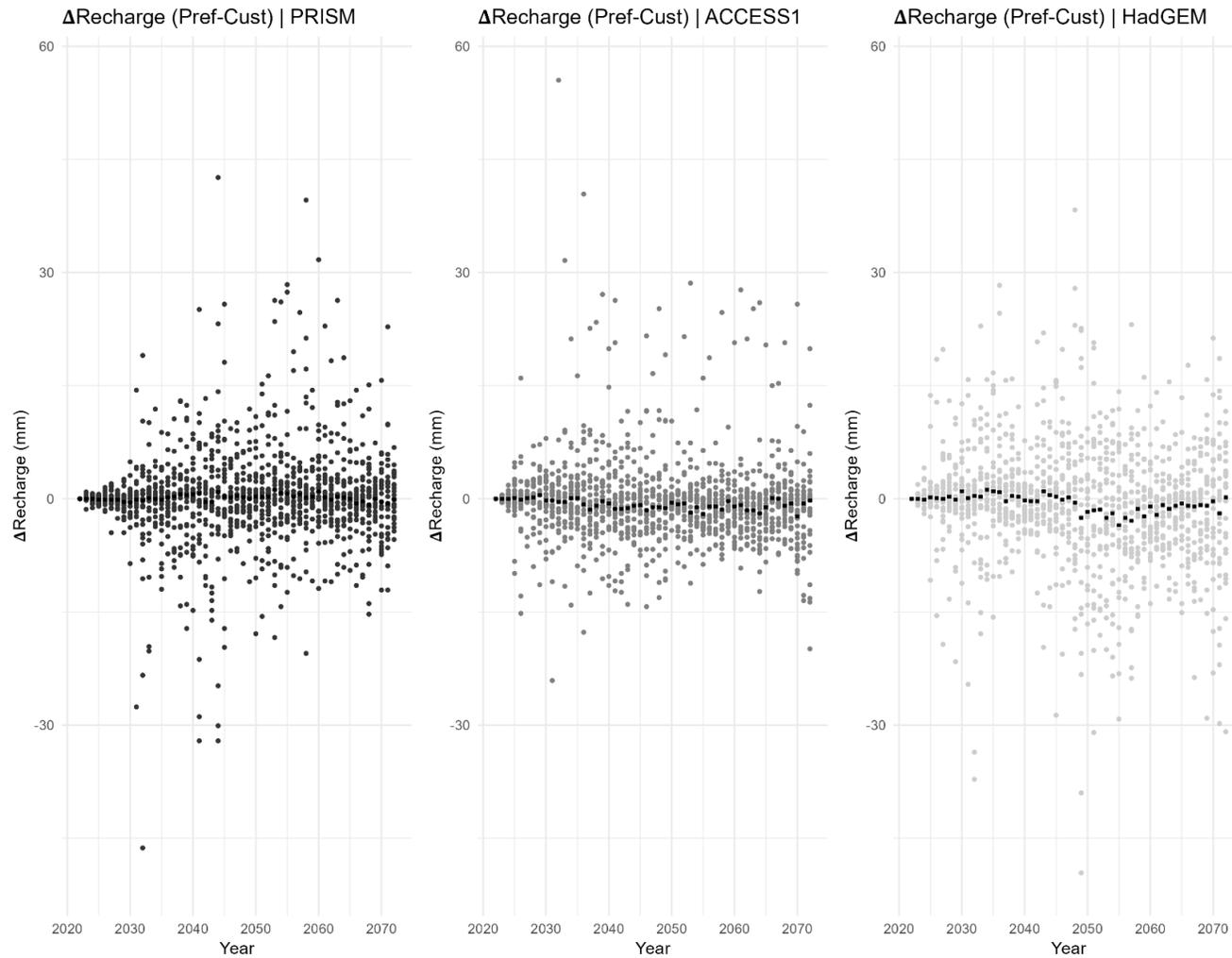


Figure 3.16. Annual recharge difference (Δ ; mm) between the preferred management and custodial management scenarios (P - C) by hydrologic basin and climate from 2023 to 2072 in iteration 4 on the South Snake Range. The three future climates were the PRISM (left panel), ACCESS1 (middle panel), and HadGEM-ES (right panel) LOCAs. Black circles indicate median differences in all basins in each year.

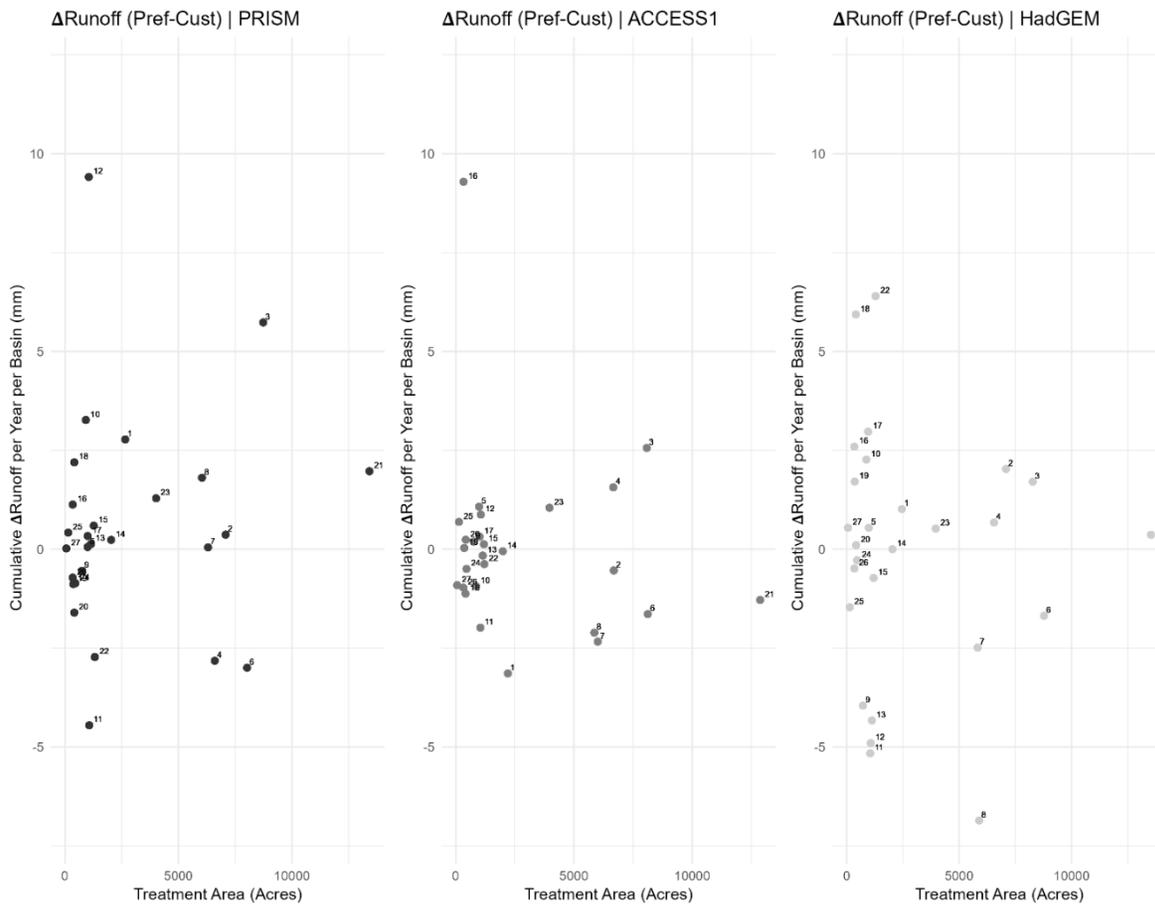


Figure 3.17. Average annual runoff difference (Δ ; mm) between the preferred management and custodial management scenarios (P - C) as a function of cumulative area treated by hydrologic basin and climate in iteration 4 on the South Snake Range. Each point in the Y by X plot represents the average annual runoff in a distinct basin indicated by the adjacent number. The three future climates were the PRISM (left panel), ACCESS1 (middle panel), and HadGEM-ES (right panel) LOCAs.

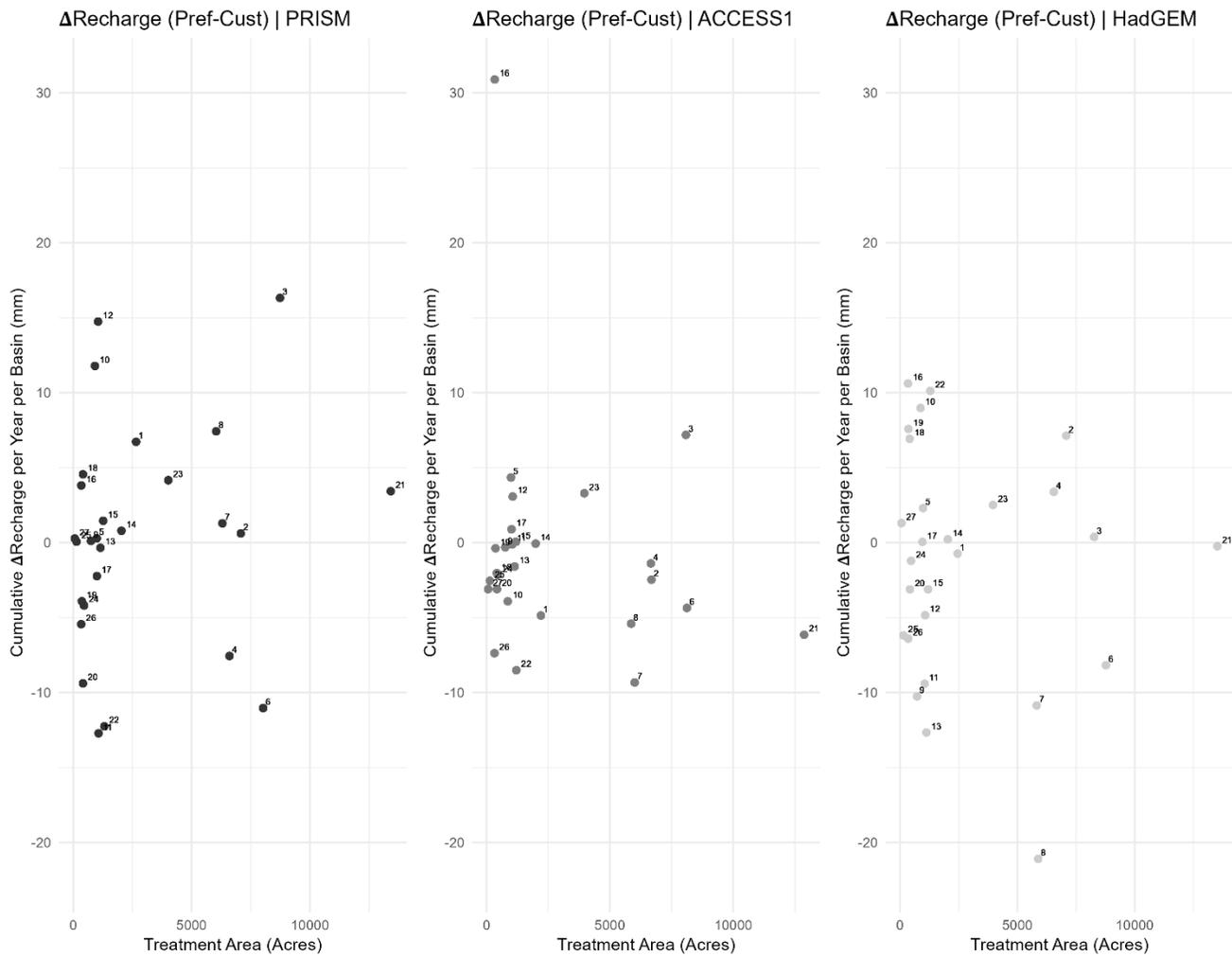


Figure 3.18. Average annual recharge difference (Δ ; mm) between the preferred management and custodial management scenarios (P - C) as a function of cumulative area treated by hydrologic basin and climate in iteration 4 on the South Snake Range. Each point in the Y by X plot represents the average annual runoff in a distinct basin indicated by the adjacent number. The three future climates were the PRISM (left panel), ACCESS1 (middle panel), and HadGEM-ES (right panel) LOCAs.

3.1.7. Fire Effects on Riparian Health

Proportion of riparian burned. The first measure of fire effects on riparian health, rather simple, was the proportion of the riparian area that burned because of wildfires mostly originating outside the riparian area (few fires can originate within the riparian). We hypothesized that fuels treatments in the basins might cumulatively lower the risk of high severity fire in riparian systems in the hope of avoiding more “Strawberry Fire” events resulting in high Bonneville cutthroat trout mortality through direct heat and sedimentation.

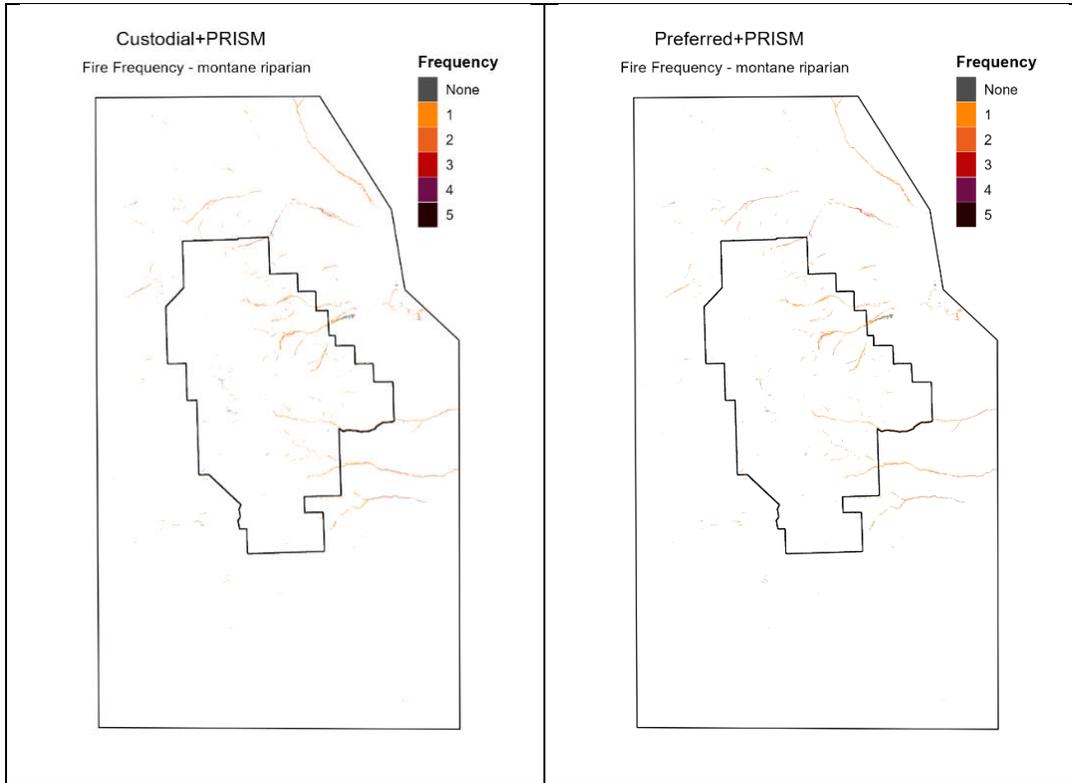
The most noticeable and consistent result for this metric was that climate scenarios that produced the most fire in the AOI (PRISM and HadGEM-ES) showed the largest proportions of riparian area burned (0.899 – 0.920), whereas the driest climate (ACCESS1) with the least area burned in the AOI resulted in the lowest percentage of riparian area burned (0.807 – 0.817; Table 3.3). The preferred management scenarios caused a reduction of the proportion of riparian burned compared to the custodial management scenario for the ACCESS1 (difference = 0.01) and HadGEM-ES (difference = 0.021) climates, but not the PRISM climate where the difference was -0.002 and likely insignificant (Table 3.3). A proportion difference of 0.021 multiplied by the size of the montane riparian area (1,941.2 acres) was 40.8 acres for HadGEM-ES, whereas the 0.01 difference in the ACCEES1 climate was 19.4 acres. For example, 1 acre is 43,560 ft²; therefore, if a stream cross-section is 100 ft wide, then the length of the fire free area would be 435.6 ft long. Therefore, 41 acres would result in about 3.5 miles of less fire in montane riparian 100 ft wide compared to doing nothing. Many streams were less than 100 ft wide; therefore, even more length of creeks would be unburned due to treatments.

Table 3.3. Proportion of riparian systems burned when wildfire originated outside systems.

Management Scenario	Proportion of Riparian Burned (%)
Custodial + PRISM	0.908
Preferred + PRISM	0.910
Custodial + ACCESS1	0.817
Preferred + ACCESS1	0.807
Custodial + HadGEM-ES	0.920
Preferred + HadGEM-ES	0.899

Fig.3.19 shows that more riparian burned in the PRISM climate than in the HadGEM-ES climate (more gray segments), whereas the ACCESS1 climate showed the greatest number of unburned segments (in gray). More noticeable unburned segments were observed in the Big Wash and Baker Creek drainages in the ACCESS1 climate than the other climates. The difference in unburnt segments between the preferred management and custodial management scenarios was more obvious in the same drainages for the HadGEM-ES climate, especially in the upper

reaches of stream systems. For the PRISM climate, the higher reaches of Pole Creek and Can Young Canyon did not burn due to treatments, although this was not reflected in Table 3.3.



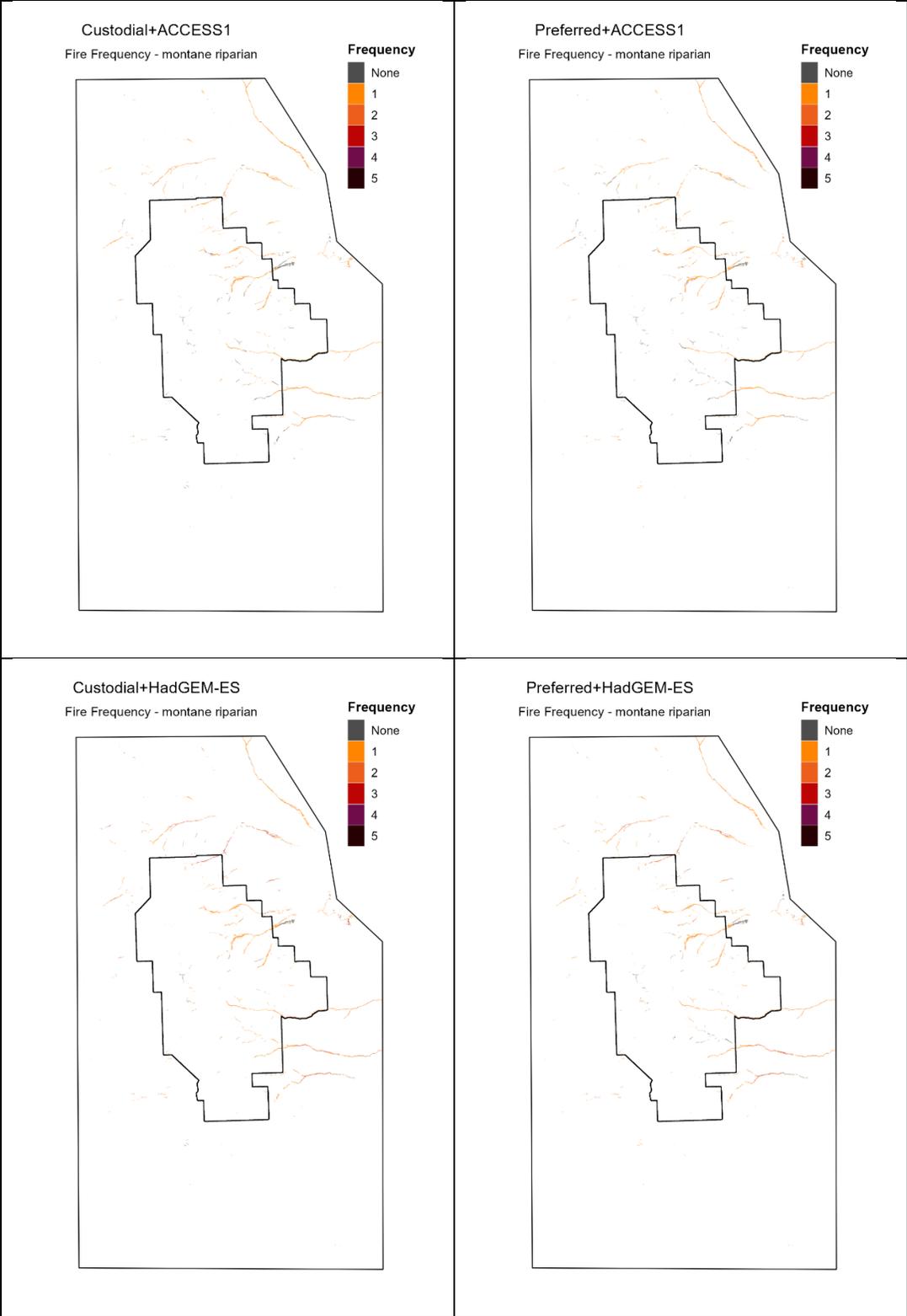


Figure 3.19. Montane riparian burned due to the cumulative effect of treatment in the preferred management scenario compared to the custodial management scenario in 2047. Six management

scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

Indicator of Riparian Health. In 2022, the index of riparian health generally was moderately high (very good) by sub-basins, but only the highest elevations sub-basins showed excellent values (Fig. 3.20). Whole stream sections within the same sub-basin were given the same values. Lower elevation sub-basins generally showed lower values of riparian health, due mostly to the shorter distance to roads and channel degradation (often caused by roads). Big Wash was a good example. If roads followed streams to higher elevations, the index was lower (Fig. 3.20). Good examples were observed in Snake Creek’s middle section, Strawberry Creek, and Lehman Creek up to the lower and upper Lehman campgrounds.

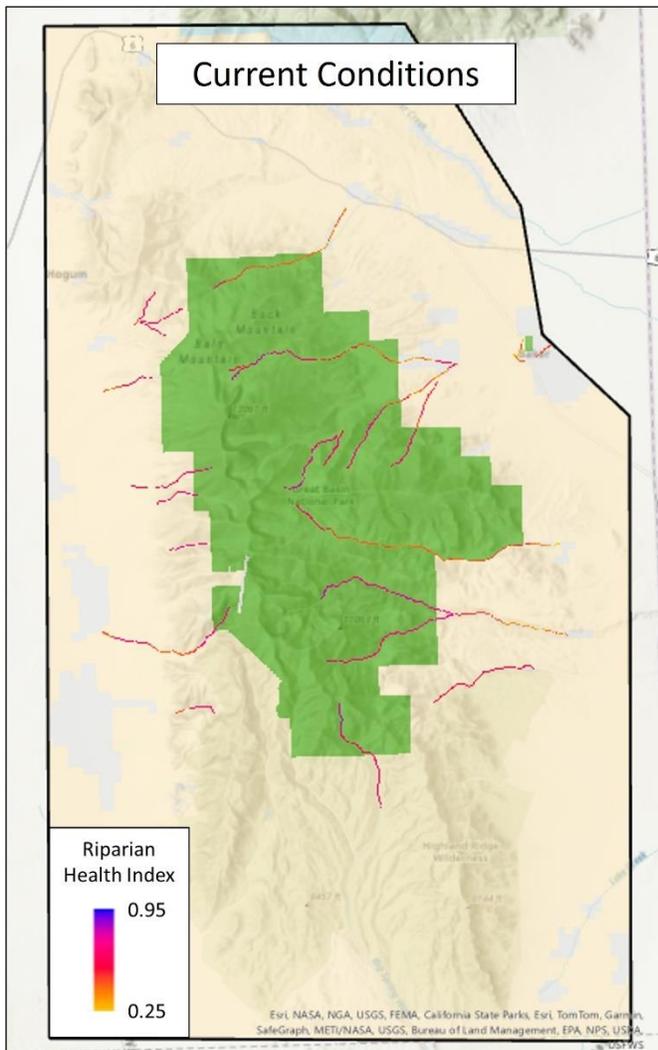
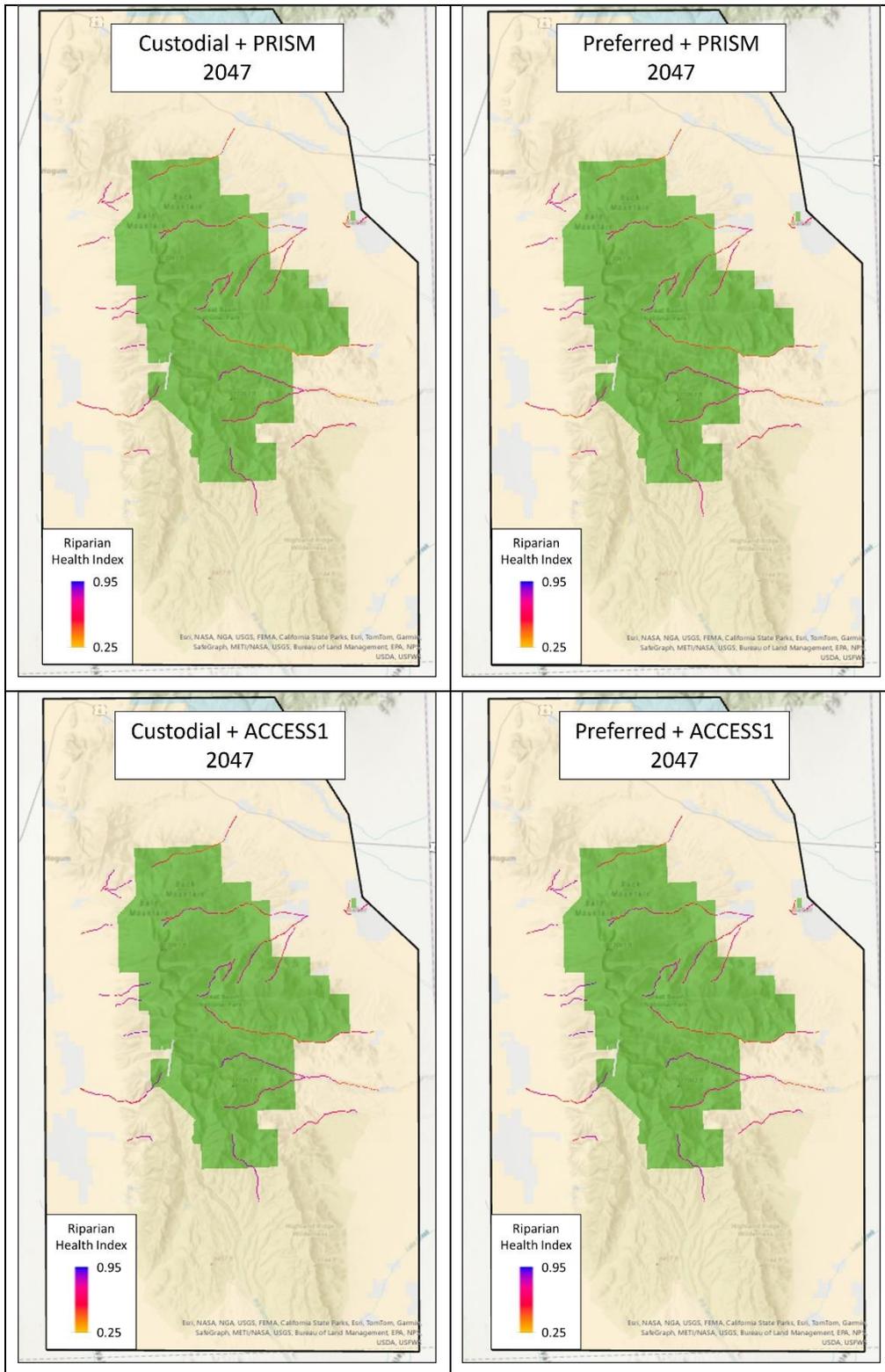


Figure 3.20. Index of riparian health estimated from the interpreted 2022 Spot 6 satellite imagery (current conditions).

Subtle differences in the index of riparian health among scenarios were observed in 2047 (Fig. 3.21). While distance from roads was a determining covariate in the 2022 results that was also important in 2047 (Fig. 3.20), channel degradation, relative moisture from BCM (between climate scenarios) and the presence of exotic forbs and trees modified results among climates and management. Comparisons will more efficiently be accomplished using Geographic Information System magnification.

Treatment levels were small in the montane riparian compared to other systems, thus effects on the index of riparian health would be small. Installation of PALS (water-table-uplift treatment) amounted to very few acres because many were installed in Strawberry Creek before the mapping occurred and they had already reduced incisions. Where PALS were simulated on BLM-managed creeks, the dominant influence of roads on the index overwhelmed improvements as incisions and roads were often co-located. The other treatment that contributed to improvement in the index was the control of exotic species. Because we used an aggressive rate of invasion that rapidly increased the area of exotic species on BLM and private lands much more than on GBNP (see later in class results; very few creeks were invaded in GBNP). The control of exotic species reduced the area in the preferred management, therefore increased the index, compared to custodial management but area still rapidly increased. However, greater annual flows were simulated to cause greater invasion of exotic species; therefore, the most notable scenario difference on the index was between the ACCESS1 climate with the lowest predicted flows and lowest observed values of the index and other climates (compare the ACCESS1 climate combined with preferred management to the PRISM climate combined with preferred management in Snake Creek; Fig. 3.21). Obviously, lower flows would reduce the value of the index, but the difference in exotic species area would be also important because the climate effect was stronger than the cumulative subbasin runoff effect.



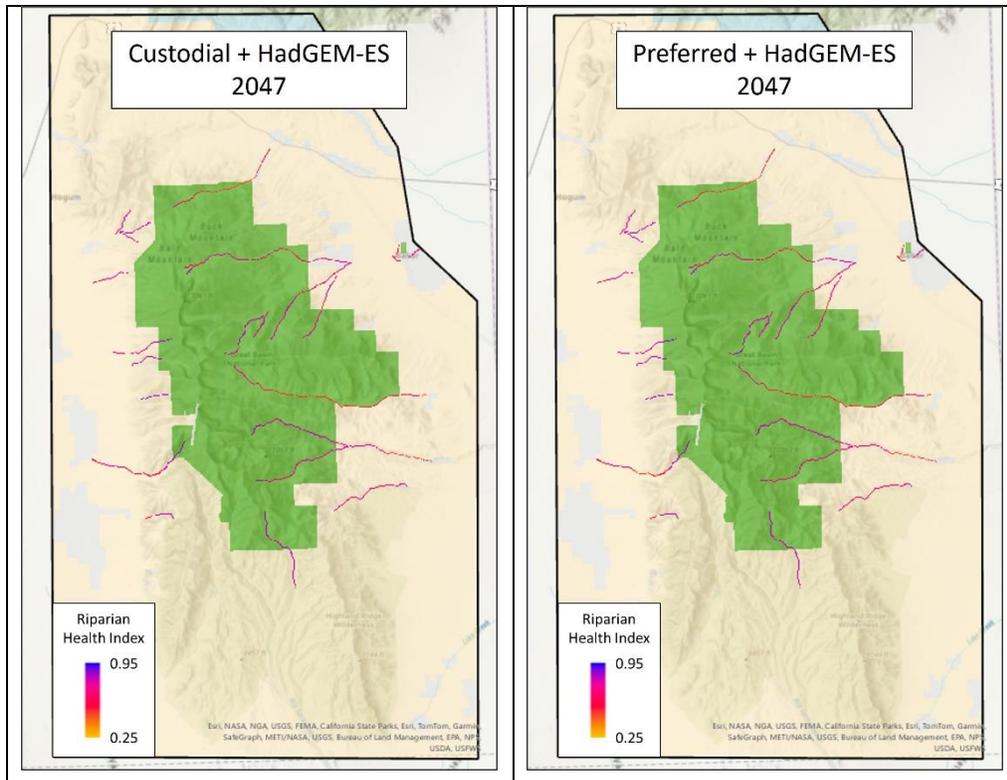


Figure 3.21. Index of riparian health (n = 10) in the six management by climate scenarios and as for year 2047 on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and Preferred (active management) combined with each of same future climates.

3.2. Ecological Systems Results

3.2.1. Antelope Bitterbrush-Black Sagebrush

2022 System acres at 14-m resolution: 11,558

2022 Landscape-wide ED: 99%

Problems or Concerns

Antelope bitterbrush-black sagebrush was dominated (about 99%) by the uncharacteristic wooded late-successional open-canopied shrubs with mixed non-native annual grasses and forbs and perennial grasses class (U-D:SAP Table 3.4). With a few more decades, the class's young conifers would mature and suppress the shrub and herbaceous understory. Not surprisingly, ED showed near complete departure from reference conditions.

Table 3.4. Vegetation classes of antelope bitterbrush-black sagebrush expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:All							19
A:Char1							1
A:Char2							1
B:Open	75	1			76	0.66	50
C:Closed							18
D:Open	60	1			61	0.53	3
E:Closed							7
U-A:Early-Shrub	1				1	0.01	0
U-A:SAP	1				1	0.01	0
U-D:SAP	10,858	301	119	141	11,419	98.79	0

Objectives for Management Actions

The primary objective was to cut young conifers occupying the antelope bitterbrush-black sagebrush shrubland and, if needed, reseed herbaceous species. While GBNP only proposed to use *small tree lopping* under the assumption of sufficient remnant native grass in the understory (no seeding needed, especially in the absence of livestock grazing), BLM deployed masticators and chainsaws to cut trees and *seeded after mastication* with either native herbaceous species or a mix of introduced and native species (Table 3.5). There were no obvious climate differences for treatment implementation. The treatment that cut the largest area of trees was *small tree lopping* with chainsaws and loppers (Table 3.5).

Table 3.5. Realized treatment totals (acres) within each period in antelope bitterbrush-black sagebrush from 2023 to 2072.

	Masticate+Native-Seed (BLM: \$577/acre; NPS: \$1,015-\$1,150/acre)	Masticate+Seed (BLM: \$577/acre)	Small-Tree Lopping (BLM: \$80/acre; NPS: \$250/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres
PRISM			
BLM			
2023-2024	0	0	0
2025-2029	0	0	4,984-5,024
2030-2034	0	0	0
2035-2039	0-124	25-588	0
2040-2072	0	0	0
NPS			
2023-2024	0	0	0
2025-2029	0	0	48-52

2030-2034	0	0	148-154
2035-2039	0	0	57-99
2040-2072	0	0	0
ACCESS1			
BLM			
2023-2024	0	0	0
2025-2029	0	0	4,976-5,020
2030-2034	0	0	0
2035-2039	0-269	4-245	0
2040-2072	0	0	0
NPS			
2023-2024	0	0	0
2025-2029	0	0	53-49
2030-2034	0	0	144-151
2035-2039	0	0	33-96
2040-2072	0	0	0
HadGEM-ES			
BLM			
2023-2024	0	0	0
2025-2029	0	0	4,976-5,020
2030-2034	0	0	0
2035-2039	1-250	0-221	0
2040-2072	0	0	0
NPS			
2023-2024	0	0	0
2025-2029	0	0	49-53
2030-2034	0	0	144-151
2035-2039	0	0	33-96

2040-2072	0	0	0
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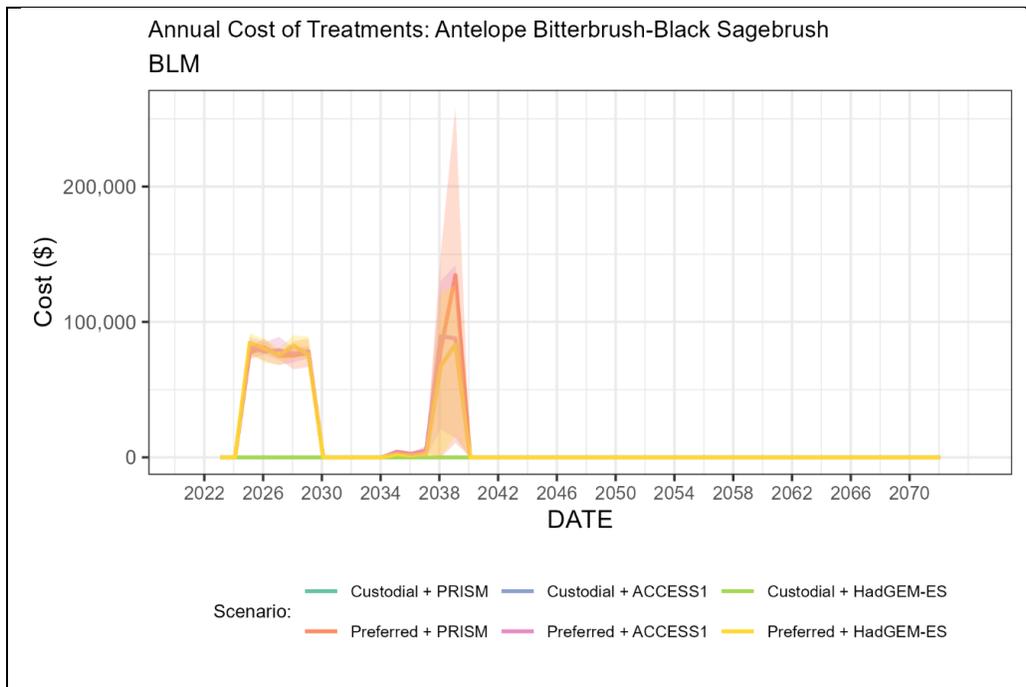
The only treatment that could cause a reduction in ED was *masticate+native seed* because it created sufficient native species seeding that eventually became a reference class. Less than 200 acres were deployed, however, which would have a small effect on ED (Table 3.6). The *small tree lopping* treatment in the D:Open could increase the reference C:Closed class area, but the D:Open class area was itself deficient relative to the reference condition. All other treatments simply shifted one uncharacteristic class to others, even at 5,000 acres of *small tree lopping* (Table 3.6), but none recruited into reference classes or changed ED. This was clearly reflected in the values below where there were no ED differences among scenarios in the same year and across years since 2022 (Table 3.6). As seen later in class charts, this lack of change happened while large area changes were observed in treated areas.

Table 3.6. Future ED in antelope bitterbrush-black sagebrush (% \pm 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED \pm 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	99% \pm <0.1%	99% \pm <0.1%
2047	99% \pm 0.1%	99% \pm 0.1%
2072	99% \pm 0.2%	99% \pm 0.2%
ACCESS1		
2035	99% \pm 0.1%	99% \pm 0.1%
2047	98% \pm 0.2%	98% \pm 0.2%
2072	98% \pm 0.3%	98% \pm 0.2%
HADGEM-ES		
2035	99% \pm 0.1%	99% \pm 0.1%
2047	98% \pm 0.3%	99% \pm 0.1%
2072	98% \pm 0.5%	98% \pm 0.3%

Cost by year (ST-Sim Results)

The primary cost was from *small tree lopping* for BLM that initially hovered at \$80,000 per year until 2024, then dropping to near zero for the remainder of the simulation, except for the 2034 to 2039 expenditure period of mastication that peaked at about \$150,000 in 2039 (Fig. 3.22). Only *small tree lopping* was used in GBNP. Cost was around \$2,200 per year until 2029, and then increased to \$7,800 per year from 2030 to 2033, after which cost dropped precipitously to near zero by 2039 (Fig. 3.22). The rapid drop in cost indicated that treatments exhausted the treatable area.



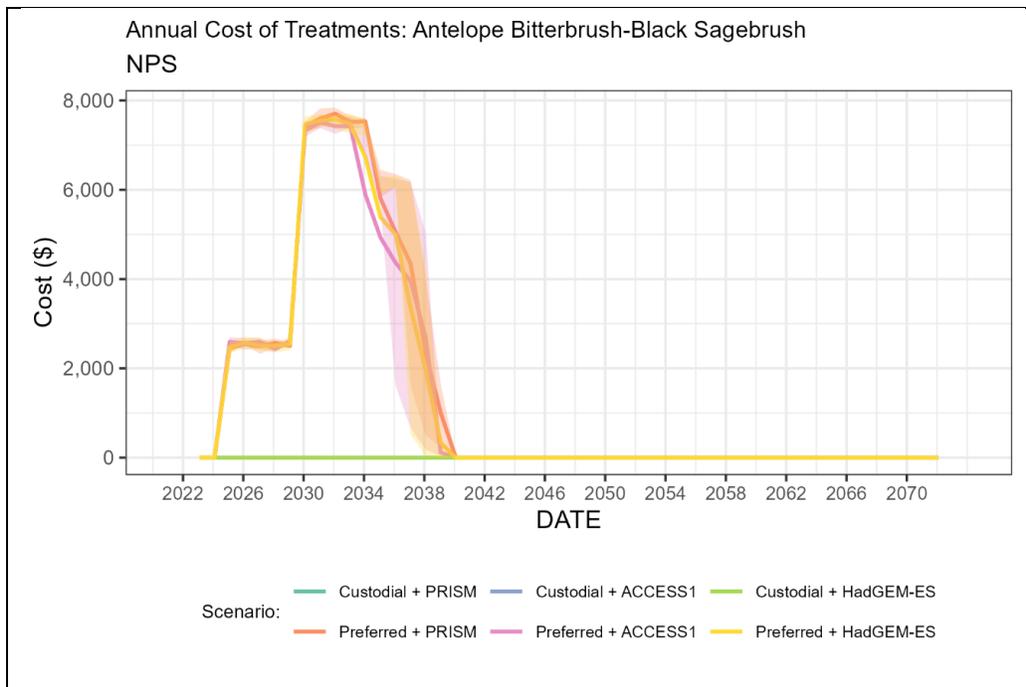


Figure 3.22. Annual cost of treatments in antelope bitterbrush-black sagebrush by ownership in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES). The line is the mean and error bars are the 25th-75th percentiles.

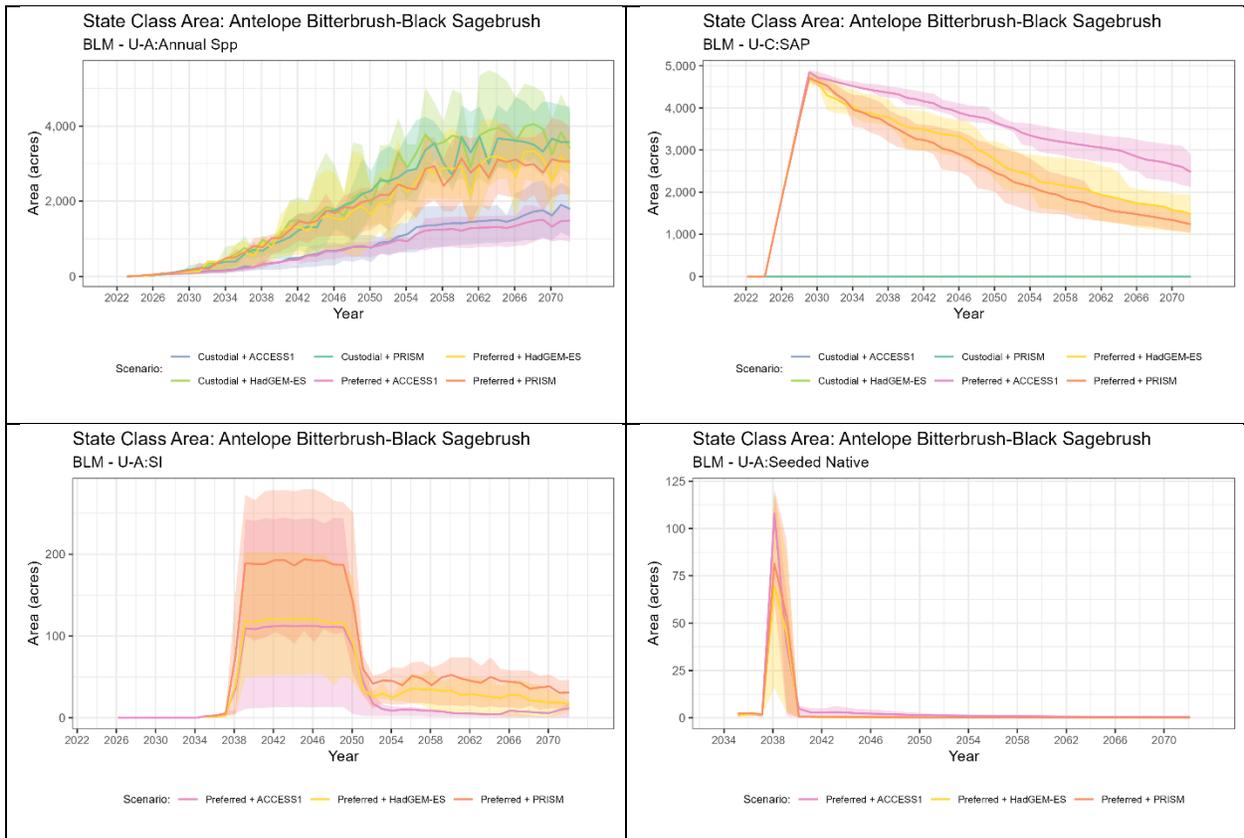
Vegetation Classes (ST-Sim Results):

Small tree lopping of young conifers either with chainsaws or loppers on BLM-managed land resulted in a decrease of the class U:D:SAP by about 5,000 acres compared to the custodial management scenario from 2025 to 2035 (Fig. 3.23). As no seeding was involved, nearly all treated areas transition to the younger successional class without trees, U-C:SAP (shrubs with non-native annual species and perennial native grasses). Using mostly masticators, the decrease of the area of U-D:SAP persisted and transitions to the native species seeding class (U-A:Seeded-Native) or mixed introduced and native species seeding class (U-A:SI) were observed (Fig. 3.23); however, the difference was not as large as the area treated was very small. Also significant as indicated by all custodial management scenarios regardless of climate, the young conifers in the U-D:SAP class matured rapidly into the tree-encroached class invaded by non-native annual species (U-E:TEA). The U-E:TEA class received some mastication at the end of the implementation phase, but the main reason for smaller areas observed in the preferred compared to the custodial management scenarios was the work accomplished in the younger class (U-D:SAP). The younger class treated with chainsaws was much cheaper to restore than masticating large trees.

In GBNP, *small tree lopping* reduced the area of the U-D:SAP class by about 250 acres (Fig. 3.24). As a result, the younger successional class U-C:SAP increased by about 250 acres as

falling young trees caused the transition from several U-D:X to U-C:X (X code for different classes) classes (Fig. 3.24). Because the U-D:SAP class was eliminated under preferred management scenarios, succession to the next oldest uncharacteristic class (U-E:TEA) did not occur (Fig. 3.24), which was a highly desirable outcome.

Climate differences were observed in mixed introduced and native species seeding, especially U-A:SI. The highest seeded area, given similar implementation rates, was twice as high for the PRISM climate (about 190 acres in U-A:SI) than the two other warming climates (about 110 acres; Fig. 3.23). The same qualitative pattern existed for native species seeding (U-A:Seeded-Native). Climate modified the effect of wildfires on the transition to non-native annual grasslands (U-A:Annual Spp) such that the drier ACCESS1 climate suppressed wildfire activity (less fine fuels build-up modeled with drought) and, as a result, the area of non-native annual species class was smallest among climates. On the other hand, moister PRISM and HadGEM-ES climates led to more wildfire activity and, as a result, more area transitioned to annual grasslands regardless of treatments (Fig. 3.23).



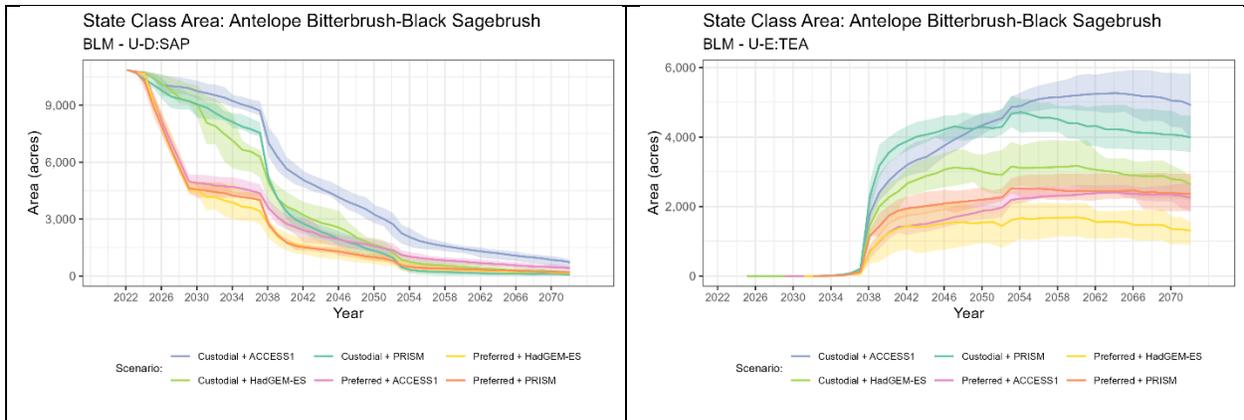


Figure 3.23. Vegetation classes of antelope bitterbrush-black sagebrush on BLM-managed land treated or recruited into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

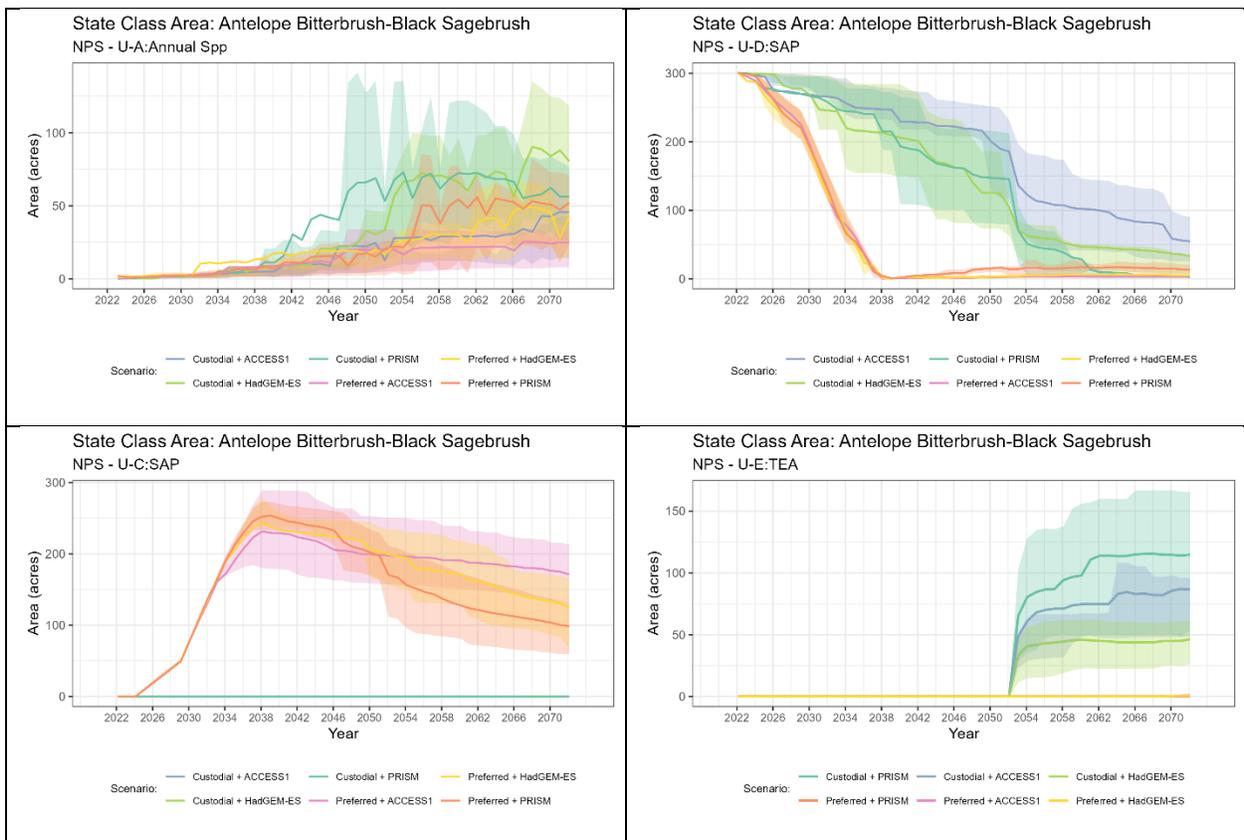


Figure 3.24. Vegetation classes of antelope bitterbrush-black sagebrush on GBNP treated or recruited into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.2. Antelope Bitterbrush-Mountain Big Sagebrush

2022 System acres at 14-m resolution: 4,380

2022 Landscape-wide ED: 73%

Problems or Concerns

Antelope bitterbrush-mountain big sagebrush was mostly occupied by five vegetation classes (Table 3.7). Three reference classes (B:Open, C:Closed, and D:Open) each accounted for >10% of the system’s total area (Table 3.7). Classes B:Open and C:Closed were highly under-represented compared to the reference condition, whereas the wooded class D:Open was over-represented by >1,400 acres. The two uncharacteristic classes were wooded with young conifers (U:D:SAP; 17%) and mature trees (U-E:TEA; 12%; Table 3.7). The patterns of class percentages were not substantially different between the BLM and GBNP. The main problem was the over-abundance of trees in the three wooded uncharacteristic classes (D:Open, U:D:SAP, and U-E:TEA) and the need for recruitment into younger reference classes.

Table 3.7. Vegetation classes of antelope bitterbrush-mountain big sagebrush expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:All							21
A:Char1							3
A:Char2							3
B:Open	510	41		0	551	12.59	50
C:Closed	526	21			547	12.49	20
D:Open	1,201	212		0	1,413	32.27	2
E:Closed	13	53			66	1.51	1
U-A:Bare Ground	2				2	0.04	0
U-A:Early-Shrub	1				1	0.02	0

U-A:SAP	8				8	0.19	0
U-A:SI+AS	<1				<1	<0.01	0
U-B:SAP	196	186	8		391	8.92	0
U-B:SI+AS	23				23	0.53	0
U-C:Depleted	0	1			1	0.03	0
U-C:SA		2			2	0.04	0
U-C:SI	73				73	1.67	0
U-C:SI+AS	5				5	0.12	0
U-D:Depleted	3				3	0.07	0
U-D:SAP	493	189	54		737	16.83	0
U-D:SI+AS	27				27	0.62	0
U-E:TEA	504	25	0		529	12.08	0

Objectives for Management Actions

The primary objective was to cut young and mature conifers occupying the antelope bitterbrush-mountain big sagebrush shrubland in reference and uncharacteristic classes and, if needed, reseed herbaceous species in U-E:TEA. A slightly greater area of treatments occurred on BLM than GBNP lands and no obvious climate differences were observed. (Table 3.8).

Table 3.8. Realized treatment totals (acres) within each period in antelope bitterbrush-mountain big sagebrush from 2023 to 2072.

	Masticate+Seed (BLM: \$577/acre)	Chainsaw+Pile- Burning+Native- Seed-contract (BLM: \$577/acre; NPS: \$1,000- \$1,250/acre)	Small-Tree Lopping (BLM: \$80/acre; NPS: \$250/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total

			treatment acres
PRISM			
BLM			
2023-2024	0	0	0
2025-2029	466-510	0	0
2030-2034	0	5.4-5.5	0
2035-2039	0	0	0
2040-2072	0	0	0
NPS			
2023-2024	0	0	0
2025-2029	0	0	96-103
2030-2034	0	0	121-127
2035-2039	0	0	0
2040-2072	0	0	0
ACCESS1			
BLM			
2023-2024	0	0	0
2025-2029	481-513	0	0
2030-2034	0	5.4-5.8	0

2035-2039		0	0	0
2040-2072		0	0	0
NPS				
2023-2024		0	0	0
2025-2029		0	0	97-101
2030-2034		0	0	122-129
2035-2039		0	0	0
2040-2072		0	0	0
HadGEM-ES				
BLM				
2023-2024		0	0	0
2025-2029		483-509	0	0
2030-2034		0	5.1-6	0
2035-2039		0	0	0
2040-2072		0	0	0
NPS				
2023-2024		0	0	0
2025-2029		0	0	97-103

2030-2034	0	0	122-129
2035-2039	0	0	0
2040-2072	0	0	0

The only treatments that could cause a reduction in ED was the *chainsaw+pile burning+native seed (contractual)* because it created a native species seeding that eventually became a reference class, and *small tree lopping* in overabundant wooded reference classes, but not uncharacteristic classes (Table 3.9). However, <6 acres of *chainsaw+pile burning+native seed* were deployed, which would have a tiny effect on ED. ED measurably decreased with the PRISM climate (3-4% absolute difference), less with the HadGEM-ES climate (1-2% absolute difference), and not at all with the drier ACCESS1 climate (Table 3.9).

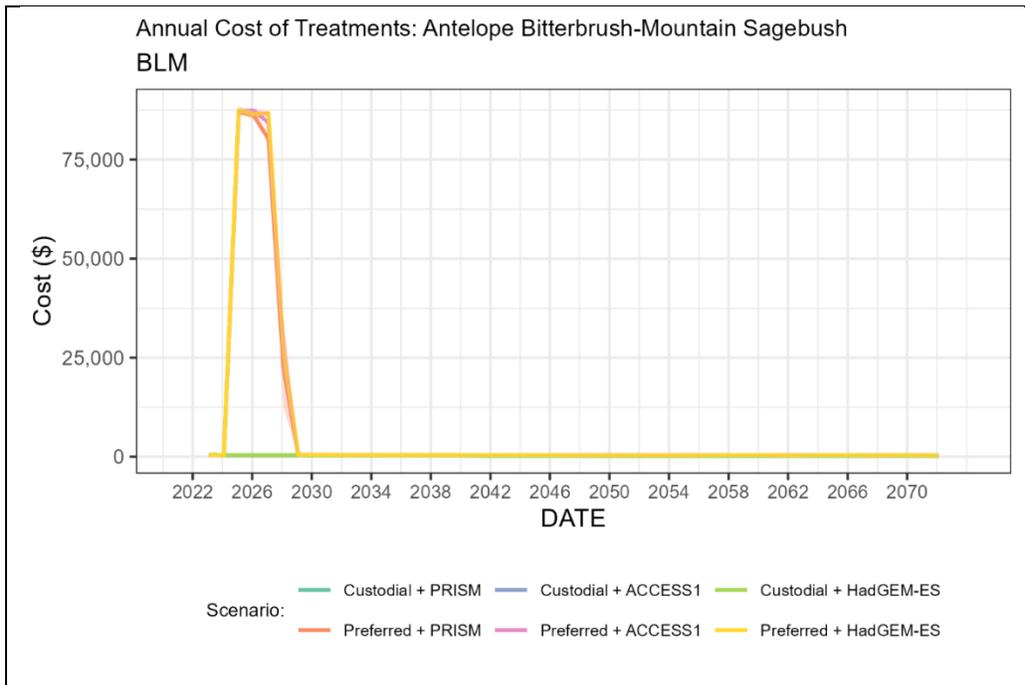
Table 3.9. Future ED in antelope bitterbrush-mountain big sagebrush (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	69% ± 2.2%	65% ± 1.7%
2047	66% ± 3.4%	64% ± 1.8%
2072	62% ± 3.0%	58% ± 3.6%
ACCESS1		
2035	69% ± 1.6%	67% ± 0.8%
2047	67% ± 3.0%	68% ± 2.3%
2072	66% ± 0%	66% ± 2.5%
HADGEM-ES		
2035	68% ± 3.8%	65% ± 2.3%
2047	64% ± 3.2%	62% ± 3.4%

2072	61% ± 3.8%	60% ± 4.3%
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Cost by year (ST-Sim Results)

The primary cost initially hovered at \$80,000 per year until 2029 due to the *masticate+seed* treatment for BLM (Fig. 3.25). From 2030 to 2034, very small amounts of *chainsaw thinning with pile burning and native seeding* accounted for a few additional years of non-zero cost (Fig. 3.25). Only *small tree lopping* was used for younger trees in GBNP in the D:Open and U-D:SAP classes. Cost was <\$15,000 from 2025 to 2034 per year with a peak in 2030 (Fig. 3.25).



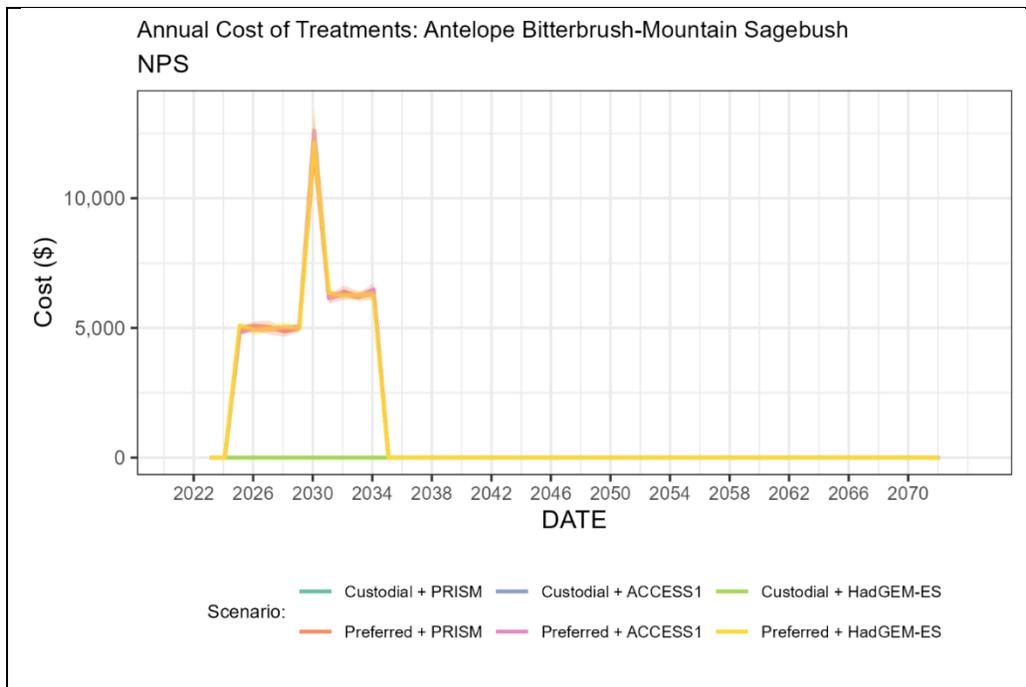


Figure 3.25. Annual cost of treatments in antelope bitterbrush-mountain big sagebrush by ownership in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

The tree-encroached class (U-E:TEA) was the most reduced of any classes by about 500 acres on BLM-managed land from 2025 to 2029 caused by *mastication followed by seeding a mix of introduced and native species seeding* (Fig. 3.26). The *mastication and seeding* treatment caused an about 250-acre increase of the seeded class U:A:SI (Fig. 3.26). Also noticeable were the differences among climates in the absence of treatments where the drier ACCESS1 climate caused less fire activity resulting in preservation of wooded vegetation classes, such as D:Open and U-E:TEA (Fig. 3.26). Similarly, the drier ACCESS1 climate caused greater failure of seedings (U-A:SI), which led to the accumulation of the non-native annual species class (U-A:Annual Spp).

In GBNP, uncharacteristic tree-encroached classes with the possible presence of non-native annual species (U-E:TEA) were slightly reduced by *chainsaw felling combined with pile burning and native species seeding* (Fig. 3.27). As a result, a few acres of native species seedings were created (U-A:Seeded Native). *Small tree lopping* reduced the late-successional open class occupied by young trees (D:Open) by about 100 acres, which caused a transition to the younger successional class with trees (C:Closed) that increased by 100 acres (Fig. 3.27).

Vegetation Classes (ST-Sim Results):

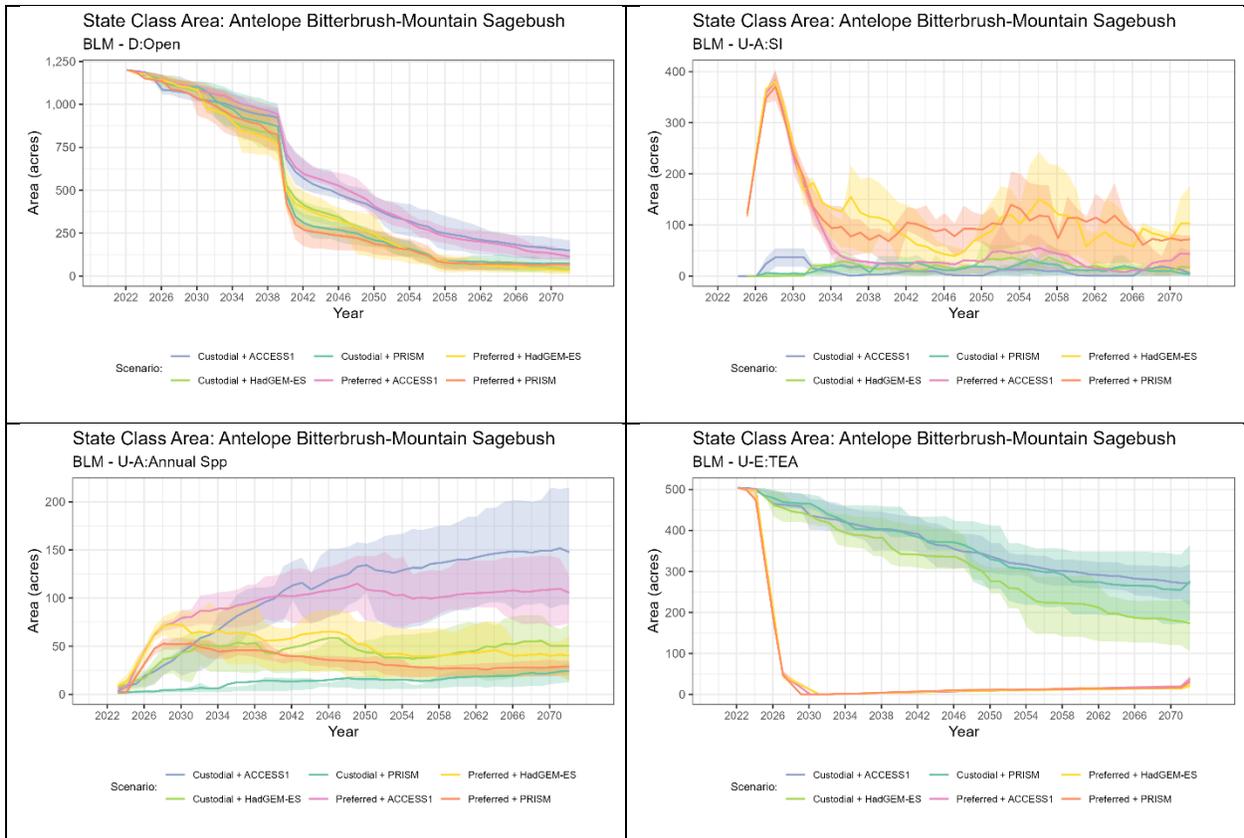
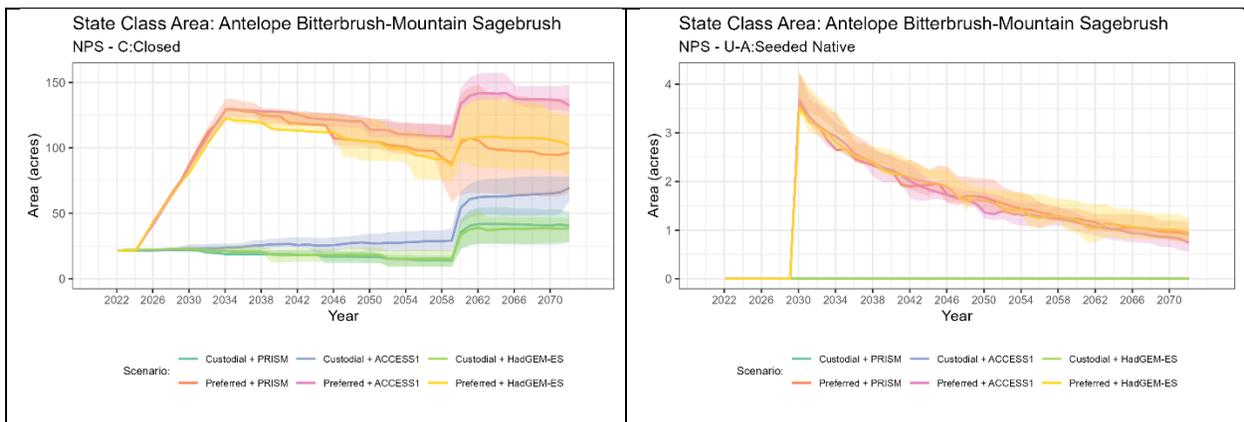


Figure 3.26. Vegetation classes of antelope bitterbrush-mountain big sagebrush on BLM-managed land treated or recruited into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.



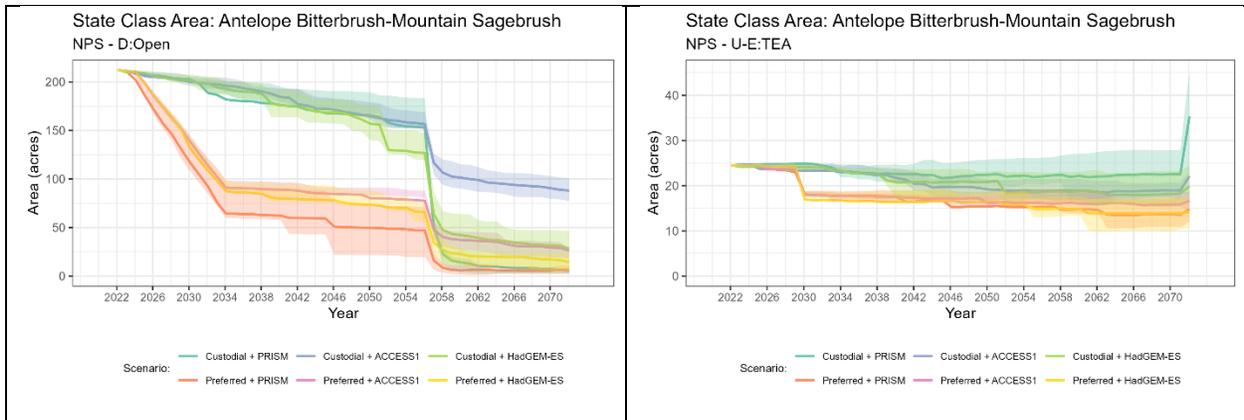


Figure 3.27. Vegetation classes of antelope bitterbrush-mountain big sagebrush on GBNP treated or recruited into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.3. Aspen Woodland

2022 System acres at 14-m resolution: 737

2022 Landscape-wide ED: 62%

Problems or Concerns

More area of aspen woodland was found in GBNP than BLM-managed land, whereas none was observed on USFS-managed or private lands (Table 3.10). Stark differences were observed between BLM and GBNP. Many of the reference and uncharacteristic classes, including depleted aspen classes, were detected in roughly comparable amounts on BLM land. The most abundant classes for GBNP were the early-successional reference class A:ALL at 164 acres, indicating resprouting after fire, and the uncharacteristic lost clone class (U-A:Lost-Aspen) at 302 acres (Table 3.10). The lost clone class was TNC's best guess at historic loss of aspen and required visual confirmation of dead aspen boles within shrublands, usually at the edge of existing aspen. Very little depleted aspen classes were observed in GBNP, further suggesting that historic management and herbivory probably caused the loss of clones a long time ago before GBNP's creation. While nothing can be done for recovery of loss clones, careful management of depleted aspen classes to prevent further clone loss on BLM lands and prescribed fire of older aspen classes could help the distribution of classes. Also, the larger abundance of young aspen in GBNP implies that the rapid growth of young aspen into older classes will eventually reestablish the distribution of classes without any additional effort from GBNP.

Table 3.10. Vegetation classes of aspen woodland expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:All	10	164			174	23.65	15
A:Char1							1
B:Closed	46	30			76	10.25	44
C:Closed	37	3			40	5.43	33
D:Open	47	18			64	8.73	7
U-A:Depleted	0				0	0.01	0

U-A:Lost-Aspen	5	302			307	41.64	0
U-B:Depleted	13				13	1.72	0
U-C:Depleted	19	0			19	2.61	0
U-D:Depleted	41	3			44	5.96	0

Objectives for Management Actions

The primary objective was to allow the recovery of the root carbohydrate reserves of depleted aspen classes with temporary fencing on BLM land (Table 3.11). *Fenced* depleted aspen classes could transition to reference classes of the matching successional age. A secondary objective was *prescribed burning* of older reference classes to recruit into younger classes or of depleted classes or wait for the transition to reference classes after a decade of fencing (Table 3.11). Prescribed fire in 2030 to 2035 would allow the maturation of current early-successional classes and create a balanced distribution of age classes. Younger classes would also provide forage for bighorn sheep.

Table 3.11. Realized treatment totals (acres) within each period in aspen woodland from 2023 to 2072.

	Fence (BLM: \$2,000/acre- \$10,000/acre)	Prescribed Burning- Aviation (BLM: \$600/acre; NPS: \$600/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres
PRISM		
BLM		

2023-2024	0	0
2025-2029	48-52	0
2030-2034	0	158-177
2035-2039	0	0
2040-2072	0	0
NPS		
2023-2024	0	0
2025-2029	0	0
2030-2034	0	23-33
2035-2039	0	0
2040-2072	0	0
ACCESS1		
BLM		
2023-2024	0	0
2025-2029	47-52	0
2030-2034	0	153-176
2035-2039	0	0
2040-2072	0	0

NPS			
2023-2024		0	0
2025-2029		0	0
2030-2034		0	23-31
2035-2039		0	0
2040-2072		0	0
HadGEM-ES			
BLM			
2023-2024		0	0
2025-2029		49-52	0
2030-2034		0	135-166
2035-2039		0	0
2040-2072		0	0
NPS			
2023-2024		0	0
2025-2029		0	0
2030-2034		0	16-25
2035-2039		0	0

2040-2072	0	0
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Fencing and prescribed burning could cause a reduction in ED if a balanced distribution of classes was achieved after maturation of the A:All class. However, classes in treated areas did not rebalance as *prescribed burning* nearly eliminated the D:Open class (see below class charts), thus causing a greater departure (Table 3.12) because 7% of the system was expected in the reference condition. Greater ED values were also found in the ACCESS1 and HadGEM-ES climates compared to the PRISM climate. By 2072, those differences were nearly gone, except in the drier ACCESS1 climate.

Table 3.12. Future ED in aspen woodland (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	51% ± 0.45%	54% ± 1.6%
2047	51% ± 0.6%	53% ± 1.5%
2072	52% ± 1.3%	51% ± 1.1%
ACCESS1		
2035	51% ± 0.3%	59% ± 2.3%
2047	51% ± 1.7%	55% ± 2.7%
2072	51% ± 2.0%	54% ± 2.6%
HADGEM-ES		
2035	53% ± 2.7%	60% ± 3.1%
2047	53% ± 3.5%	57% ± 2.8%
2072	58% ± 2.2%	58% ± 2.8%

Cost by year (ST-Sim Results)

While more aspen woodland was found in GBNP, cost was generally greater on BLM-managed land, although it did not exceed \$80,000 per year (Fig. 3.28). *Fencing* applied from 2025 to 2029 that was used to rest depleted aspen and protect young suckers, was one of the most expensive actions per unit area. *Prescribed burning ignited from a helicopter* was implemented at a higher rate on BLM-managed land than on GBNP from 2030 to 2034 (Fig. 3.28).

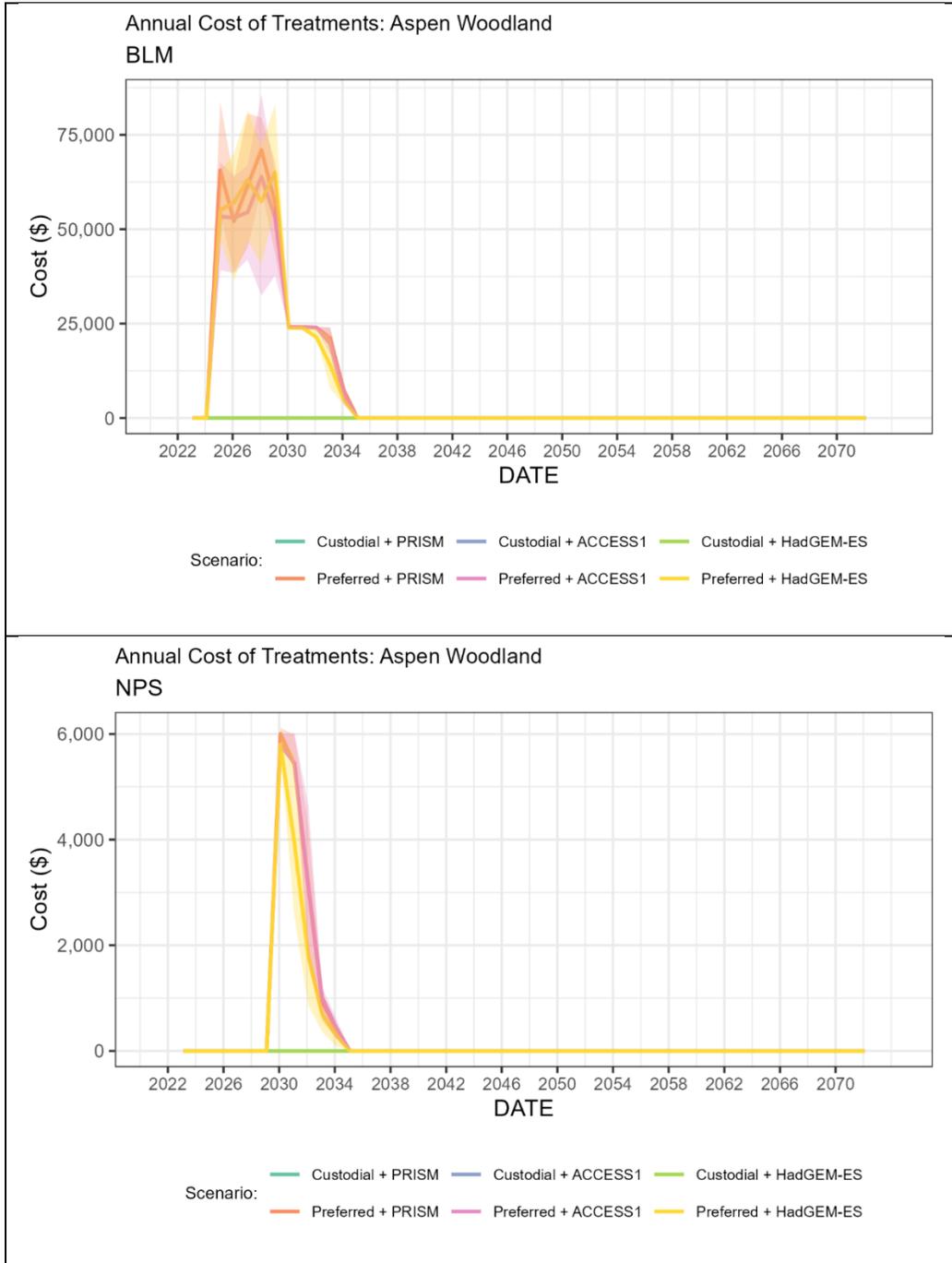


Figure 3.28. Annual cost of treatments in aspen woodland by ownership in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

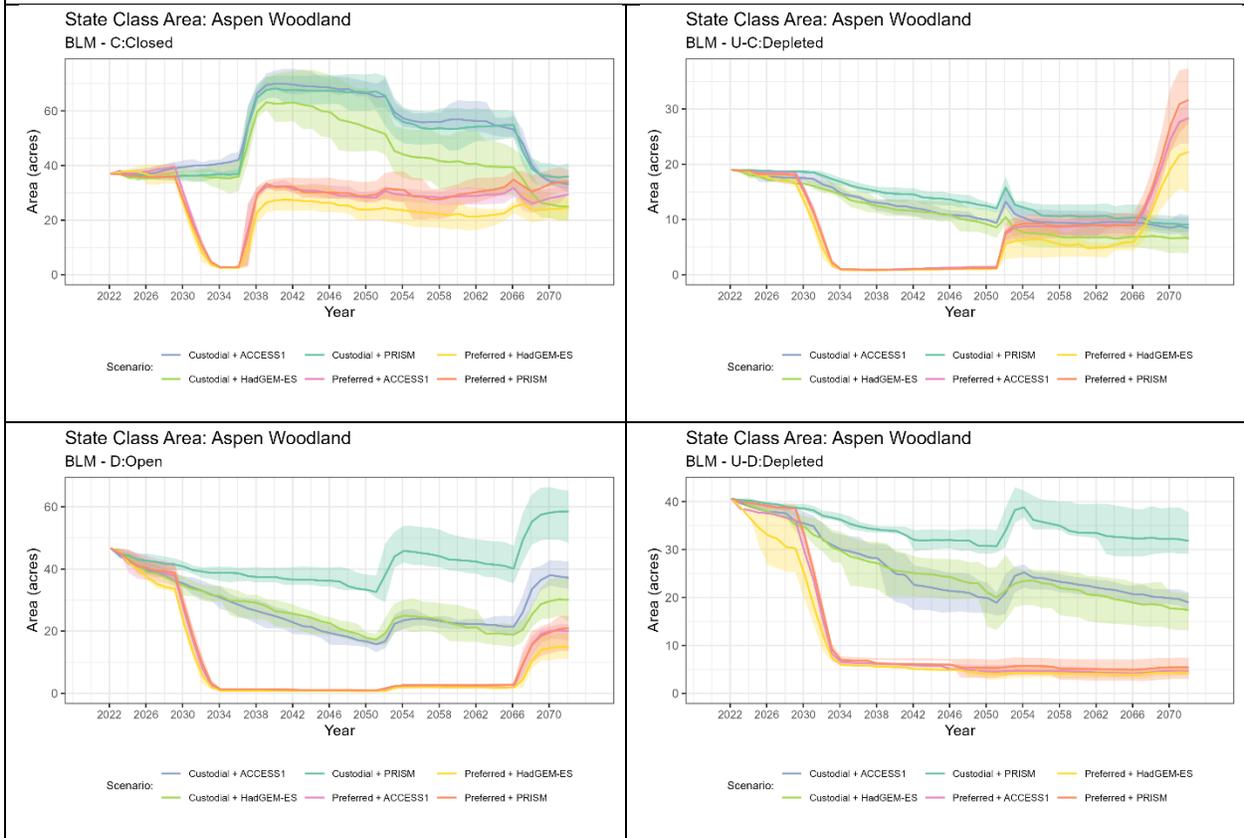
Vegetation Classes (ST-Sim Results):

Two result panels were presented for BLM-managed land because many classes were treated (Fig. 3.29A), and several others were recipient of fire transitions (Fig. 3.29B). While the effect of *fencing* was not visible as a transition from depleted to reference classes (the transition is called “natural recovery” after a decade of rest), especially implemented at low rates, the effect of *prescribed burning* was highly visible as a sudden reduction of all older reference (C:Closed and D:Open) and depleted classes (U-C:Depleted and U-D:Depleted) after 2029 compared to custodial management scenarios (Fig. 3.29A).

Direct recipient classes were the early-successional reference (A:All) and depleted (U-A:Depleted) classes that suddenly increased after 2029 (Fig. 3.29B). Furthermore, a fraction of the A:All class received *fencing* to protect suckers for about 10 years. With one to two decades, the early successional classes matured into the mid-successional classes B:Closed and U-B:Depleted (results not shown but succession caused the late-successional classes to grow; Fig. 3.29B). An interesting and unpredicted result was that treatments slightly reduced the future area of loss clones compared to the custodial scenarios (Fig. 3.29B). In the model, treatments such as *prescribed burning* and mechanical operations in depleted aspen could cause collateral loss of clones; however, *fencing* and the decadal rest prevent this collateral loss and moves areas from depleted to reference classes; therefore, *fencing* prevented permanent loss of aspen woodlands.

In GBNP, *prescribed burning* was primarily applied to the late successional reference class (D:Open) after 2029, which rapidly decreased, as the area of depleted classes was small (Fig. 3.30). The amount burned was so small that it was barely observed in the early-successional class (A:All; Fig. 3.30). The dynamics of aspen woodland were driven by the dominance of the A:All in initial conditions, such that we suggest that GBNP could reduce cost by not treating in aspen woodland as it became deficient of the D:Open class, whereas the custodial management scenario retained a desirable area of the D:Open class.

A. Treated classes



B. Recipient classes

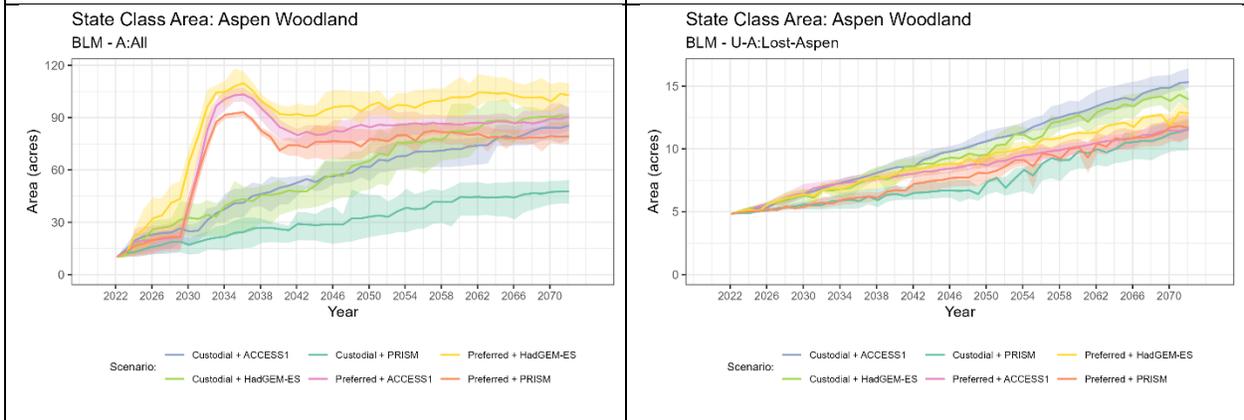
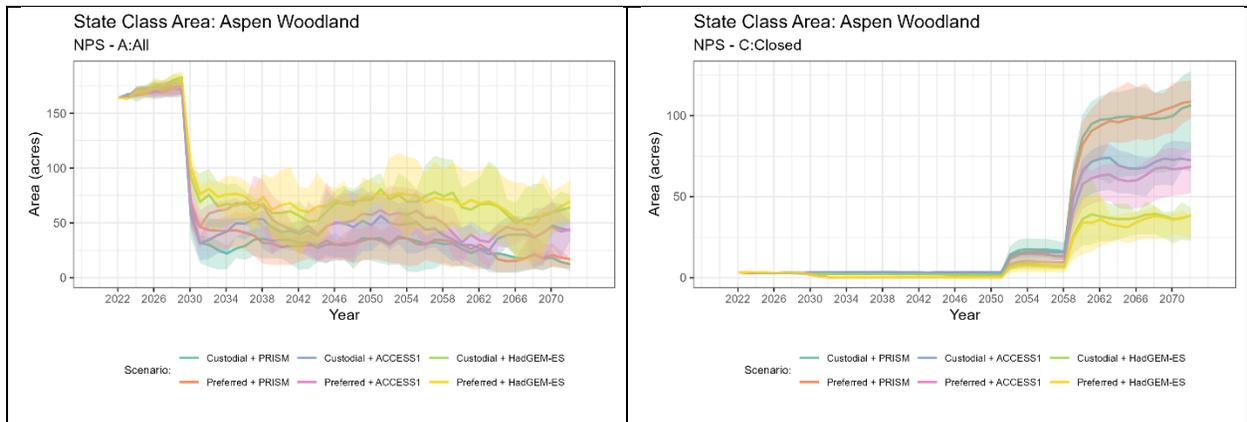




Figure 3.29. Vegetation classes of aspen woodland on BLM-managed land treated or recruited into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and proposed (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.



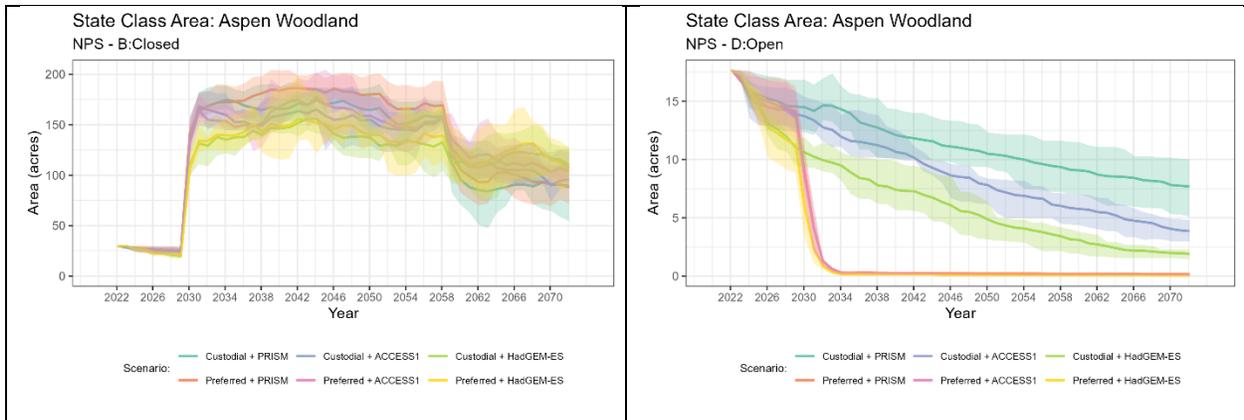


Figure 3.30. Vegetation classes of aspen woodland on GBNP treated or recruited into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.4. Aspen-Mixed Conifer

2022 System acres at 14-m resolution: 11,558

2022 Landscape-wide ED: 84%

Problems or Concerns

About five times more aspen-mixed conifer was found in GBNP than BLM-managed land, whereas only 5 acres was observed on private lands (Table 3.13). Patterns were similar between BLM and GBNP where older classes dominated by conifers were substantially more abundant than other classes (Table 3.13). The most abundant class was the late-successional class dominated by conifer (E:Closed; Table 3.13). Also common was the late-successional open class where aspen and fire-sensitive conifers co-dominate (D:Open). Other problems were a non-trivial area of depleted classes mostly located on BLM-managed lands.

Table 3.13. Vegetation classes of aspen-mixed conifer expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:All	15	53			68	0.58	15
A:Char1							1
B:Closed	53	338			391	3.33	47
C:Closed	21	677			698	5.94	31
D:Open	358	857			1,214	10.34	4
E:Closed	1,116	7,900			9,016	76.79	2
U-A:Depleted	16	1			17	0.15	0
U-A:Lost-Aspen	70	52			122	1.04	0
U-C:Depleted	55	0			55	0.47	0

U- D:Depleted	134	21	5		160	1.36	0
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Objectives for Management Actions

The primary objective was to reduce the area of older reference and depleted classes occupied by conifers and recruit into younger vegetation classes without conifers (Table 3.14). Two types of *helicopter-based prescribed burning* were used to reduce conifer encroachment: a) dropping incendiary devices into aspen with abundant and likely older mixed conifers that can easily ignite and carry fire and b) first felling conifers where they may not yet dominate aspen and use the resinous fuel on the ground to carry fire started from a helicopter. A secondary objective was *fencing* to give time for depleted aspen classes to rebuild root reserves before burning them with the goal to minimize the loss of clones (Table 3.14).

Table 3.14. Realized treatment totals (acres) within each period in aspen-mixed conifer from 2023 to 2072.

	Fence (BLM: \$2,000/acre- \$10,000/acre)	Lop and Scatter + Prescribed Burning- Aviation (BLM: \$600/acre; NPS: \$750/acre)	Prescribed Burning- Aviation (BLM: \$600/acre; NPS: \$600/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres
PRISM			
BLM			
2023-2024	0	0	0
2025-2029	48-52	121-133	0
2030-2034	0	492-505	244-252
2035-2039	0	0	0
2040-2072	0	0	0
NPS			

2023-2024	0	0	0
2025-2029	0	146-153	146-153
2030-2034	0	171-178	150-155
2035-2039	0	0	0
2040-2072	0	0	0
ACCESS1			
BLM			
2023-2024	0	0	0
2025-2029	48-52	122-128	0
2030-2034	0	487- 508	246-253
2035-2039	0	0	0
2040-2072	0	0	0
NPS			
2023-2024	0	0	0
2025-2029	0	147-154	147-155
2030-2034	0	170-178	147-155
2035-2039	0	0	0
2040-2072	0	0	0
HadGEM-ES			
BLM			
2023-2024	0	0	0
2025-2029	48-52	147-155	0
2030-2034	0	171-179	236-255
2035-2039	0	0	0
2040-2072	0	0	0
NPS			
2023-2024	0	0	0
2025-2029	0	147-152	145-153

2030-2034	0	171-178	145-153
2035-2039	0	0	0
2040-2072	0	0	0

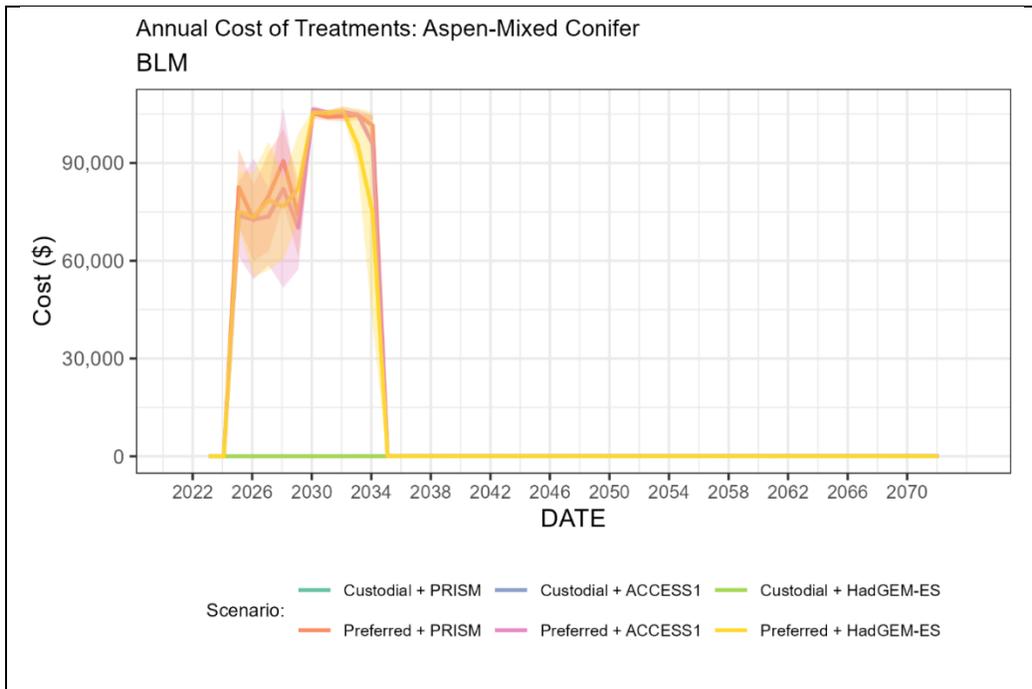
Fencing and prescribed burning caused a reduction of ED from 4-6% within reporting years compared to the custodial management for the PRISM climate; however, differences were smaller to none for the HadGEM-ES and ACCESS1 climates (Table 3.15). The 95% CI was sufficiently high to make any difference inconclusive. Especially noticeable, was the gradual decrease in ED over time in the custodial and preferred management scenarios, and the greater decrease in the HadGEM-ES and ACCESS1 climates than PRISM climate. Because the area of aspen-mixed conifer was predominantly located on GBNP, the cause of ED decrease should be observed in the class charts of GBNP.

Table 3.15. Future ED in aspen (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	65% ± 7.7%	59% ± 7.0%
2047	54% ± 7.5%	49% ± 6.8%
2072	41% ± 10.0%	37% ± 8.7%
ACCESS1		
2035	60% ± 4.7%	60% ± 4.6%
2047	44% ± 6.0%	41% ± 6.1%
2072	30% ± 6.0%	27% ± 6.0%
HADGEM-ES		
2035	58% ± 5.0%	54% ± 6.0%
2047	41% ± 6.4%	39% ± 5.6%
2072	27% ± 6.0%	30% ± 4.6%

Cost by year (ST-Sim Results)

While aspen-mixed conifer was five times more abundant in GBNP, cost was twice as large reaching about \$110,000 between 2025 and 2034 on BLM-managed land (Fig. 3.31). The cost of *fencing* on BLM-managed land applied from 2025 to 2029 was about \$20,000 cheaper from the cost of aggressive *prescribed burning ignited from a helicopter*. The \$40,000-\$45,000 cost of *prescribed burning* from 2030 to 2034 for GBNP reflected both lower rates than for BLM and the fact that the helicopter operations of BLM were cooperatively extended to GBNP (Fig. 3.31).



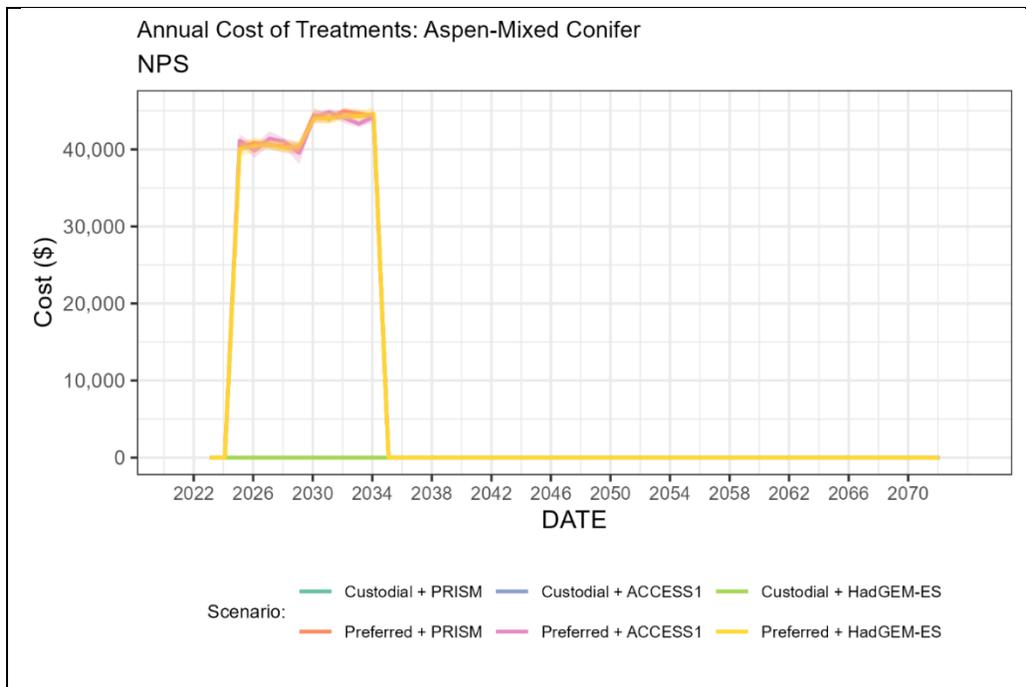


Figure 3.31. Annual cost of treatments in aspen-mixed conifer by ownership in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

Changes in area due to treatments shown in Figs. 3.32 and 3.33 were deceptive because the effect of climate scenarios were far greater than *prescribed burning*. The late-successional class dominated by conifers was decreased by 400-600 acres of BLM-managed land with *prescribed burning* in the PRISM climate, but the decreases caused by the ACCESS1 and HadGEM-ES climates were >600 acres compared to the about 100 acres of decrease due to *prescribed burning* within those latter two climates (Fig. 3.32). In GBNP, the moderate implementation rates, such as 150 acres per 5-year period, caused <300 acres of class area decrease due to *prescribed burning* compared to the >2,000 acres reduction caused by drier climates (Fig. 3.32).

ED reductions described above were greater under drier climates compared to the PRISM climate because drier climates most caused the area reduction of the late-successional class dominated by conifers (E:Closed), and increased the area of younger classes (A:All, B:Closed; Figs. 3.32 and 3.33). This counter-intuitive result happened through greater activity from stand-replacing events under the HadGem-ES climate, less in the ACCESS1 and even less in the PRISM climates. Surprisingly, greater avalanche activity, but not fire (results not shown), was the cause of greater tree mortality because the magnitude of very wet years (dominant precursor of avalanche activity) separated by drier years was substantially greater in the HadGEM-ES and ACCESS1 climates than PRISM climate. In other words, the HadGEM-ES and ACEES1 climates

showed greater precipitation variability (i.e., very wet years alternating with very dry years) than the PRISM climate.

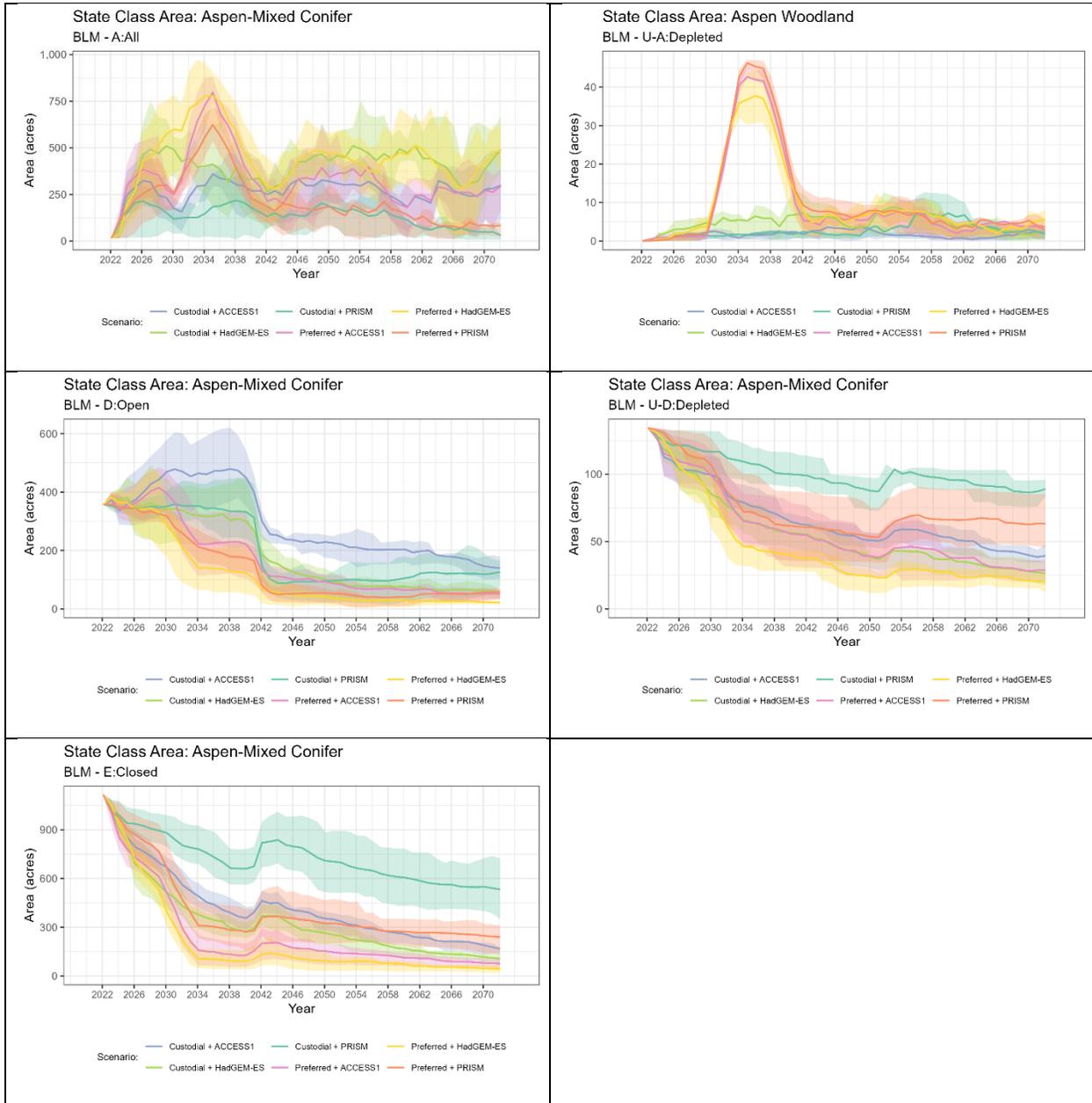


Figure 3.32. Vegetation classes of aspen-mixed conifer on BLM-managed land treated or recruited into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

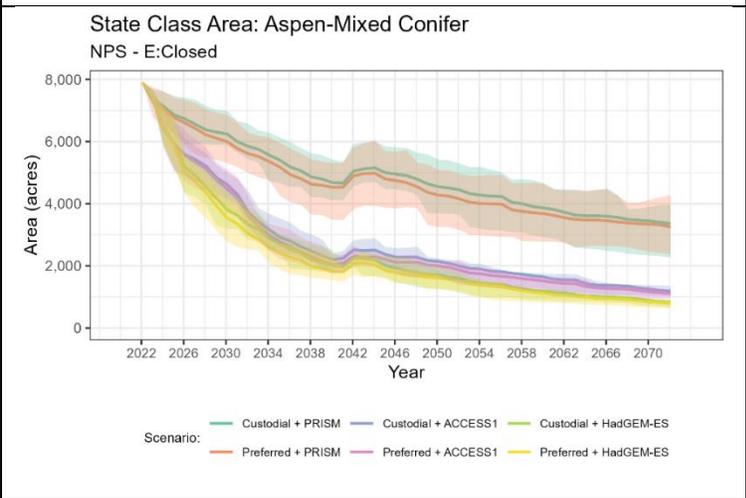
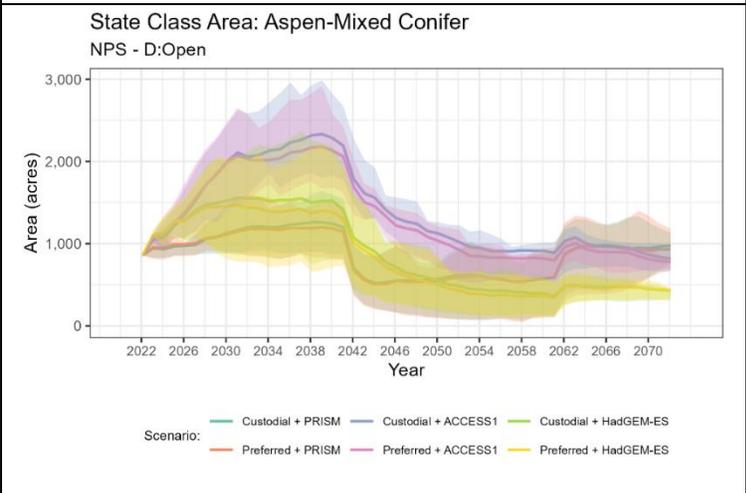
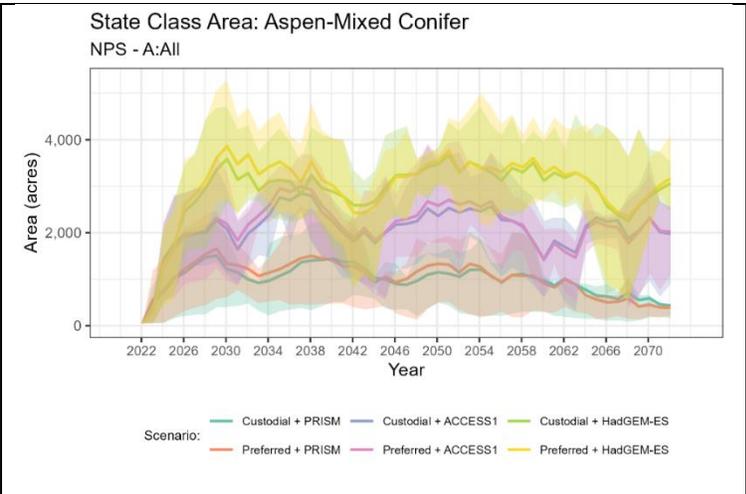


Figure 3.33. Vegetation classes of aspen-mixed conifer on GBNP treated or recruited into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.5. Aspen-Subalpine Conifer

2022 System acres at 14-m resolution: 11,058

2022 Landscape-wide ED: 36%

Problems or Concerns

There was >10,000 acres of aspen-subalpine conifer in GBNP compared to 300 acres on BLM-managed land (Table 3.16). Three times more of the reference late-successional class dominated by conifers was observed on GBNP compared to the reference condition (Table 3.16). While all reference classes were well represented, the most abundant one was the early-successional class at four times the reference condition, thus indicating past fires (Philips Ranch Fire and Strawberry Fire) caused a pulse of aspen suckering on GBNP.

Table 3.16. Vegetation classes of aspen-subalpine conifer expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							<1
A:All	8	3,800			3808	34.4	9
B:Closed	76	3,056			3132	28.3	37
C:Closed	100	2,346			2446	22.1	49
D:Open	87	1,530	1		1618	14.6	5
U-A:Depleted		17			17	0.2	0
U-A:Lost-Aspen	23	2			25	0.2	0
U-C:Depleted	6	7			13	0.1	0

Objectives for Management Actions

The primary objective was to create bighorn sheep browsing vegetation by reducing the over-represented older reference class occupied by conifers through the recruitment into younger vegetation classes without conifers (Table 3.17). A secondary objective was to reduce ED as much as possible if treatment were of sufficient size. Only *aerially-ignited prescribed burning* onto conifers could feasibly achieve the objective. This goal might be counter-intuitive given the over-abundance of the youngest vegetation class (A:All), but the abundant early-successional class lasting only 10 years in theory was about to transition to the mid-successional class that was likely caused by the Philips Ranch Fire (2000) and the Strawberry Creek Fire (2016). A greater area of *prescribed burning* was proposed for GBNP than BLM-managed lands.

Table 3.17. Realized treatment totals (acres) within each period in aspen-subalpine conifer from 2023 to 2072.

		Prescribed Burning- Aviation (BLM: \$600/acre; NPS: \$600/acre)
Years		25 th – 75 th percentiles of total treatment acres
PRISM		
BLM		
2023- 2024		0
2025- 2029		48-52
2030- 2034		0
2035- 2039		0
2040- 2072		0
NPS		
2023- 2024		0

2025-2029			396-404
2030-2034			293-301
2035-2039			0
2040-2072			0
ACCESS1			
BLM			
2023-2024			0
2025-2029			48-52
2030-2034			0
2035-2039			0
2040-2072			0
NPS			
2023-2024			0
2025-2029			394-407
2030-2034			297-305
2035-2039			0
2040-2072			0
HadGEM-ES			

BLM			
2023-2024			0
2025-2029			48-51
2030-2034			0
2035-2039			0
2040-2072			0
NPS			
2023-2024			0
2025-2029			395-405
2030-2034			297-306
2035-2039			0
2040-2072			0

The small levels of *prescribed burning* relative to the size of the system's area had no effect on ED compared to the custodial management; however, climate scenarios had a large effect on ED (Table 3.18). Only in the PRISM climate did ED get to low values of about 16%-17%, while ED remained moderately departed in the ACCESS1 and HadGEM-ES climates. The odd results were addressed below in class charts.

Table 3.18. Future ED in aspen-subalpine conifer ($\% \pm 1$ 95% Confidence Interval, $n = 10$). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED \pm 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	37% \pm 2.6%	39% \pm 2.0%
2047	41% \pm 2.6%	43% \pm 2.8%
2072	16% \pm 4.0%	17% \pm 3.9%
ACCESS1		
2035	41% \pm 1.0%	43% \pm 41.3%
2047	46% \pm 1.6%	48% \pm 1.8%
2072	37% \pm 3.7%	37% \pm 4.5%
HADGEM-ES		
2035	43% \pm 1.7%	45% \pm 2.2%
2047	47% \pm 1.6%	48% \pm 1.8%
2072	41% \pm 6.0%	41% \pm 3.2%

Cost by year (ST-Sim Results)

Ten times more annual funding (\$35,000 - \$47,000) was used for *aerially ignited prescribed burning* applied in aspen-subalpine conifer on GBNP than on BLM-managed land (Fig. 3.34). Moreover, funding was for 10 years in GBNP, but only for 5 years on BLM-managed land. No climate differences were observed (Fig. 3.34).

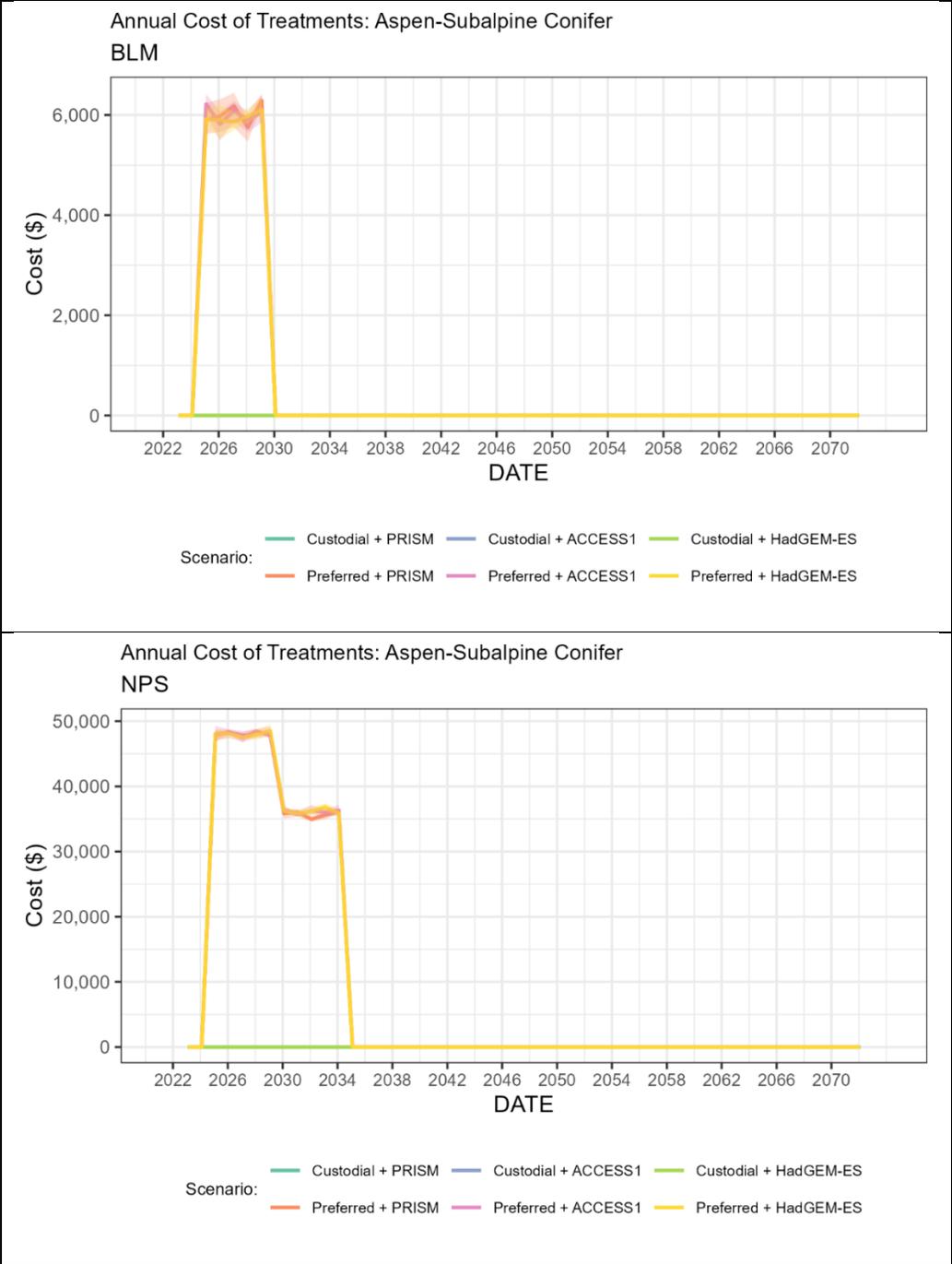


Figure 3.34. Annual cost of treatments in aspen-subalpine conifer by ownership in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

Class results of aspen-subalpine conifer were eerily like those of aspen-mixed conifer because both shared the same influence of avalanches mediated through climate. Prescribed burning contributed little to the reduction of the late-successional reference class dominated by conifers (results not shown; D:Open) compared to the effect of climates (Figs. 3.35 and 3.36). In GBNP, where nearly all the aspen-subalpine conifer was located (Fig. 3.36), *prescribed burning* accounted for about 100 acres of class reduction compared to custodial management within climates, but roughly 1,000 acres less were found in the HadGEM climate than PRISM climates (Fig. 3.36). The area of the early-succession class closely reflected the opposite pattern. Greater avalanche activity in the HadGEM-ES than ACCESS1 climates, and least in the PRISM climate explained these results also found in aspen-mixed conifer.

ED values were lower in the PRISM than other climates because the lesser avalanche activity in the PRISM climate maintained enough of the D:Open class to be close to the reference condition (Figs. 3.35 and 3.36). The reference condition of aspen-subalpine conifer favored more area of reference late successional classes than for aspen-mixed conifer.

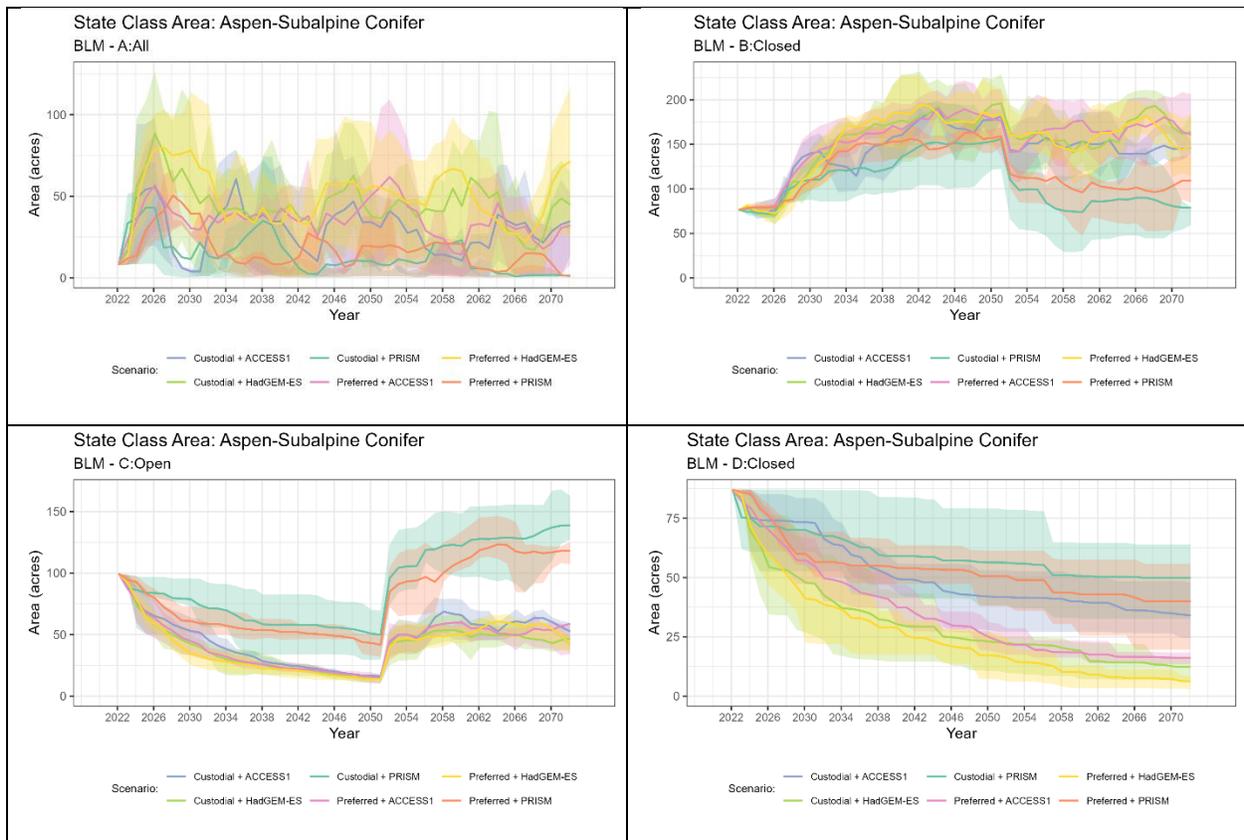


Figure 3.35. Vegetation classes of aspen-subalpine conifer on BLM-managed land treated or recruited into after treatment summed over all ownerships on the South Snake Range. Six management scenarios

were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

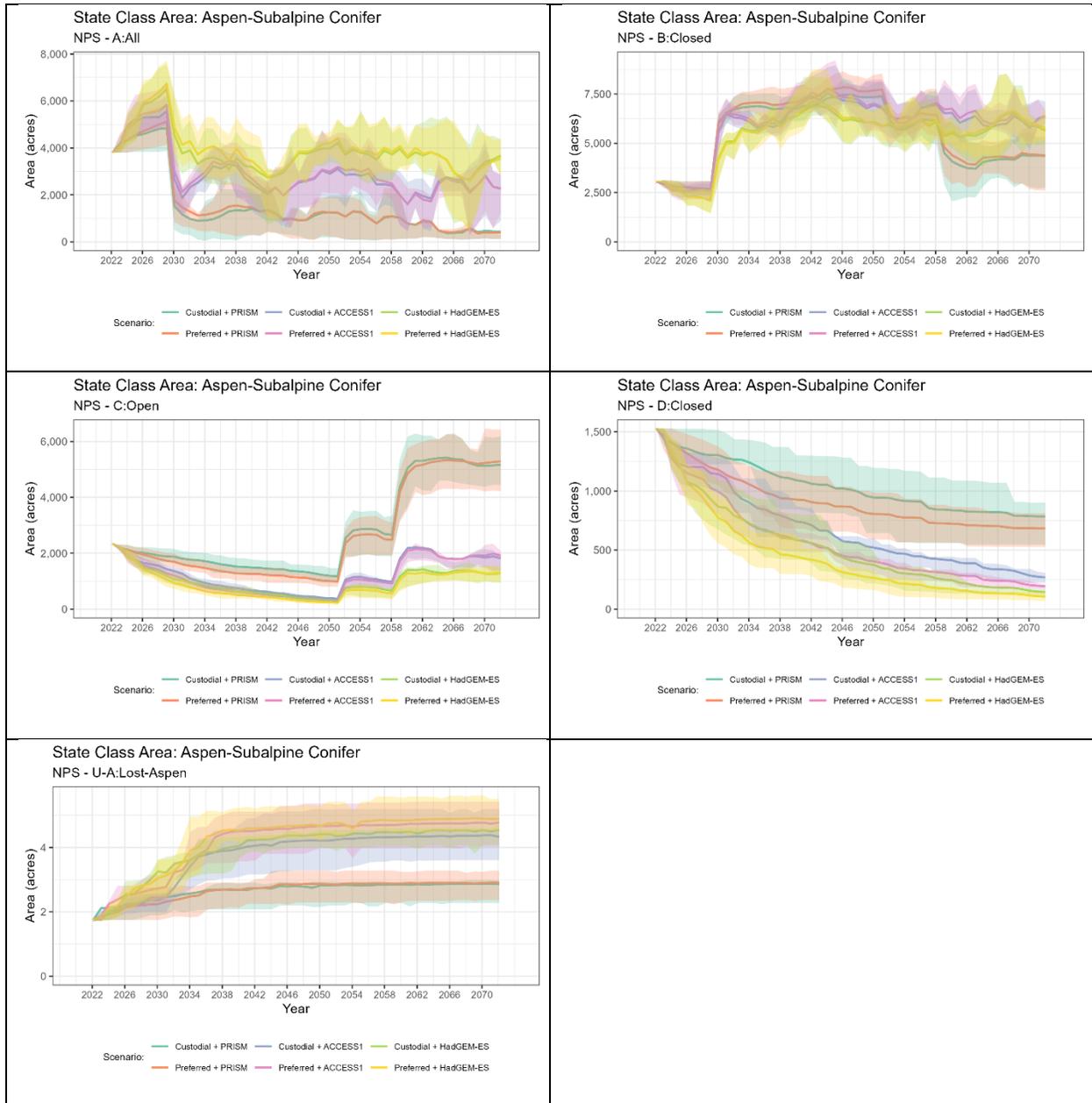


Figure 3.36. Vegetation classes of aspen-subalpine conifer on GBNP treated or recruited into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.6. Basin Wildrye

2022 System acres at 14-m resolution: 2,205

2022 Landscape-wide ED: 98%

Problems or Concerns

Basin wildrye was found in all four ownerships: 1,285 acres on BLM-managed land, 202 acres on GBNP, 691 acres on private lands, and 27 acres on USFS-managed land (Tables 3.1 and 3.19). Except for GBNP, few class areas (2.4% of total system) were in the reference condition on BLM-managed, private, and USFS-managed lands. This explained the very high ED value of 98%. Several uncharacteristic classes were problematic on BLM-managed land and GBNP (uncharacteristic classes on private and USFS-managed lands not discussed). The most extensive class requiring management was the late successional shrub-dominated class with mixed non-native annual species and perennial species (U-C:SAP) at 718 acres on BLM-managed land and only 9 acres on GBNP (Table 3.19). Depleted basin wildrye dominated by pure basin big sagebrush or a mix of sagebrush and rabbitbrush and lacking an herbaceous understory (U-C:Depleted) was the second most extensive class on BLM-managed land and GBNP, respectively, at 333 acres and 56 acres. The most extensive class on GBNP was tree-encroached basin wildrye (U-C:TEA) at 79 acres and was the target of restoration since 2010. The U-C:TEA class was the fourth most extensive on BLM-managed land at 75 acres. The non-native annual species class (U-A:Annual Spp) occupied 88 acres of BLM-managed land, but was absent from GBNP.

Table 3.19. Vegetation classes of basin wildrye expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1					3		3
A:All		3			3	0.1	21
B:Closed	4	9			13	0.6	67
C:Open	5	32	0	0	37	1.7	9
U-A:Annual Spp	88		94		182	8.2	0

U-A:Bare Ground	0		3		3	0.1	0
U-A:Early-Shrub	47	13	84		144	6.5	0
U-A:Exotic Forb	2		20		22	1.0	0
U-A:SAP	5	2	10		17	0.8	0
U-A:SI	8		59		67	3.0	0
U-A:SI+AS	1			1	2	0.1	0
U-C:Depleted	333	56	126	3	518	23.5	0
U-C:SAP	718	9	246	22	995	45.1	0
U-C:TEA	75	79	48		203	9.2	0

Objectives for Management Actions

Three objectives applied to basin wildrye designed to recruit into the reference mid-successional class (B:Closed): a) cut conifers that encroach the grassland (U-C:TEA), b) reduce the area of uncharacteristic classes dominated by shrubs (U-C:Depleted and U-C:SAP), and c) control non-native noxious forbs. Five treatments were used, although the spraying of well-established patches of exotic species followed by native species seeding was rarely used and not further discussed (Table 3.20). Restoration of the non-native annual species class (U-A:Annual Spp) was not proposed by BLM. Conifers were cut and biomass treated with two treatments: a) chainsaw felling followed by chipping and seeding of native species on GBNP only (*Chainsaw+Chip+Herbicide+Native-Seed*) and b) chainsaw felling following by pile burning and mixed introduced and native species seeding only on BLM-managed land (*Chainsaw+Pile - Burning+Seed*). Shrubs dominating in uncharacteristic classes were mechanically thinned with a mower followed by herbicide spraying of non-native annual species and seeding native species on both BLM-managed land and GBNP (Table 3.20). The only exotic species control was *weed surveys combined with spraying of exotic forb species occurrences on location*.

Table 3.20. Realized treatment totals (acres) within each period in basin wildrye from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Chainsaw+Chip+Herbicide+Native-Seed (NPS: \$650/acre)	Chainsaw+Pile-Burning+Seed	Exotic-Control+Native-Seed (BLM: \$400/acre;	Thin+Herbicide+Native-Seed (BLM: \$350/acre;	Weed-Inventory+Spot-Treat (BLM: \$115/acre;
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		(BLM: \$637/acre)	NPS: \$400/acre)	NPS: \$350/acre)	NPS: \$115/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentile s of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentile s of total treatment acres
PRISM					
BLM					
2023-2024	0	0	0	0	0
2025-2029	0	0	0	0	48-51
2030-2034	0	43-52	0	297-305	48-52
2035-2039	0	0	0	0	0
2040-2072	0	0	0	0	0
NPS					
2023-2024	0	0	0	0	0
2025-2029	0	0	0	0	49-52
2030-2034	36-42	0	0	47-51	48-52
2035-2039	0	0	<1	0	0
2040-2072	0	0	0	0	0

ACCES S1						
BLM						
2023- 2024	0	0	0	0	0	
2025- 2029	0	0	0	0	0	48-52
2030- 2034	0	49-54	0	0	294-303	49-52
2035- 2039	0	0	0	0	0	0
2040- 2072	0	0	0	0	0	0
NPS						
2023- 2024	0	0	0	0	0	0
2025- 2029	0	0	0	0	0	48-51
2030- 2034	39-42	0	0	0	48-52	49-52
2035- 2039	0	0	0	0	0	0
2040- 2072	0	0	0	0	0	0
HadGE M-ES						
BLM						
2023- 2024	0	0	0	0	0	0
2025- 2029	0	0	0	0	0	47-51
2030- 2034	0	48-53	0	0	294-304	48-52

2035-2039	0	0	0	0	0
2040-2072	0	0	0	0	0
NPS					
2023-2024	0	0	0	0	0
2025-2029	0	0	0	0	49-53
2030-2034	40-42	0	0	46-52	48-52
2035-2039	0	0	0	0	0
2040-2072	0	0	0	0	0

Proposed treatments and a measurable, but small effects on the highly departed and future ED compared to the custodial management (Table 3.21). Climate scenarios showed no discernable effects on ED.

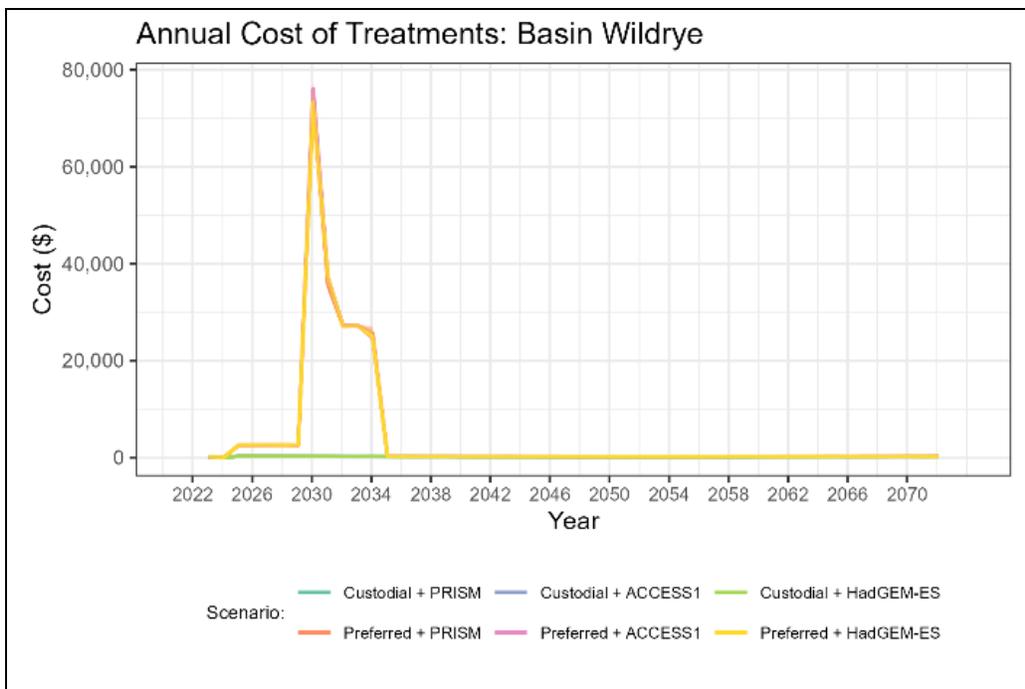
Table 3.21. Future ED in basin wildrye (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
PRISM	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
2035	98% ± <0.2%	95% ± 0.3%
2047	98% ± 0.3%	94% ± 0.3%
2072	98% ± <0.1%	94% ± 0.3%
ACCESS1		

2035	98% ± <0.1%	94% ± 0.4%
2047	98% ± <0.1%	94% ± 0.3%
2072	98% ± <0.1%	93% ± 0.2%
HADGEM-ES		
2035	98% ± <0.1%	94% ± 0.4%
2047	98% ± <0.1%	94% ± 0.4%
2072	99% ± <0.1%	93% ± 0.3%

Cost by year (ST-Sim Results)

Cost started and peaked in 2030 and ended in 2034. Three times more annual funding was spent on BLM-managed land (\$75,000) than GBNP (\$20,000; Fig. 3.37). No climate differences were observed (Fig. 3.37).



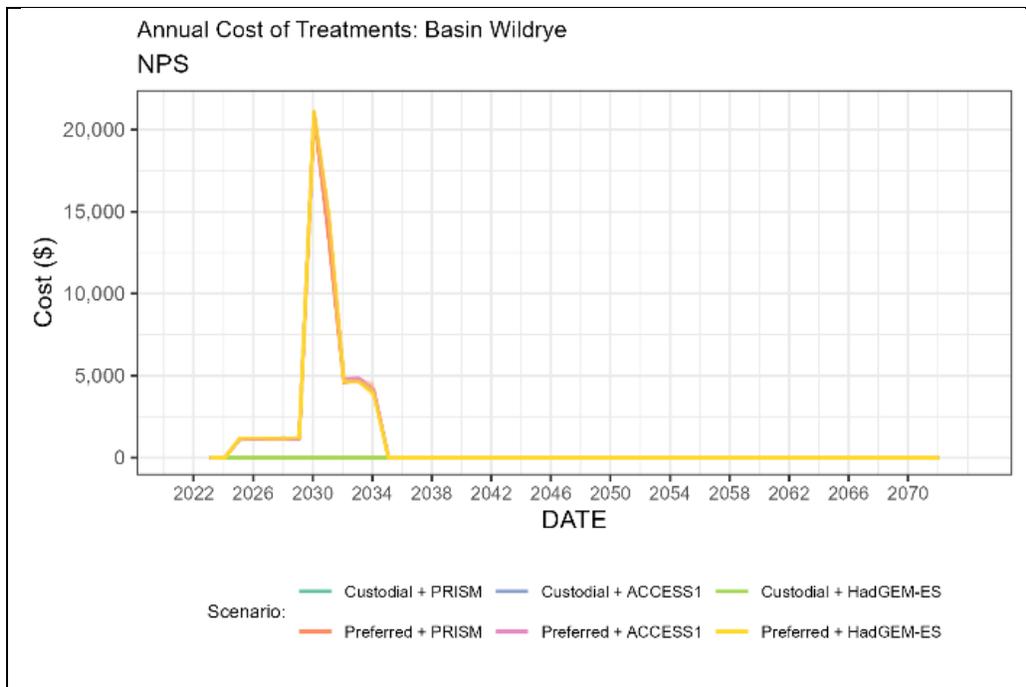


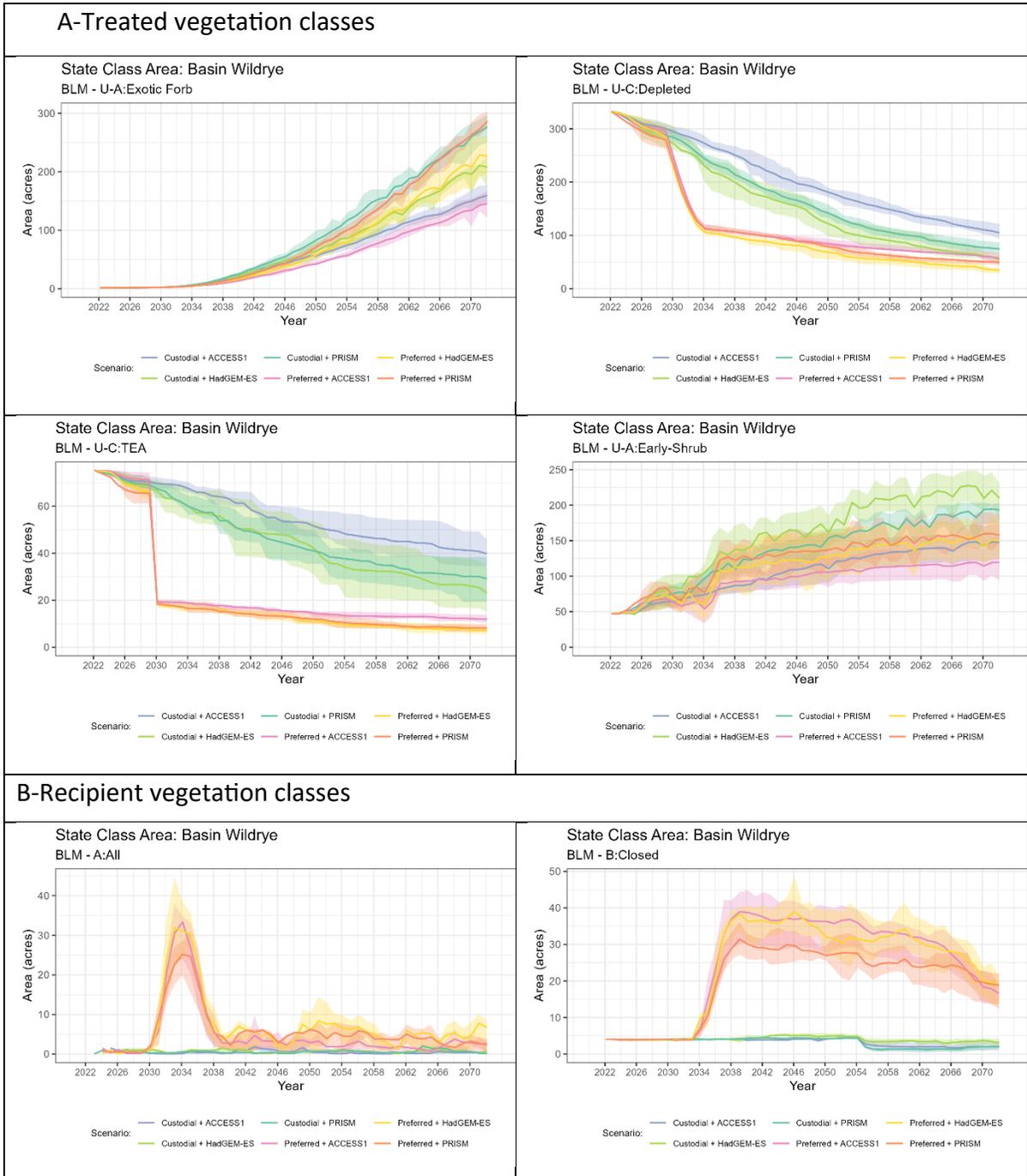
Figure 3.37. Annual cost of treatments in basin wildrye by ownership in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

Mechanical treatments and class area decreases started in 2030 for BLM-managed land for treated classes (Fig. 3.38A). The areas of the tree-encroached class (U-C:TEA) and depleted class (U-C:Depleted) rapidly decreased, respectively, by about 40 acres and 175 acres compared to custodial management (Fig. 3.38A). Preventive and minor active control of exotic forb species resulted in at most 10 acres of reduction compared to custodial management; however, climate differences accounted for about 100 acres of difference between the ACCESS1 (exotic invasion increased during wetter 12-month years) and PRISM climate (wetter climate; Fig. 3.38A). It is noteworthy that the exotic forb invasion rate modeled was aggressive; therefore, the trend for the area occupied by exotic noxious species was upwards over time.

Several classes were the recipient of management actions either as successes or failures on BLM-managed land (Fig. 3.38B). *Chainsaw+Pile-Burning+Seed* applied to the tree-encroached class (U-C:TEA) resulted in an about 40 acres increase of mixed introduced and native species seeding class (U-A:SI). The two mechanical treatments with native species seeding caused an about 90-acre increase of the native seeding class (U-A:Seeded-Native), which after 5 years of natural recovery transitioned by 35 acres at most in one year to the reference early successional class (A:All; Fig. 3.38B). Both succession in the A:All class and further natural recovery and succession in the U-A:Seeded-Native class caused the increase of the mid-

successional class (B:Closed) by 40 acres (Fig. 3.38B). The increase of A:All and B:Closed both are the reason for ED decreasing by 4-8% in absolute value.



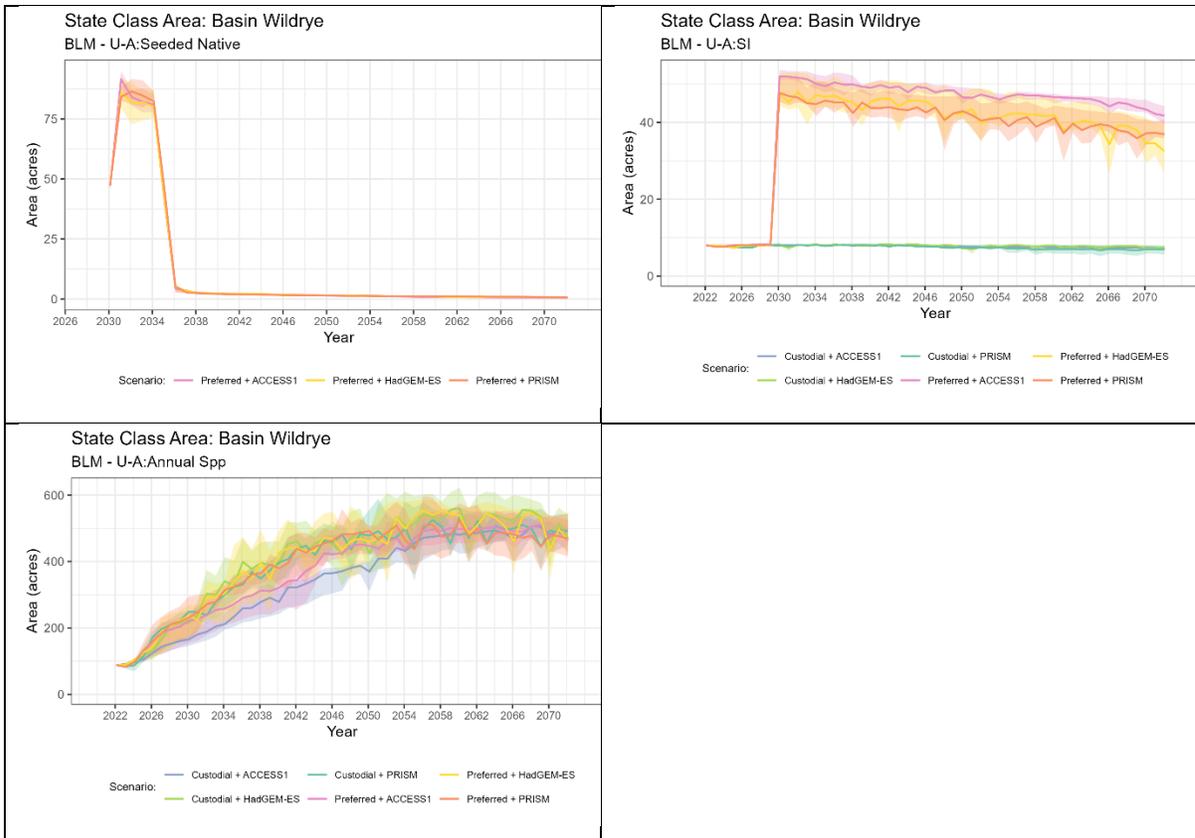
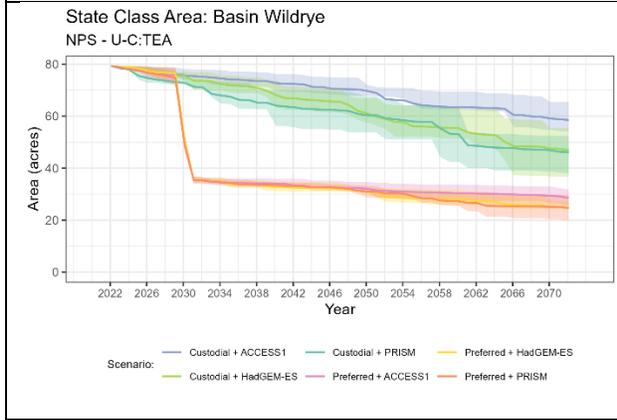
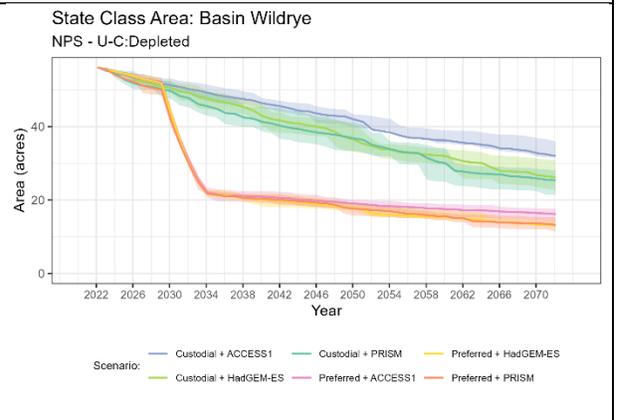
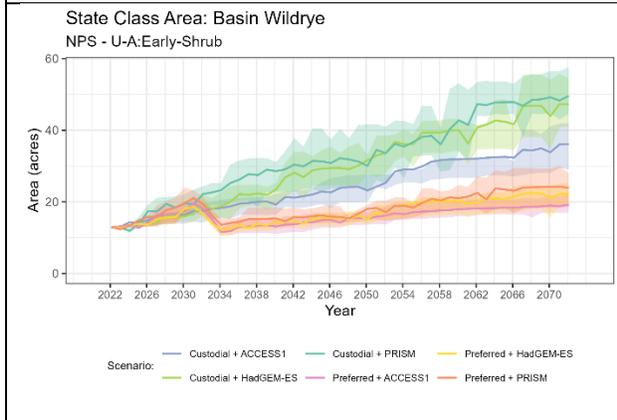
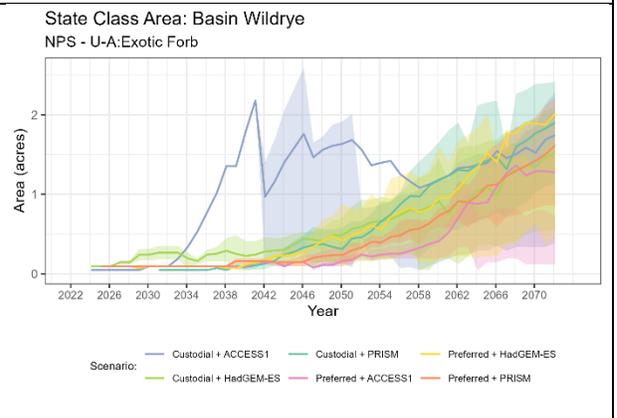
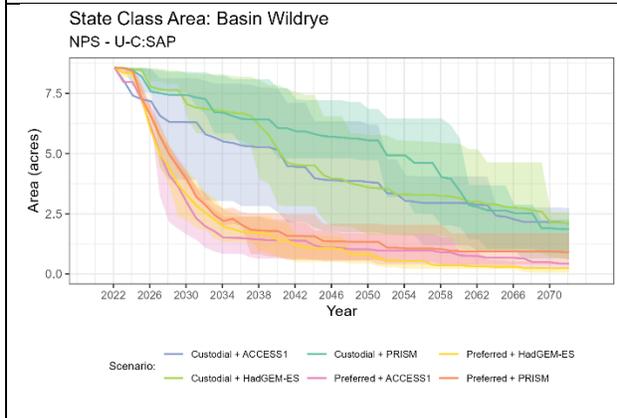


Figure 3.38. Vegetation classes of basin wildrye on BLM-managed land treated (A) or recruited (B) into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

In GBNP, all mechanical treatments, which used only native species seeding, caused the reduction of the tree-encroached class (U-C:TEA) by about 20 acres, the U-C:Depleted class (U-C:Depleted) by about 25 acres, and a tiny 6 acres of U-C:SAP (Fig. 3.39A). *Exotic noxious species tracking and spot-treatment in uninvaded classes* resulted in about 1 acre decrease of the invaded classes (U-A:Exotic-Forb) entirely through prevention (Fig. 3.39A). As expected, the area of the native seeding class (U-A:Seeded-Native) increased by about 40 acres compared to custodial management, which was explained above for BLM-managed land, eventually caused the increase of the A:All and B:Closed classes through natural recovery and succession (Fig.3.39B). Reduction the U-TEA and U-C:Depleted classes had collateral effects by later reducing the area of the early-shrub class.

A-Treated vegetation classes



B-Recipient vegetation classes

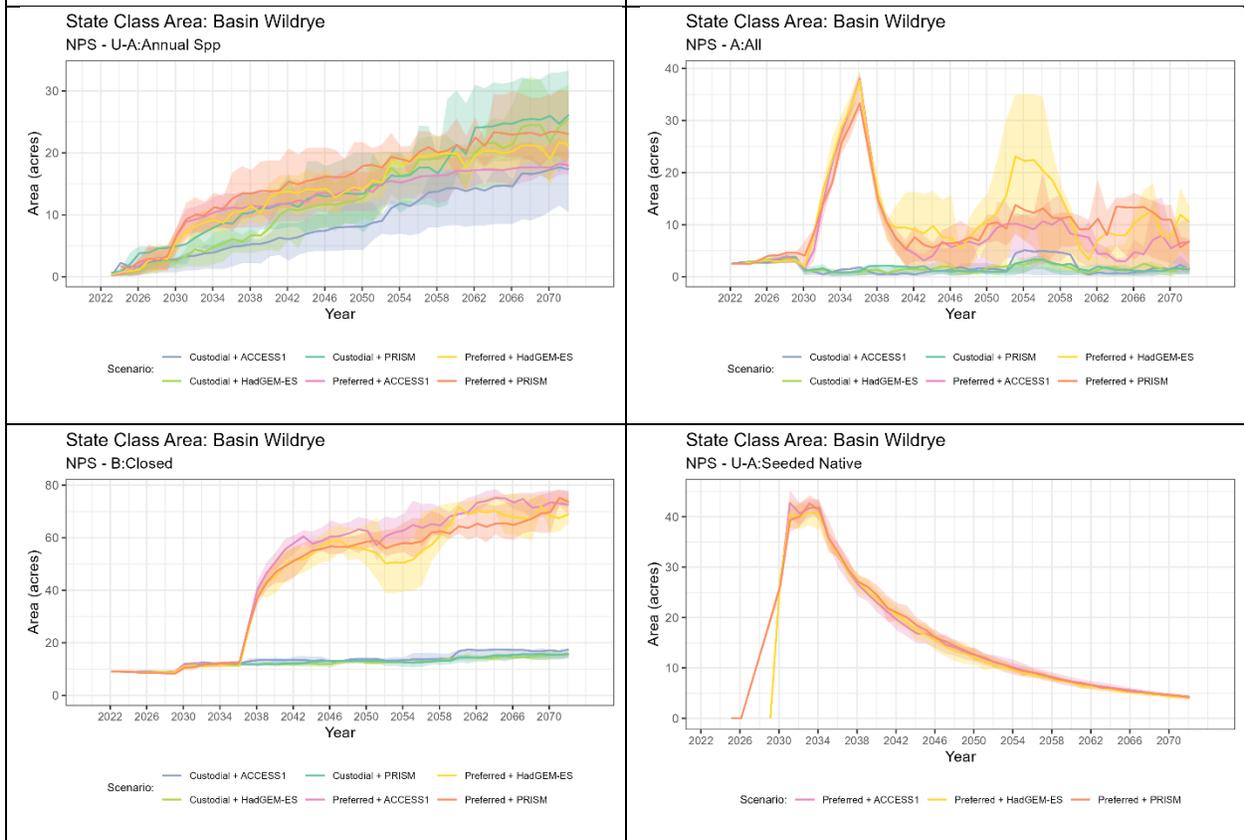


Figure 3.39. Vegetation classes of basin wildrye on GBNP treated (A) or recruited (B) into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.7. Black Sagebrush

2022 System acres at 14-m resolution: 116,802

2022 Landscape-wide ED: 69%

Problems or Concerns

Black sagebrush was mostly found on BLM-managed lands (109,612 acres) although also mapped in the three other ownerships (GBNP: 2,050 acres, private: 1,524 acres, and USF: 3,616 acres; Tables 3.1 and 3.22). Many reference and uncharacteristic classes were well represented. Among the reference classes, the areas of mid-successional open (B:Open), late-successional closed-canopy shrubland (C:Closed), late-successional wooded classes (D:Open), respectively, were 20,079 acres (18%), 4,016 acres (3.4%), and 16,173 acres (13.8%; Table 3.22). The presence of the under-represented B:Open and C:Closed classes alone caused the reduction of ED to the observed 69%, although this still was high departure. The under-representation of A:All, B:Open, and C:Closed classes was a problem that required treatment of the over-represented wooded D:Open class and many uncharacteristic classes on primarily BLM-managed lands.

Not all uncharacteristic classes could be recommended for treatment or viewed as a problem. For example, the mid-successional shrublands class occupied by non-native annual and native perennial species (U-B:SAP) was the most dominant of all classes at 27% of the system’s area (30,075 acres; Table 3.22). This vegetation retains enough native species and benefits wildlife as-is that managers will not view it as problem given limited resources. That was not the case of vegetation dominated by non-native annual species (U-A:Annual Spp) covering about 8% of total system area on BLM-managed land, but non-existent on GBNP (Table 3.22). This class is a major source of future and frequent fires, and an abundant source of non-native propagules and with no collateral benefits. Other abundant problem classes either lacking an herbaceous understory (U-C:Depleted at 7,326 acres), invaded by non-naive species below the shrub canopy (U-C:SA at 2,878 acres and U-C:SAP at 6,005 acres), or encroached by conifers and invaded by non-native annuals (U-D:SA at 11,326 acres and U-D:SAP at 3,980 acres) required management attention because wildfire could turn them into new non-native annual grasslands. The challenges in black sagebrush on BLM-managed lands were sizable.

Table 3.22. Vegetation classes of black sagebrush expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a.,
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							NRV) % of Total
A:Animal Mound							2
A:Char1							1
A:Char2							1
A:All	21			3	24	0.0	19
B:Open	19,123	341	102	1,413	20979	18.0	50
C:Closed	3,975	4	21	15	4016	3.4	18
D:Open	13,903	1,683	240	347	16173	13.8	3
E:Closed							7
U-A:Annual Spp	9,202		184	14	9399	8.0	0
U-A:Bare Ground	56		3		59	0.1	0
U-A:Early-Shrub	281		4	1	285	0.2	0
U-A:Exotic Forb	29		1		30	0.0	0
U-A:SAP	902	1	65	4	972	0.8	0
U-A:SI+AS	48		0		49	0.0	0
U-B:SAP	30,075	1	415	1,011	31502	27.0	0
U-B:SI	21				21	0.0	0
U-B:SI+AS	374			2	375	0.3	0
U-C:Depleted	7,326	1	83	230	7641	6.5	0
U-C:SA	2,879	0	20	10	2909	2.5	0
U-C:SAP	6,005		171	402	6577	5.6	0
U-C:SI	27		5		32	0.0	0
U-C:SI+AS	6				6	0.0	0
U-D:SA	11,364	10	100	52	11526	9.9	0
U-D:SAP	3,986	9	110	113	4218	3.6	0

U-D:SI	9		1	11	0.0	0
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Objectives for Management Actions

The ultimate objective was to recruit into the reference early (A:All), mid (B:Open), and late successional classes (C:Closed) to reduce ED; however, that was not often possible in black sagebrush as some of its lower elevations and drier soils might not be conducive to successful seeding with native species. Alternatively, the success rate of introduced species was proposed to be between 50%-70% by workshop experts and used. Only seeding native species can eventually cause expansion of reference classes. The two actions below with native seed or that preserved the native seed understory were *Masticate+Native-Seed* and *small tree lopping*, respectively (Table 3.23). The secondary objective was to reduce the area of the reference wooded late-successional class (D:Open) to 3% of the system’s area with *small tree lopping*. *Masticate+Native-Seed* was also applied to the growing U-E:TEA class to recruit into the U-A:Seeded-Native class; however, area was small during the period of implementation.

The action *Masticate+Seed* and *small tree lopping* were used in uncharacteristic late-successional classes with either young trees (U-D:Depleted and U-D:SAP) or heavy tree-encroachment (U-E:TEA). Removal of conifers with a *masticator and seeding with introduced species* would cause a transition to the U-A:SI class if successful, but to U-A:SI+AS (seeding invaded by non-native annual species) and U-A:Annual species if less successful. When *small tree lopping* was used, it simply returned the class to the previous succession class without trees without changing the fate of the understory composition (i.e., U-C:Depleted and U-C:SAP). While this action delayed future tree encroachment, the key result was to make the recipient vegetation classes available to be treated with *Mow+Seed* (i.e., mowing shrubs and seeding introduced species). *Mow+Seed* created introduced species seedings (U-A:SI).

Seeding perennial herbaceous and shrub species into vegetation dominated by non-native annual species (U-A:Annual Spp) was an important objective to prevent future frequent fires and reestablish wildlife foraging and livestock grazing areas. This action created introduced species seedings (U-A:SI), which also belonged to an uncharacteristic class. This objective was accomplished with the action *Herbicide+Plateau+Seed* (Table 3.23).

Overall, actions in black sagebrush were implemented at some of the largest rates ranging over 5 to 15 years and only on BLM-managed land.

Table 3.23. Realized treatment totals (acres) within each period in black sagebrush from 2023 to 20 72. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Herbicide-Plateau+Seed	Masticate+Native-Seed	Masticate+Seed	Mow+Seed	Small-Tree Lopping
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	(BLM: \$237/acre)	(BLM: \$577/acre)	(BLM: \$577/acre)	(BLM: \$170/acre-\$185/acre)	(BLM: \$65/acre-\$95/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres
PRISM					
BLM					
2023-2024	0	0	0	0	0
2025-2029	992-1,008	492-508	731-381	0	1,985-2,012
2030-2034	1,470-1503	0	0	992-1,011	1,988-2,015
2035-2039	495-507	0	0	494-507	0
2040-2072	0	0	0	0	0
NPS					
2023-2024	0	0	0	0	0
2025-2029	0	0	0	0	0
2030-2034	0	0	0	0	0
2035-2039	0	0	0	0	0

2040-2072	0	0	0	0	0
ACCE SS1					
BLM					
2023-2024	0	0	0	0	0
2025-2029	982-1,011	495-506	367-377	0	1,983-2,011
2030-2034	1,174-1,504	0	0	991-1,015	1,985-2,012
2035-2039	494-503	0	0	495-506	0
2040-2072	0	0	0	0	0
NPS					
2023-2024	0	0	0	0	0
2025-2029	0	0	0	0	0
2030-2034	0	0	0	0	0
2035-2039	0	0	0	0	0
2040-2072	0	0	0	0	0
HadG EM- ES					
BLM					
2023-2024	0	0	0	0	0

2025-2029	933-1,004	492-505	371-382	0	0
2030-2034	1430-1,506	0	0	994-1,009	0
2035-2039	496-507	0	0	494-506	0
2040-2072	0	0	0	0	0
NPS					
2023-2024	0	0	0	0	0
2025-2029	0	0	0	0	1,997-2,022
2030-2034	0	0	0	0	1,992-2,012
2035-2039	0	0	0	0	0
2040-2072	0	0	0	0	0

Proposed treatments had a measurable but small effect on the highly departed and future ED compared to the custodial management (Table 3.24). Because the treatment with native seed was the least used and for the shortest period, it became swamped by large areas of introduced species seeding (U-A:SI); thus, a very large proportion of uncharacteristic classes were replaced by more desirable, but still uncharacteristic classes. Climate scenarios showed no discernable effect on ED.

Table 3.24. Future ED in black sagebrush (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
PRISM	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
2035	98% ± <0.2%	95% ± 0.3%

2047	98% ± 0.3%	94% ± 0.3%
2072	98% ± <0.1%	94% ± 0.3%
ACCESS1		
2035	98% ± <0.1%	94% ± 0.4%
2047	98% ± <0.1%	94% ± 0.3%
2072	98% ± <0.1%	93% ± 0.2%
HADGEM-ES		
2035	98% ± <0.1%	94% ± 0.4%
2047	98% ± <0.1%	94% ± 0.4%
2072	99% ± <0.1%	93% ± 0.3%

Cost by year (ST-Sim Results)

Annual cost of about \$190,000 started to be incurred in 2025 until 2029 and only for BLM-managed land (Fig. 3.40). The cost dropped to about \$150,000 from 2030 to 2034, and dropped again to about \$50,000 from 2035 to 2039 (Fig. 3.40).

No appreciable climate differences were observed (Fig. 3.40).

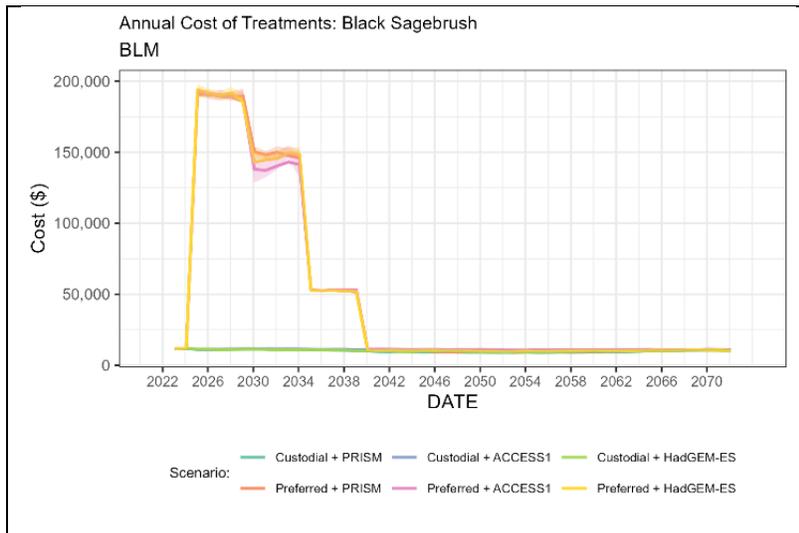


Figure 3.40. Annual cost of treatments in black sagebrush by ownership in the South Snake Range. Cost was only incurred on BLM-managed land. Cost only applied to the preferred management combined

with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

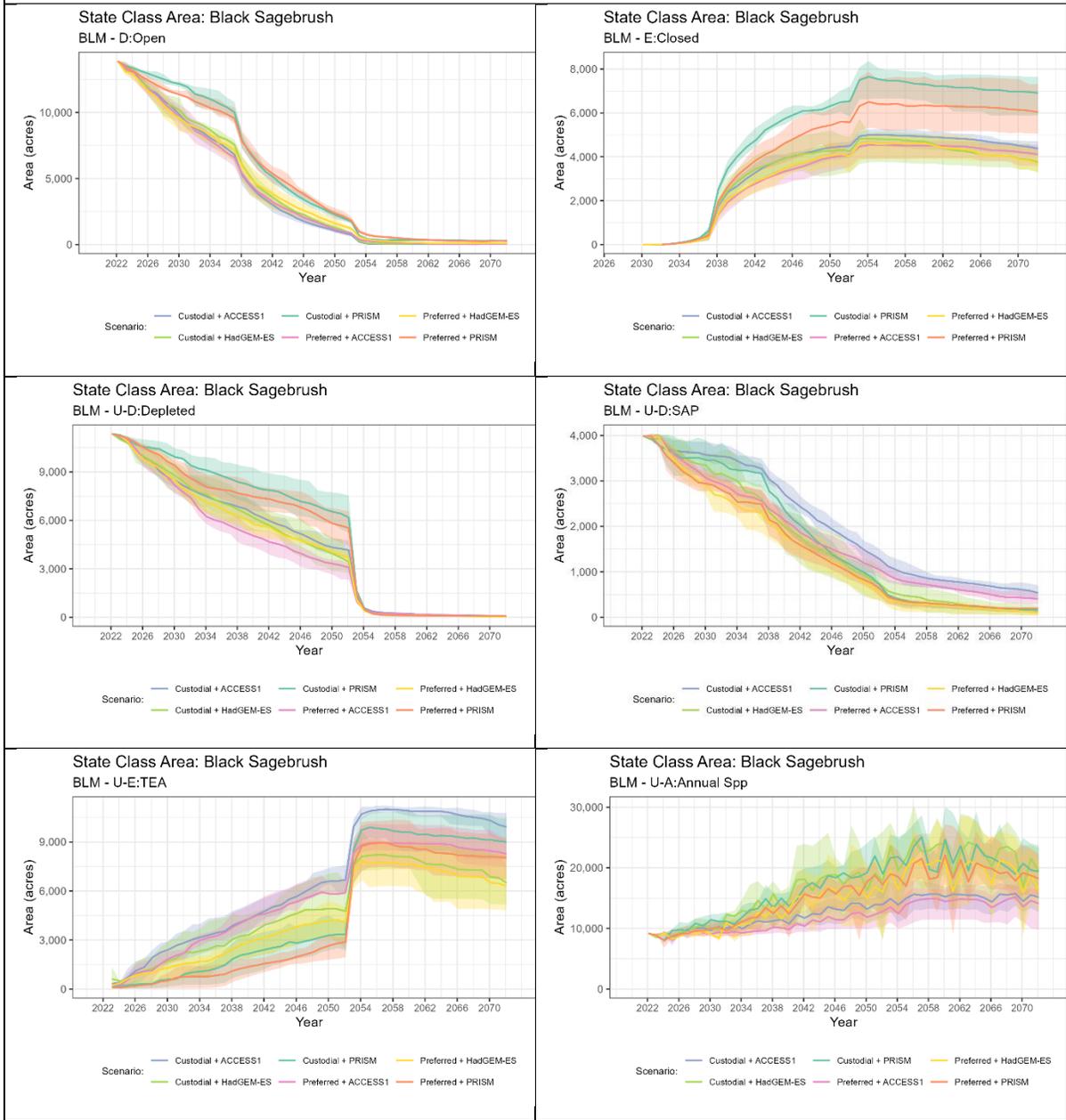
A general pattern observed in all woody-reduction treatment classes, which was hard to see below in charts with percentiles, was that various mechanical actions caused a 500-1,000-acre annual reduction of treated class area in preferred compared to custodial management scenarios, but climate scenarios reductions ranged from 1,000-3,000-acre lower in ACCESS1 compared to PRISM (Fig. 3.41A). The HadGEM-ES results were often similar to those of the PRISM climate. When fine fuels from non-native annual species were not part of a class (U-D:Depleted), the ACCESS1 and HadGEM-ES completely overlapped; therefore, shorter fire-return intervals in classes with non-native annual fuels strongly suggested that differential fire frequency combined with less fine fuel production in the drier ACCESS1 explained the results, which were strong. Therefore, woody reduction treatments were successful.

Seeding in the non-native annual species dominated shrublands (U-A:Annual Spp) also showed the same magnitude of area reduction due to the treatment (500-1,000 acres) but the climate pattern was maintained with the drier ACCESS1 regardless of management (Fig. 3.41A). The least area of U-A:Annual Spp was in the ACCESS1 climate because less fire was achieved in that climate (Fig. 3.41A). The PRISM and HadGEM-ES climate results completely overlapped.

Another interesting pattern of late-successional open-canopy classes was the downward trend in area in all scenarios and commensurate increase of area of late-successional closed-canopy classes due entirely to succession (E:Closed and U-E:TEA; Fig. 3.41A). It was noticeable that drier climates scenarios (ACCESS1 and HadGEM-ES) recruited more trees in E:Closed and U-E:TEA because lower fire activity was present with those climate scenarios than the PRISM climate.

The areas of recipient classes were a direct reflection of what happened to the treated class (Fig. 3.41B). Only the native species seeding showed differences during the period of implementation among climates within the preferred management scenarios because the U-E:TEA class contained more area to treat in the ACCESS1, less in the HadGEM-ES, and least in the PRISM climates (Figs. 3.41A and 3.41B). Also, years after the period of implementation the drier ACCESS1 climate with less fire appreciably preserved more woody vegetation than moister PRISM and HadGEM-ES climates in management scenarios because of less fire activity in drier climates (Fig. 3.41B).

A-Treated vegetation classes



B-Recipient vegetation classes

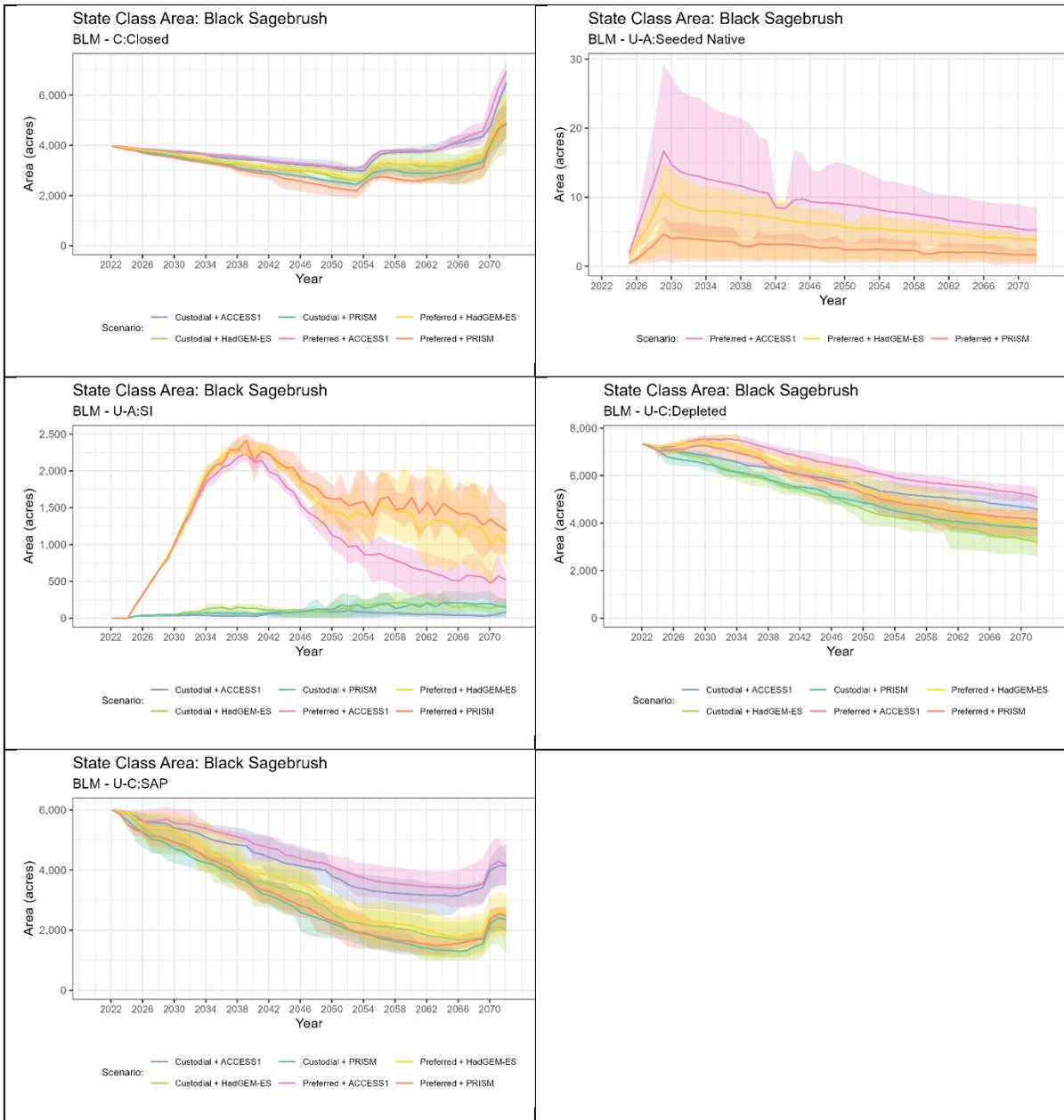


Figure 3.41. Vegetation classes of black sagebrush on BLM-managed land treated (A) or recruited (B) into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.8. Dry Wet Meadow

2022 System acres at 14-m resolution: 362 acres

2022 Landscape-wide ED: 53%

Problems or Concerns

Dry wet meadow was found in all ownerships, but least on USFS-managed land (BLM: 205.5, GBNP: 35.6 acres, private: 120.5 acres, and USFS: 0.7 acres; Table 3.25). About 93% of the entire dry wet meadow should be in the mid-successional closed-canopy class (B:Closed) but only 45% of the area was in the class (Table 3.25). The dominant uncharacteristic class was the late-successional class dominated by various unpalatable shrubs and forbs (U:C-Shrb-Frb-Encr); however, this class was primarily on BLM-managed land. Differences among ownerships were substantial as GBNP was nearly at reference condition whereas BLM-managed land was co-dominated by the reference mid-successional closed class (B:Closed) and the uncharacteristic U-C:Shrb-Frb-Encr class. GBNP contained 3 acres of U-C:Shrb-Frb-Encr. Three acres of vegetation with noxious exotic forbs (U-A:Exotic-Forb) were found on BLM-managed land but none on GBNP.

Table 3.25. Vegetation classes of dry wet meadow expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							<0.1
A:All	1		1		2	0.6	3
B:Closed	89	27	45	1	162	44.8	93
C:Open	4	2			6	1.7	4
U-A:Annual Spp	0		4		4	1.2	0
U-A:Bare Ground	1	0			1	0.3	0
U-A:Early-Shrub	2				2	0.5	0
U-A:Exotic Forb	3		7		10	2.7	0
U-A:SAP	1		1		2	0.6	0

U-A:SI	0				0	0.1	0
U-B:SAP	1	3	0		4	1.2	0
U-C:Shrb-Frb Encr	90	3	61	0	154	42.5	0
U-C:TEA	13		0		13	3.7	0

Objectives for Management Actions

For GBNP, maintenance actions into the future were recommended to keep the B:Closed class dominant either using occasional *prescribed burning* to keep the area of woody vegetation classes nearly absent or stopping new invasions by noxious plant species by *periodically visiting meadows and spot treating invading noxious plants* (Table 3.26). For BLM, the same maintenance actions applied but the additional intervention was to *spray existing exotic forbs in established patches* (Table 3.26), preferably with greater effort in the 2025-2029 period to prevent propagules from spreading from existing invasions.

Table 3.26. Realized treatment totals (acres) within each period in dry wet meadow from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Exotic Control (BLM: \$200/acre)	Prescribed Burning – Ground Ignition (BLM: \$250/acre; NPS: \$1,134/acre)	Weed Inventory + Spot Treatment (BLM: \$115/acre; NPS: \$115/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres
PRISM			
BLM			
2023-2024	0	0	0

2025-2029	2.5-2.8	48-51	48-53
2030-2034	<0.1-0.3	0	49-52
2035-2039	0.5-1.1	23-26	48-52
2040-2072	0	0	0
NPS			
2023-2024	0	0	0
2025-2029	0	21-22	19-21
2030-2034	0	14-16	19-21
2035-2039	0	7-9	38-41
2040-2072	0	0	0
ACCE SS1			
BLM			
2023-2024	0	0	0
2025-2029	2.5-2.7	49-52	48-52
2030-2034	<0.1-0.4	0	48-53
2035-2039	0.3-1.0	24-26	47-51
2040-2072	0	0	0
NPS			

2023-2024	0	0	0
2025-2029	0	2-22	18-22
2030-2034	0	13-15	19-22
2035-2039	0	7-13	39-41
2040-2072	0	0	0
HadGEM-ES			
BLM			
2023-2024	0	0	0
2025-2029	2.5-2.8	48-51	48-53
2030-2034	0-0.1	0	49-52
2035-2039	0.4-0.9	24-26	49-52
2040-2072	0	0	0
NPS			
2023-2024	0	0	0
2025-2029	0	21-22	19-21

2030-2034	0	14-16	19-21
2035-2039	0	6-10	38-42
2040-2072	0	0	0

From 2022 to 2035, ED was forecasted to increase from moderate (55%) to high departure (Table 3.27) due to the aggressive modeled exotic forb invasion rate. Treatments caused a measurable small decrease of landscape-wide ED during the first two periods but no differences in ED were observed in the last period, which was not treated, compared to the custodial management (Table 3.27). Also, ED increased over time as exotic noxious weeds were forecasted to increase, especially during wetter years (model assumption). During the last period when no treatments were implemented, ED was about 5% lower in the HadGEM-ES scenario than others.

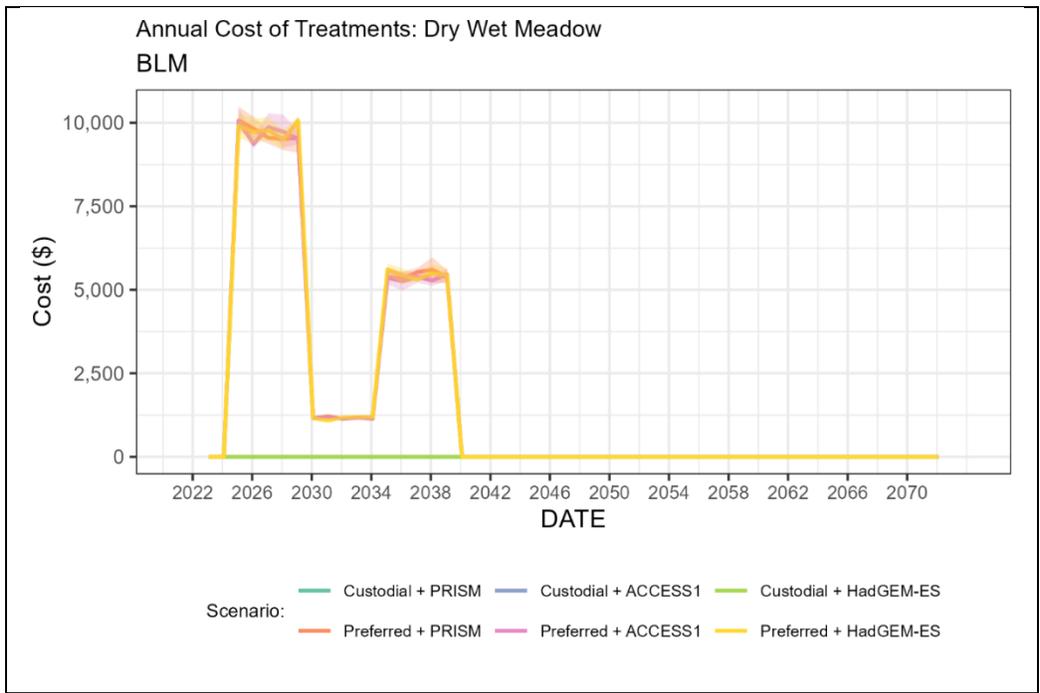
Table 3.27. Future ED of dry wet meadow (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	77% ± 2.9%	75% ± 3.2%
2047	86% ± 2.9%	85% ± 2.6%
2072	90% ± 1.2%	89% ± 1.9%
ACCESS1		
2035	79% ± 2.9%	78% ± 2.2%
2047	87% ± 2.8%	86% ± 2.3%
2072	90% ± 2.0%	90% ± 1.7%
HADGEM-ES		
2035	78% ± 2.8%	75% ± 3.0%

2047	84% ± 3.0%	84% ± 2.9%
2072	85% ± 2.9%	85% ± 3.0%

Cost by year (ST-Sim Results)

The annual cost for GBNP ranged between \$6,000 and \$3,000, then dropped to zero after 2035 (Fig. 3.42). From 2025-2029 on BLM-managed land, cost was just below \$10,000, dropped to \$1,200 from 2030 to 2034 when *ground ignited prescribed burning* was not used, and rebounded to about \$5,000 in 2035 when *prescribed burning* was added to weed management treatments. No appreciable climate differences were observed (Fig. 3.42).



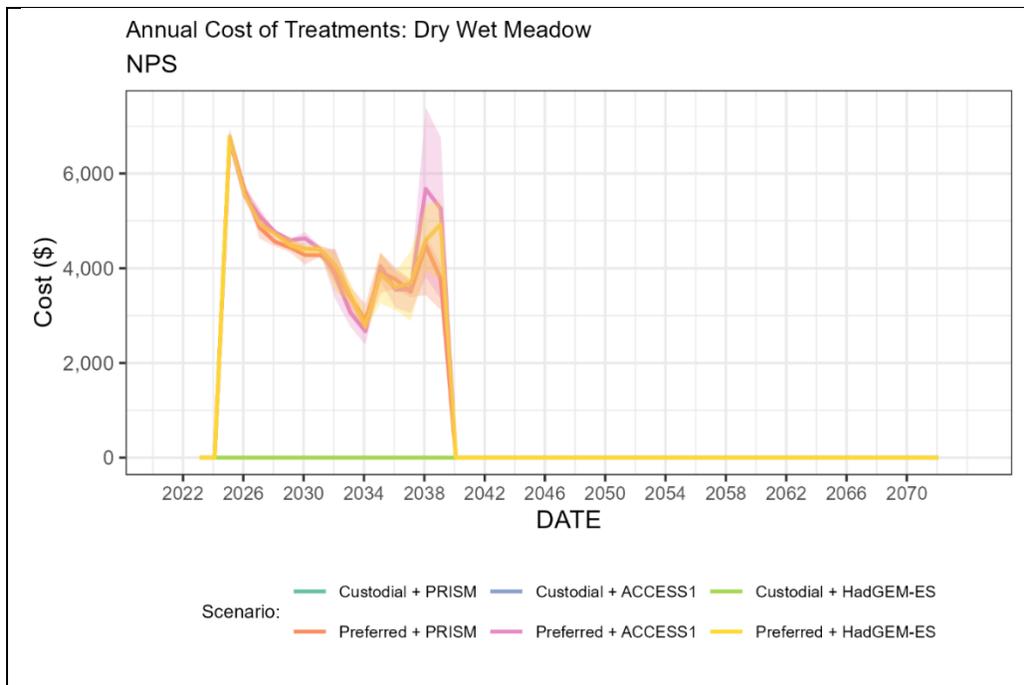


Figure 3.42. Annual cost of treatments in dry wet meadow by ownership in the South Snake Range. Cost was only incurred on BLM-managed land. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

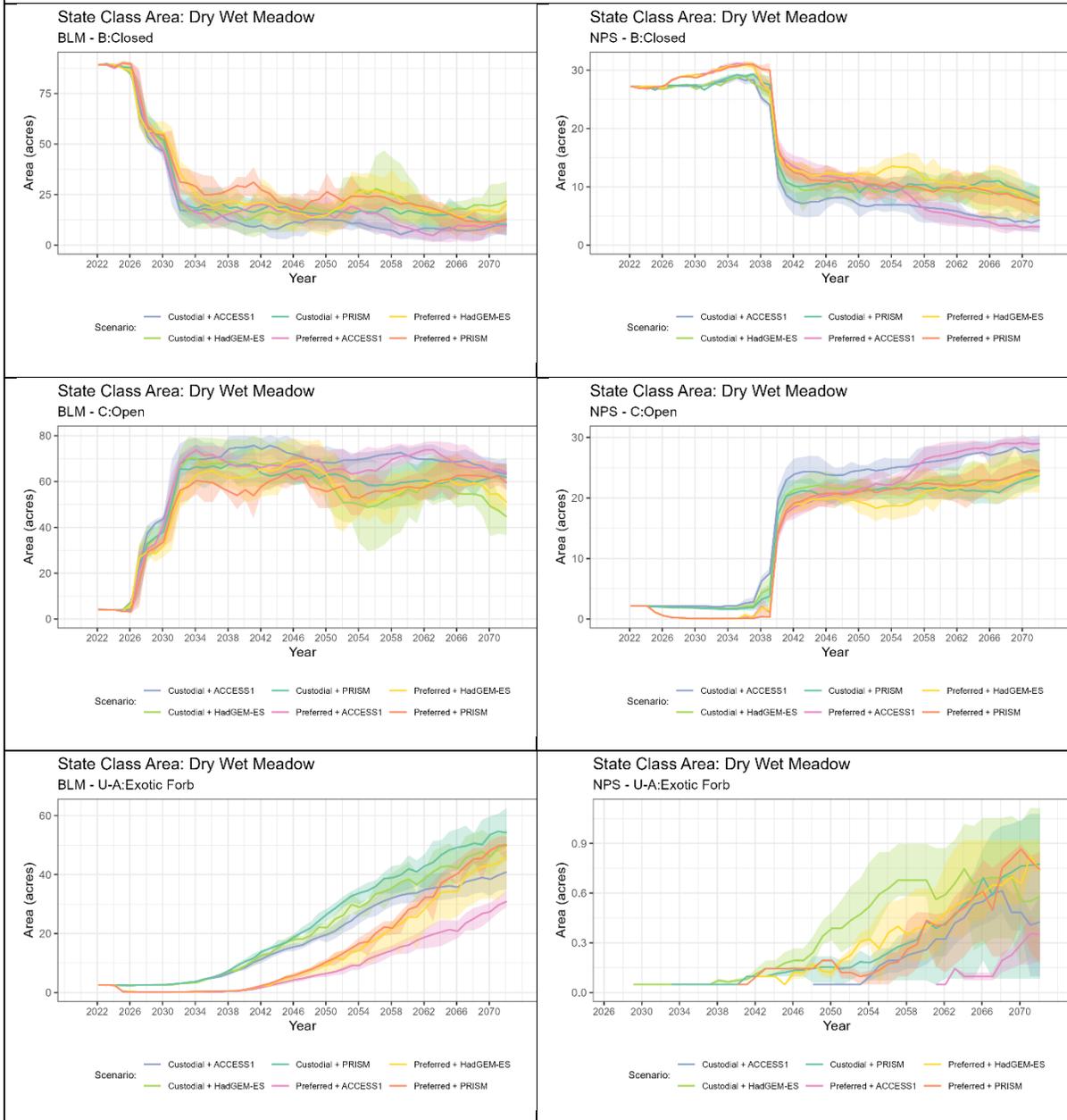
Vegetation Classes (ST-Sim Results):

Treatments in the exotic forb class (U-A:Exotic-Forb) and in the shrubby late-successional classes (C:Closed and U-C:Shrb-Frb-Encr) increased the reference mid-successional closed canopy class (B:Closed) by about 5-10 acres after 2029 in BLM-managed land, but differences were minuscule in GBNP because the B:Open was already dominant (Fig. 3.41). On BLM-managed land where exotic forbs were mapped, *exotic control* reduced the U-A:Exotic-Forb class by as much as 15 acres compared to custodial scenarios after 2042, although invasion increased over time in all scenarios due to the aggressive rate in the model (Fig. 3.43).

Prescribed burning mostly reduced the reference late-succession class (C:Open) by 10-15 acres compared to custodial management scenarios (Fig. 3.43). Both *exotic control* and *prescribed burning* caused the increase of the B:Closed class.

Succession caused the B:Closed class to substantially transition to the reference late-successional open class (C:Open) starting in 2025, which contained scattered woody shrubs (Fig. 3.43). We are convinced the successional transition was an error because we used the incorrect succession term to make succession dependent on at least one year of severe drought before allowing succession; therefore, succession from B to C was erroneously unimpeded. This mistake caused dry wet meadows to be more departed than they should have been. We did not make this mistake for wetter wet meadows.

A-Treated vegetation classes



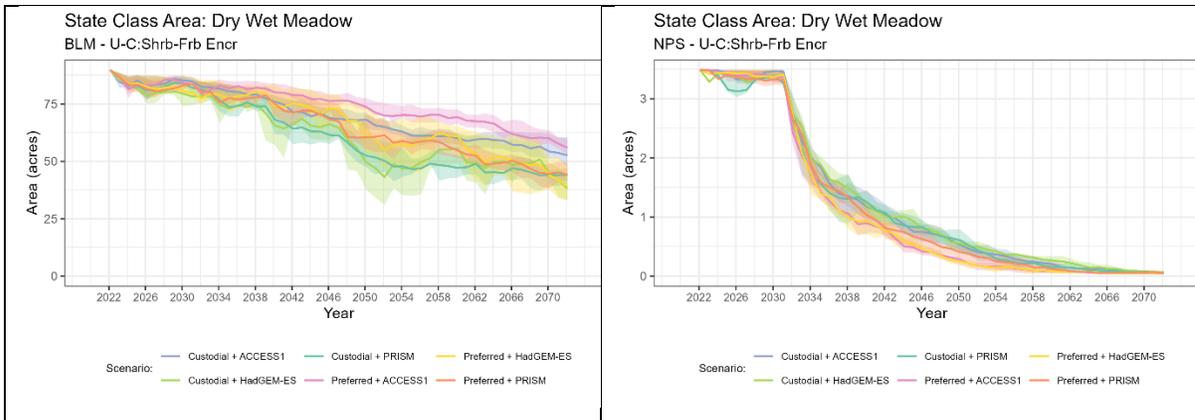


Figure 3.43. Vegetation classes of dry wet meadow on BLM-managed land treated (A) or recruited (B) into after treatment summed over all ownerships on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.9. Limber-Bristlecone Pine-mesic

2022 System acres at 14-m resolution: 5,638

2022 Landscape-wide ED: 18%

Problems or Concerns

Limber-bristlecone pine-mesic was more abundant on GBNP (3,057 acres), less on BLM-managed land (2,522 acres), least on private lands (60 acres), and absent on USFS-managed land. This system lumped in its name the two subalpine species, but bristlecone pine was overwhelmingly dominant in this community uniquely found in the south Snake Range.

With a non-spatial ED of 18%, there were no problems with this system. Due to the Philips Ranch Fire, primarily, Black Fire, and small Granite Peak Fire more than a decade ago, more early successional vegetation (A:All) was observed (23%) than expected in the reference condition (5%; Table 3.28). The early successional period was modeled to be about 50 years long; therefore the impact of even decade old fires can persist for many more decades. Because bighorn sheep preferentially browse in the early successional vegetation, the observed departure was more than acceptable.

Table 3.28. Vegetation classes of limber-bristlecone pine-mesic expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							<0.1
A:Char2							<0.1
A:All	346	906	45		1,297	23.0	5
B:Closed	283	320	<1		603	10.7	30
C:Open	1,894	1,830	15		3,739	66.3	66

Objectives for Management Actions

The objective for mesic bristlecone pine (and occasional limber pine) was the maintenance and creation of bighorn sheep foraging areas, which was achieved with *prescribed burning ignited*

from a helicopter (Table 3.29). This objective only applied to GBNP. This implied that more early successional vegetation area would be created and likely *increase* ED.

Table 3.29. Realized treatment totals (acres) within each period in limber-bristlecone pine-mesic from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	RxFire – Aerial Ignition (BLM & NPS: \$600/acre)
Years	25 th – 75 th percentiles of total treatment acres
PRISM	
BLM	
2023-2024	0
2025-2029	0
2030-2034	0
2035-2039	0
2040-2072	0
NPS	
2023-2024	0
2025-2029	121-129
2030-2034	121-128
2035-2039	0
2040-2072	0
ACCESS1	
BLM	
2023-2024	0
2025-2029	0
2030-2034	0
2035-2039	0

2040-2072		0
NPS		
2023-2024		0
2025-2029		121-129
2030-2034		121-126
2035-2039		0
2040-2072		0
HadGEM-ES		
BLM		
2023-2024		0
2025-2029		0
2030-2034		0
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		122-128
2030-2034		123-129
2035-2039		0
2040-2072		0

About 250 acres were *prescribed burned* over a 10-year period; on average 125 acres from 2025-2029 and 125 acres from 2030-2034 (Table 3.30). In all periods, *prescribed burning* caused the expected increase (95% C.I. did not overlap) of 2-4% (absolute value) of ED in the preferred management compared to custodial management (Table 37). Also, low ED (<34%) was achieved in all scenarios. In the last year of 2072, departure was as low as 2-4% in the PRISM and HadGEM-ES climates, but <11% in the ACCESS1 climate (Table 3.30). Therefore, *prescribed burning* in GBNP achieved its objective while maintaining low departure.

Table 3.30. Future ED of limber-bristlecone pine-mesic ($\% \pm 1$ 95% Confidence Interval, $n = 10$). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	18% \pm 0.06%	22% \pm 0.09%
2047	18% \pm 0.1%	22% \pm 0.1%
2072	2% \pm 1.2%	4% \pm 0.2%
ACCESS1		
2035	19% \pm 0.1%	22% \pm 0.1%
2047	19% \pm 0.2%	23% \pm 0.2%
2072	8% \pm 1.3%	10% \pm 1.2%
HADGEM-ES		
2035	19% \pm 0.1%	22% \pm 0.2%
2047	19% \pm 0.2%	23% \pm 0.3%
2072	4% \pm 1.2%	6% \pm 1.2%

Cost by year (ST-Sim Results)

The annual cost fluctuated around \$15,000 from 2025 to 2034 (Fig. 3.44). The expenditure was somewhat higher in the HadGEM-ES climate during the 2030-2034 period (Fig. 3.44), which matched the slightly higher implementation rates in that same climate (Table 3.41).

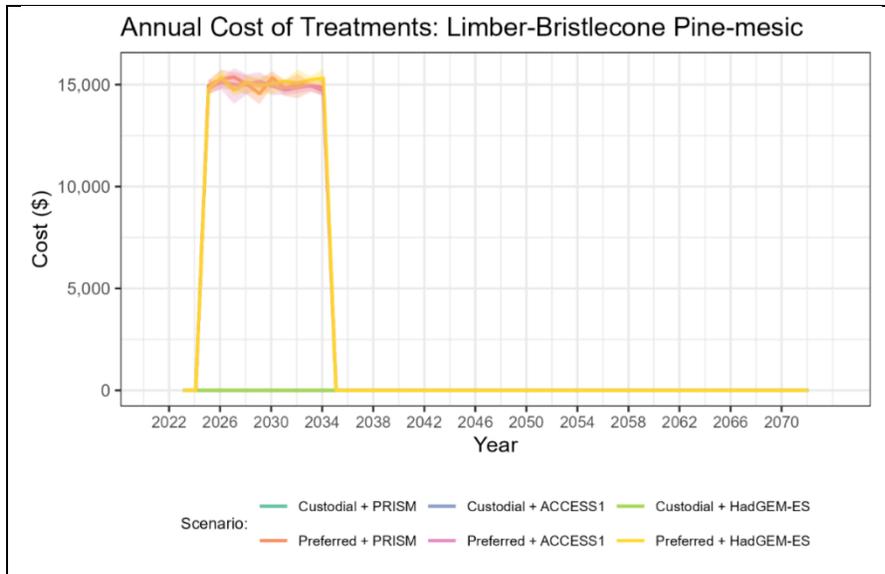


Figure 3.44. Annual cost of treatments in limber-bristlecone pine-mesic for GBNP in the South Snake Range. Cost was only incurred for GBNP. Cost only applied to the preferred management scenario combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES). The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

Prescribed burning in the preferred management scenario reduced the reference late-successional class (C:Closed) by about 200 acres by 2034 compared to the custodial management scenario in GBNP, whereas nothing was detected for BLM-managed land (Fig. 3.45). As a result, the area of reference early successional class (A:All) increased by 200 acres by 2034 in GBNP, but not on BLM-managed lands.

About 50 years later, succession from classes A:All to B:Open occurred in many 100s of acres (Fig. 3.45). This rebalancing of successional classes was responsible for the lowest ED achieved. The least area of successional transition was for the ACCESS1 scenario (about 125 acres less) compared to other climates (Fig. 3.45), thus resulting in slighter greater ED in year 2072 (Table 3.30).

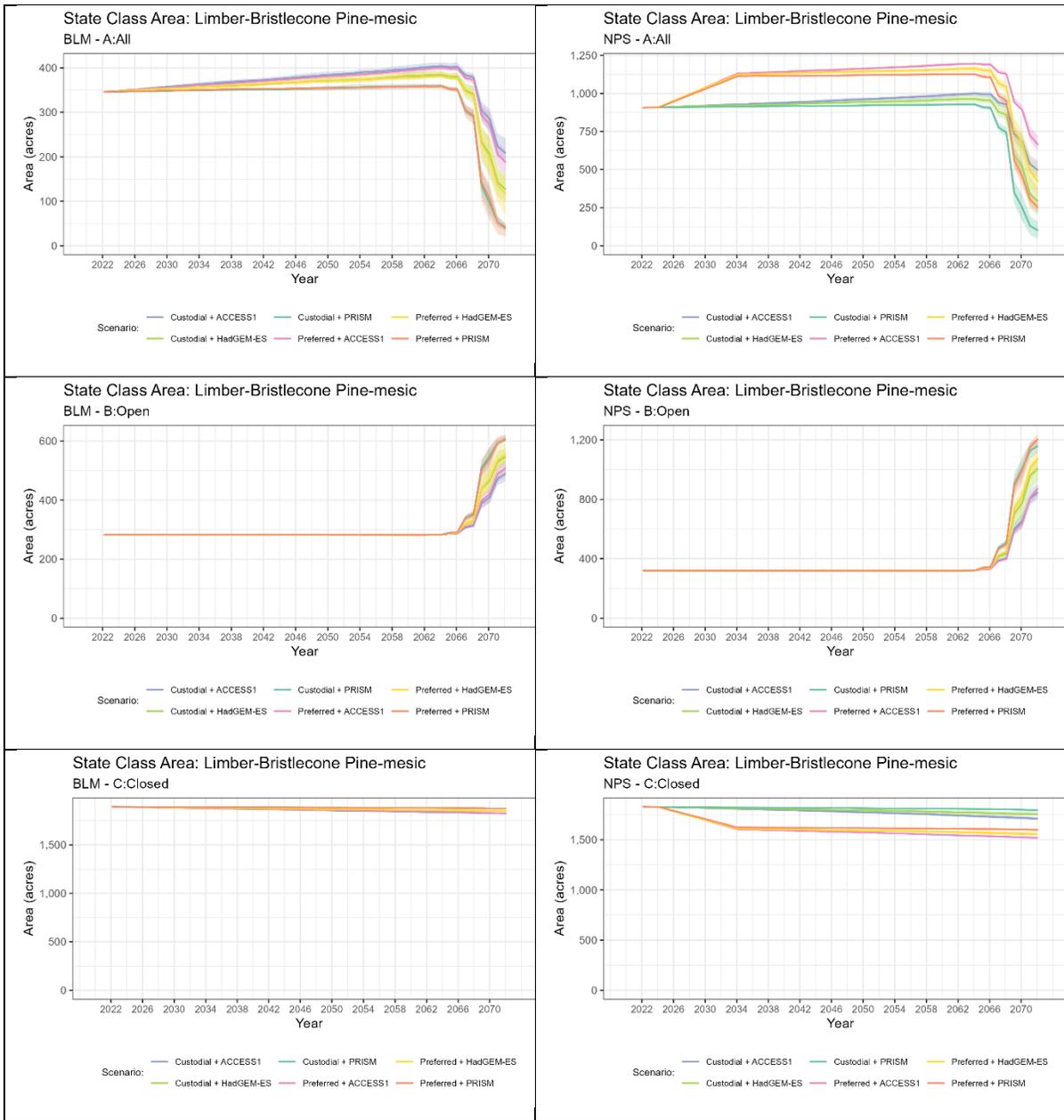


Figure 3.45. Vegetation classes of limber-bristlecone pine-mesic on BLM-managed land (left panel) and GBNP (right panels) on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.10. Littleleaf Mountain Mahogany

2022 System acres at 14-m resolution: 14,397

2022 Landscape-wide ED: 21%

Problems or Concerns

Littleleaf mountain mahogany was predominantly found on BLM-managed land (13,127 acres), whereas GBNP contained 832 acres, private lands had 62 acres, and USFS-managed land disproportionately contained 375 acres. Littleleaf mountain mahogany was 21% departed from the reference condition; therefore, problems based on departure were small. The main problems were too little (0.4% observed *versus* 14% expected) of the reference early-successional class (A:All) and too much of the reference late-successional class (C:Closed, 56.6% observed *versus* 22% expected) and uncharacteristic mid-successional shrub with annual and perennial grasses class (U-A:SAP, 6.4% observed *versus* 0% expected; Table 3.31). Most likely, historic and current fire exclusion favored the late-successional class and, on the other hand, decades-old fires (e.g., Philips Ranch Fire) might have caused the emergence of dormant non-native annual species from the seedbank and the shrubland had matured into the U-B:SAP class.

Table 3.31. Vegetation classes of littleleaf mountain mahogany expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							<0.1
A:Char2							<0.1
A:All	38	19		0	57	0.4	14
B:Open	7,046	731	33	355	8165	56.7	64
C:Closed	5,113	81	29	20	5243	36.4	22
U-A:SAP	11				11	0.1	0
U-B:SAP	920	0	0		920	6.4	0

Objectives for Management Actions

In many western landscapes where Landscape Conservation Forecasting was applied that contain large enough areas of littleleaf mountain mahogany, it was never proposed for special management because it was considered too unproductive, difficult to access on remote limestone shelves and ridges, and a system that rarely burned because it did not contain enough fine fuels that would carry fire. Therefore, the objective for littleleaf mountain mahogany was only for the maintenance or creation of bighorn sheep foraging areas for the project area (Table 3.32). This objective was only requested for BLM-managed land.

Because this system does not easily carry fire and its patches were imbedded in other systems where fire might not be easily controlled (e.g., mixture and shrublands and pinyon-juniper woodland), *lop and scatter* was selected to reduce the late successional class by cutting pinyon and juniper amongst shrubs and recruit into the younger classes. Because shrubs were not cut when trees were felled, the transition was only to the reference mid-successional class as per model assumptions (B:Open; Table 3.32). No seeding would be needed for application to the reference late-successional class. Also, this system did not require urgent management; therefore, it was implemented in the second period from 2030-2034 (Table 3.32).

Table 3.32. Realized treatment totals (acres) within each period in littleleaf mountain mahogany from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Lop and Scatter (BLM: \$65-\$95/acre; NPS: \$250/acre)
Years	25 th – 75 th percentiles of total treatment acres
PRISM	
BLM	
2023-2024	0
2025-2029	0
2030-2034	1,242-1,261
2035-2039	0
2040-2072	0
NPS	

2023-2024		0
2025-2029		0
2030-2034		0
2035-2039		0
2040-2072		0
ACCESS1		
BLM		
2023-2024		0
2025-2029		0
2030-2034		1,241-1,251
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		0
2030-2034		0
2035-2039		0
2040-2072		0
HadGEM-ES		
BLM		
2023-2024		0
2025-2029		0
2030-2034		1,241-1,248
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		0

2030-2034		0
2035-2039		0
2040-2072		0

About 1,245 acres were cut by chainsaws from 2030 to 2034 (Table 3.33). *Lop and scatter* decreased ED (95% C.I. did not overlap) by at most 10% in 2035 (absolute value) in the preferred management scenario compared to custodial management scenario, although the differences decreased to nothing by 2072 (Table 3.33). Low ED (<20%) was achieved in all scenarios. In 2035 when greater differences were observed, the effect of *lop and scatter* was greatest in the PRISM climate and least in the HadGEM-ES climate. Therefore, treatment only on BLM-managed land achieved both the goal of decreasing ED and doing so for all land ownerships combined without others incurring any costs.

Table 3.33. Future ED of littleleaf mountain mahogany (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	20% ± 0.06%	9% ± 0.09%
2047	18% ± 0.1%	10% ± 0.1%
2072	14% ± 1.2%	11% ± 0.2%
ACCESS1		
2035	16% ± 0.1%	11% ± 0.1%
2047	18% ± 0.2%	11% ± 0.2%
2072	16% ± 1.3%	13% ± 1.2%
HADGEM-ES		
2035	12% ± 0.1%	11% ± 0.2%
2047	10% ± 0.2%	9% ± 0.3%
2072	15% ± 1.2%	17% ± 1.2%

Cost by year (ST-Sim Results)

The annual cost narrowly fluctuated around \$25,000 from 2030 to 2034 (Fig. 3.46). Differences were negligible among climates (Fig. 3.46) as suggested by the similar implementation rates among climates (Table 3.32).

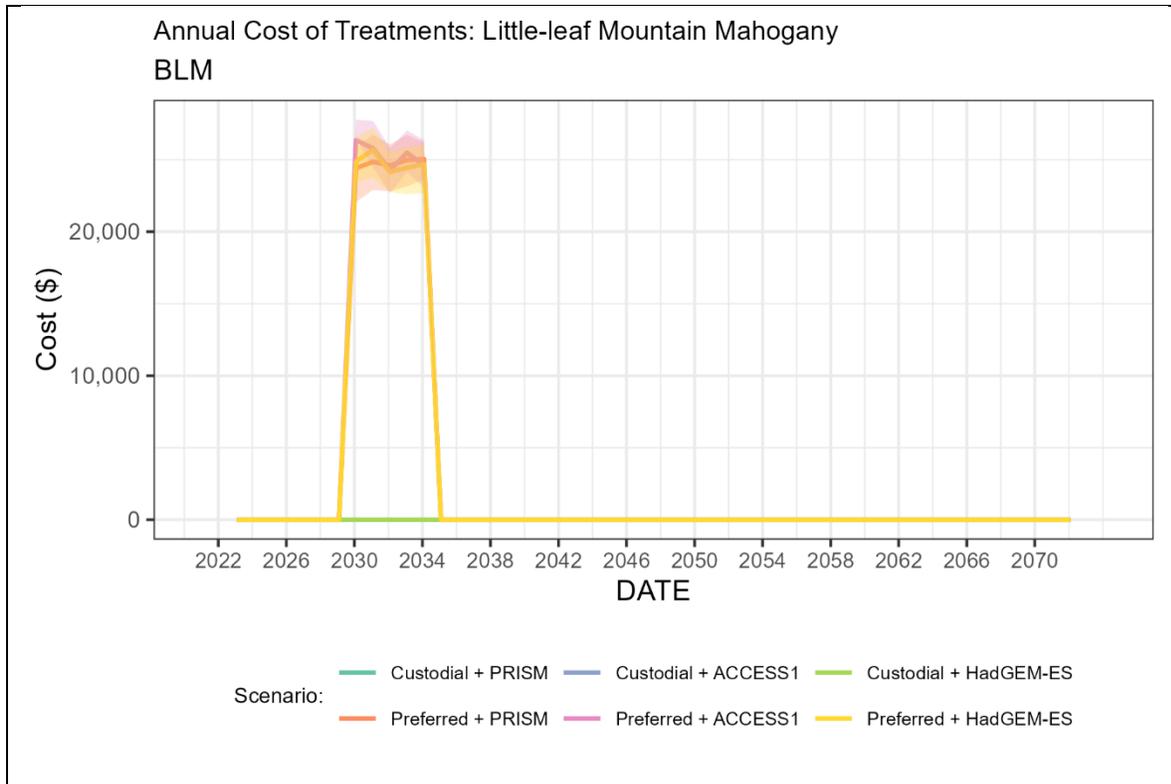


Figure 3.46. Annual cost of treatments in littleleaf mountain mahogany for BLM-managed land in the South Snake Range. Cost was only incurred for GBNP. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

Lop and scatter in the preferred management scenario reduced the area of the reference late-successional class (C:Closed) by about 1,000 acres compared to the custodial management scenario on BLM-managed land (Fig. 3.47). The difference between the custodial and preferred management scenarios was maintained for decades until succession from the younger B:Open class caused the area of C:Closed to approach the area found in the custodial management scenario in the final years (Fig. 3.47). No change was noted in GBNP where treatments were not used.

The main climate effect was the preservation of the area of woody classes (B:Open and C:Closed) in the ACCESS1 climate scenario compared to others (Fig. 3.47). The ACCESS1 climate scenario experienced less fire.

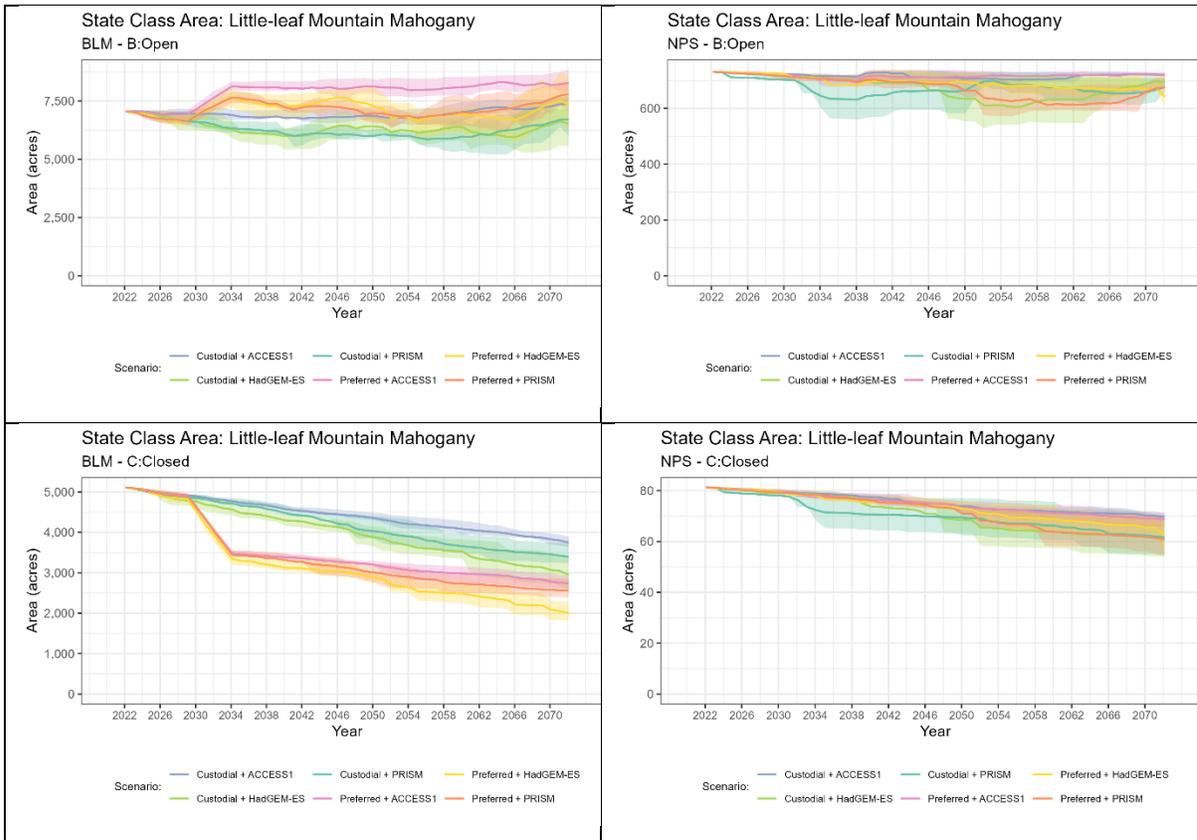


Figure 3.47. Vegetation classes of little mountain mahogany on BLM-managed land (left panel) and GBNP (right panels) on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.11. Low Sagebrush-semi-desert

2022 System acres at 14-m resolution: 371

2022 Landscape-wide ED: 71%

Problems or Concerns

We mapped 371 acres of low sagebrush-semi-desert, of which 370.8 acres were on BLM-managed land and the remaining 0.4 acres on private lands. The system was highly departed (71%) from reference condition (Table 3.44). The primary source of departure was 51% of the system's area in the uncharacteristic tree-encroached class (U-C:TEA) that should be in the under-represented three reference classes (A:All, B:Open, and C:Closed), especially the reference early successional class that was absent (Table 3.44).

Table 3.44. Vegetation classes of low sagebrush-semi-desert expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							1
A:Char2							1
A:All							11
B:Open	63				63	16.9	45
C:Closed	46				46	12.5	43
U-A:Early Shrub	0				0	0.1	0
U-A:SAP	1				1	0.2	0
U-B:SAP	5				5	1.3	0
U-B:SI	5				5	1.4	0
U-B:SI+AS	19				19	5.2	0
U-C:SAP	3		0.4		4	1.0	0
U-C:SI	15				15	4.1	0
U-C:SI+AS	24				24	6.5	0

U-C:TEA	188				188	50.8	0
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Objectives for Management Actions

The objective was to cut the trees in the tree-encroached class and recruit into the reference classes to decrease ED (Table 3.45). *Small tree lopping* was used. In the model, low sagebrush-semi-desert was unique among many shrublands in that tree-encroached class was caused by even 5% cover of conifers without, however, elimination of the understory. Therefore, *small tree lopping* caused a transition to the reference mid-successional open class (B:Open).

Table 3.45. Realized treatment totals (acres) within each period in low sagebrush-semi-desert from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Small Tree Lopping (BLM: \$65-\$95/acre; NPS: \$250/acre)
Years	25 th – 75 th percentiles of total treatment acres
PRISM	
BLM	
2023-2024	0
2025-2029	0
2030-2034	164-174
2035-2039	0
2040-2072	0
NPS	
2023-2024	0
2025-2029	0
2030-2034	0
2035-2039	0
2040-2072	0
ACCESS1	

BLM		
2023-2024		0
2025-2029		0
2030-2034		168-182
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		0
2030-2034		0
2035-2039		0
2040-2072		0
HadGEM-ES		
BLM		
2023-2024		0
2025-2029		0
2030-2034		166-181
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		0
2030-2034		0
2035-2039		0
2040-2072		0

About 172 acres were cut by chainsaw from 2030 to 2034 (Table 3.46). *Small tree lopping* decreased ED (95% C.I. did not overlap) by about 30% to 35% in all years (absolute value) in the

preferred management scenario compared to custodial management scenario. Climate scenarios did not appear to change results (Table 3.46).

Table 3.46. Future ED of low sagebrush-semi-desert (± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	72% \pm 1.3%	40% \pm 2.2%
2047	72% \pm 0.7%	38% \pm 1.9%
2072	73% \pm 2.4%	38% \pm 2.6%
ACCESS1		
2035	72% \pm 0.1%	42% \pm 2.6%
2047	72% \pm 1%	40% \pm 1%
2072	73% \pm 1%	40% \pm 2.1%
HADGEM-ES		
2035	73% \pm 1%	38% \pm 0.6%
2047	72% \pm 1.4%	38% \pm 1.7%
2072	73% \pm 1.6%	43% \pm 3.4%

Cost by year (ST-Sim Results)

The annual cost ranged between 4,200 and 5,000 acres only incurred in BLM-managed land (Fig. 3.48). About \$500 per year less was spent in the ACCESS1 climate scenario compared to other climates.

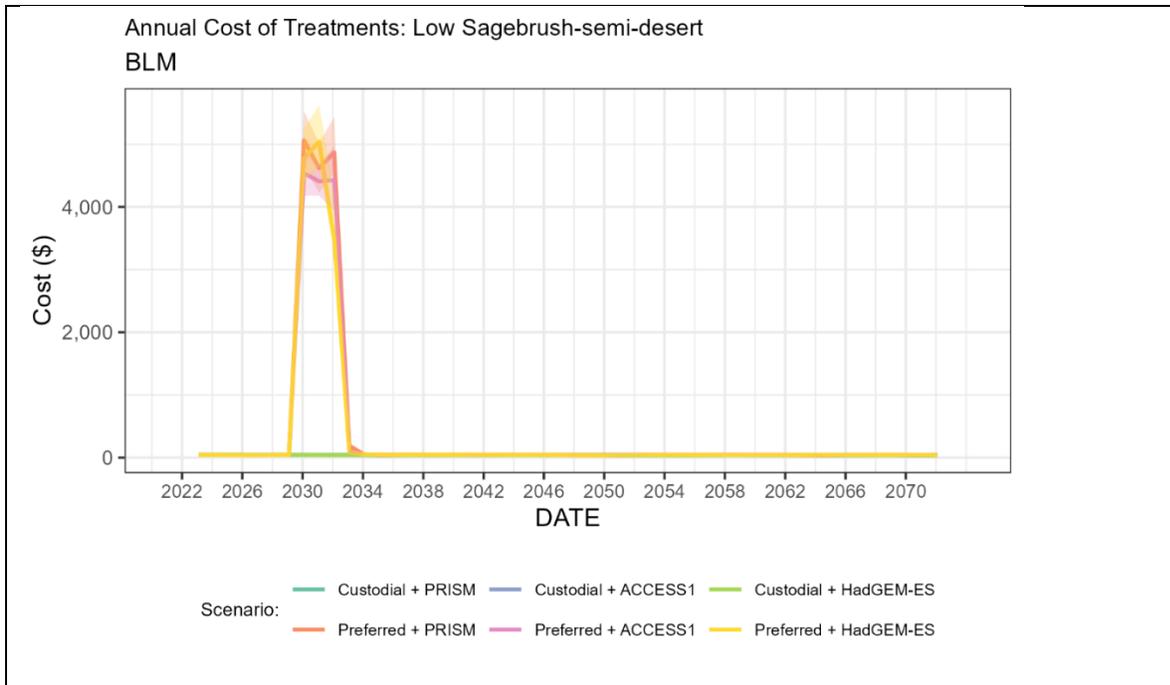


Figure 3.48. Annual cost of treatments in low sagebrush-semi-desert for BLM-managed land in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

Small tree lopping decreased the tree-encroached class (U-C:TEA) by about 125 acres in the preferred management scenario compared to the custodial management scenario in 2030 (Fig. 3.49). As a result, the reference mid-successional class open-canopied (B:Open) increased by the same amount. This alone decreased ED.

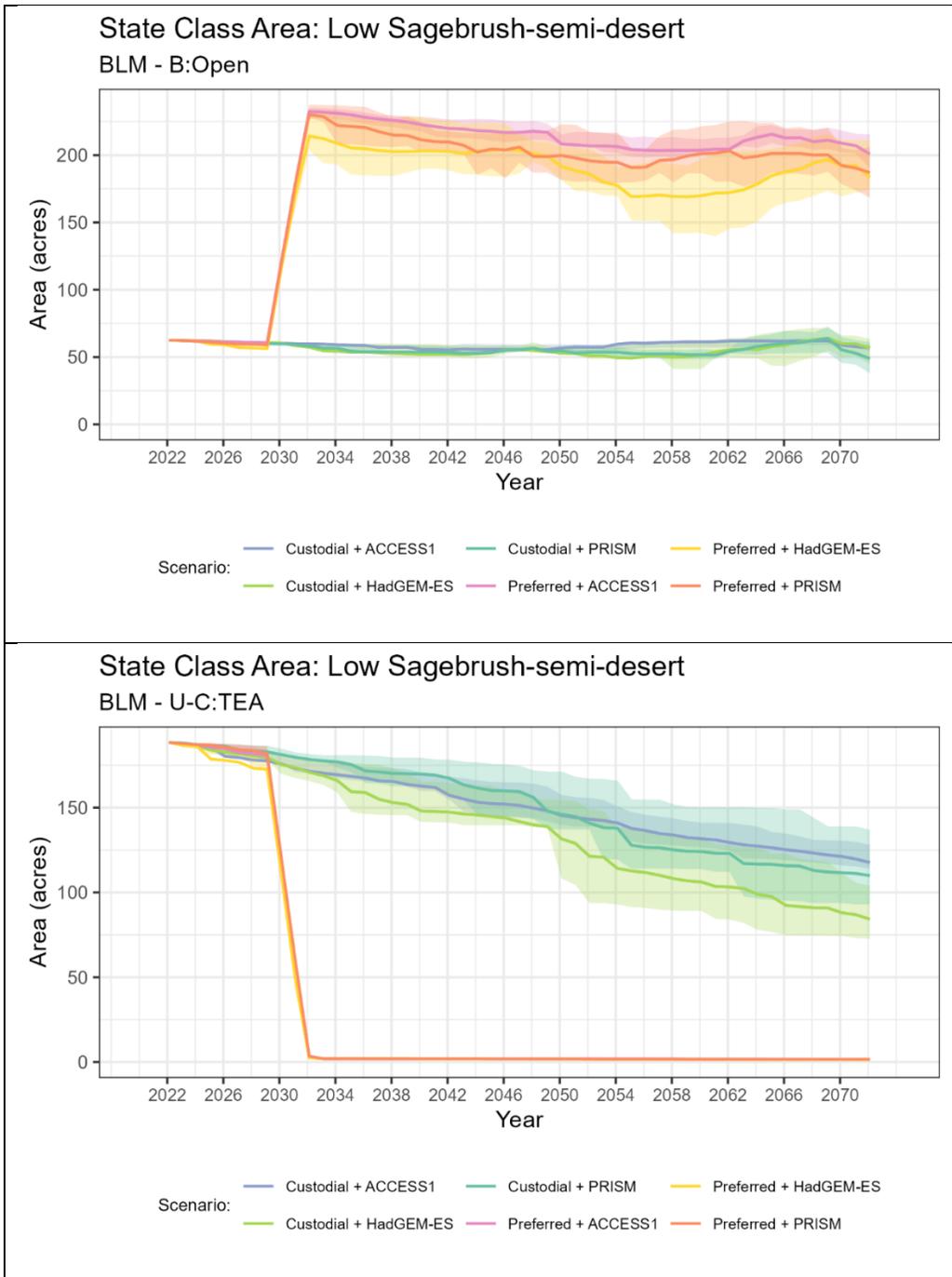


Figure 3.49. Vegetation classes of low sagebrush-semi-desert on BLM-managed land on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.12. Low Sagebrush Steppe

2022 System acres at 14-m resolution: 2,281

2022 Landscape-wide ED: 63%

Problems or Concerns

Low sagebrush steppe was a subalpine (typically above 8,500 ft) shrubland containing high grass cover and was assumed to burn twice more frequently than its semi-desert counterpart. Most low sagebrush steppe was found on BLM-managed land (1,437 acres). GBNP contained 801 acres, none was found on private lands, and 43 acres were mapped on the higher slopes of USFS-managed land. Low sagebrush steppe was at the high end of moderate departure at 63%.

While 67% of the system was in reference classes, the late successional closed canopy class (C:Closed) was over-represented (43%) compared to the expected percentage from the reference condition (10%; Table 3.47). This likely result of historic fire exclusion caused too little area in the mid-successional class (24% *versus* the expected value of 60%) and nearly none in the early successional class (0.2% mapped compared to 29% expected). An additional problem was the 19% of the area in the uncharacteristic tree-encroached class (U-C:TEA; Table 3.47), also a legacy of fire exclusion.

Table 3.47. Vegetation classes of low sagebrush steppe expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							1
A:All	1	4			5	0.2	29
B:Open	446	192			638	24.1	60
C:Closed	614	524			1138	42.9	10
U-A:Early Shrub	3				3	0.1	0
U-B:Depleted				0	0	0.0	0
U-B:SAP	2				2	0.1	0
U-C:TEA	371	80		42	494	18.6	0

Objectives for Management Actions

The two objectives for low sagebrush steppe were to reduce ED and improve bighorn sheep forage area as low sagebrush steppe is within sheep habitat and highly palatable. Reducing conifer cover in the tree-encroached class and recruiting into younger successional classes in the treeless late successional class was the path to achieve the objectives. Prescribed fire aerially (helicopter) ignited over a 10-year period (2025-2034) on both BLM-managed land and GBNP was the chosen action to achieve objectives (Table 3.48). The action would likely be accomplished when burning in adjacent aspen systems and limber-bristlecone pine-mesic forest. The greatest period of implementation was from 2025 to 2029 (Table 3.48).

Table 3.48. Realized treatment totals (acres) within each period in low sagebrush steppe from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Prescribed Fire – aerial ignition (BLM & NPS: \$600/acre)
Years	25 th – 75 th percentiles of total treatment acres
PRISM	
BLM	
2023-2024	0
2025-2029	745-756
2030-2034	237-276
2035-2039	0
2040-2072	0
NPS	
2023-2024	0
2025-2029	98-103
2030-2034	34-37
2035-2039	0
2040-2072	0

ACCESS1		
BLM		
2023-2024		0
2025-2029		745-775
2030-2034		254-280
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		98-105
2030-2034		33-37
2035-2039		0
2040-2072		0
HadGEM-ES		
BLM		
2023-2024		0
2025-2029		744-756
2030-2034		225-288
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		98-103
2030-2034		33-36
2035-2039		0
2040-2072		0

About 982 to 1,016 acres were *prescribed burned* on BLM-managed land and about 136 acres burned in GBNP from 2025 to 2034 (Table 3.49). *Prescribed burning* decreased landscape-wide ED (95% C.I. did not overlap) by 16% to 25% (absolute value) in the preferred management scenario compared to custodial management scenario (Table 3.49). ED ranged from 47% to 59% in the custodial management scenario and from 30% to 36% in the preferred management scenario. A low level of departure (ED <34%) was reached in many preferred management scenarios and replicates. The effect of climate was not observed. Therefore, the objective of reducing ED was achieved.

Table 3.49. Future ED of low sagebrush steppe (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	59% ± 1.4%	36% ± 1.1%
2047	55% ± 3.3 %	30% ± 1.7%
2072	55% ± 4.3%	33% ± 3%
ACCESS1		
2035	60% ± 0.7%	34% ± 0.3%
2047	57% ± 1%	31% ± 0.5%
2072	54% ± 2.1%	32% ± 0.9%
HADGEM-ES		
2035	58% ± 1.9%	36% ± 1.8 %
2047	55% ± 3.2%	30% ± 2.6%
2072	47% ± 5%	31% ± 2.6%

Cost by year (ST-Sim Results)

The largest annual cost was just above \$100,000 from 2025-2029 and then rapidly dropped to about \$12,000 in 2034 on BLM-managed land (Fig. 3.50). The rapid decrease in BLM cost after 2029 indicated that late-successional areas were nearly all treated. The cost incurred for GBNP showed two plateaus of spending at about \$12,000 annually from 2025 to 2029, and \$4,000

from 2030 to 2034. Because there was no precipitous decrease of expenditures in the second 5-year period, many treatable areas remained untreated.

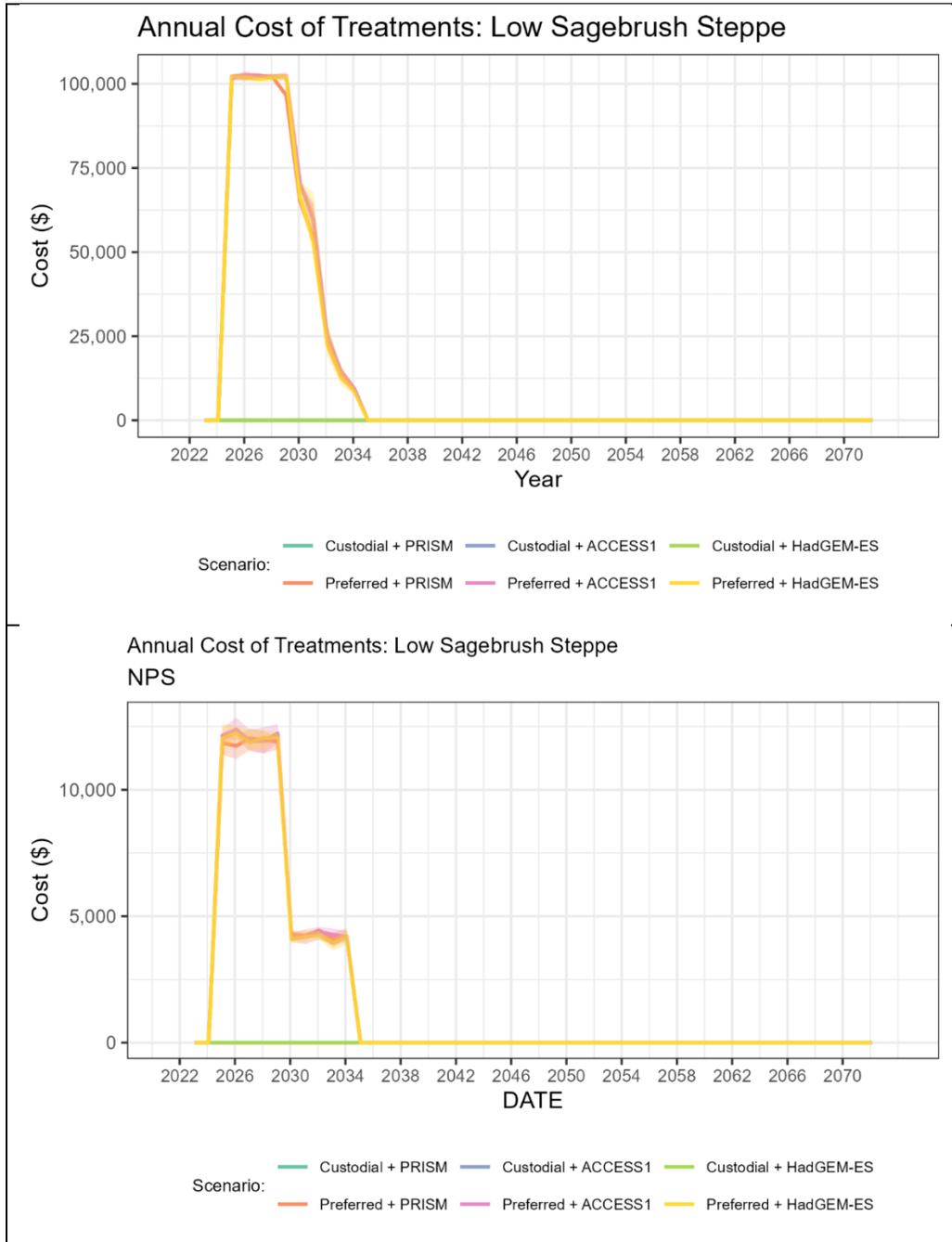
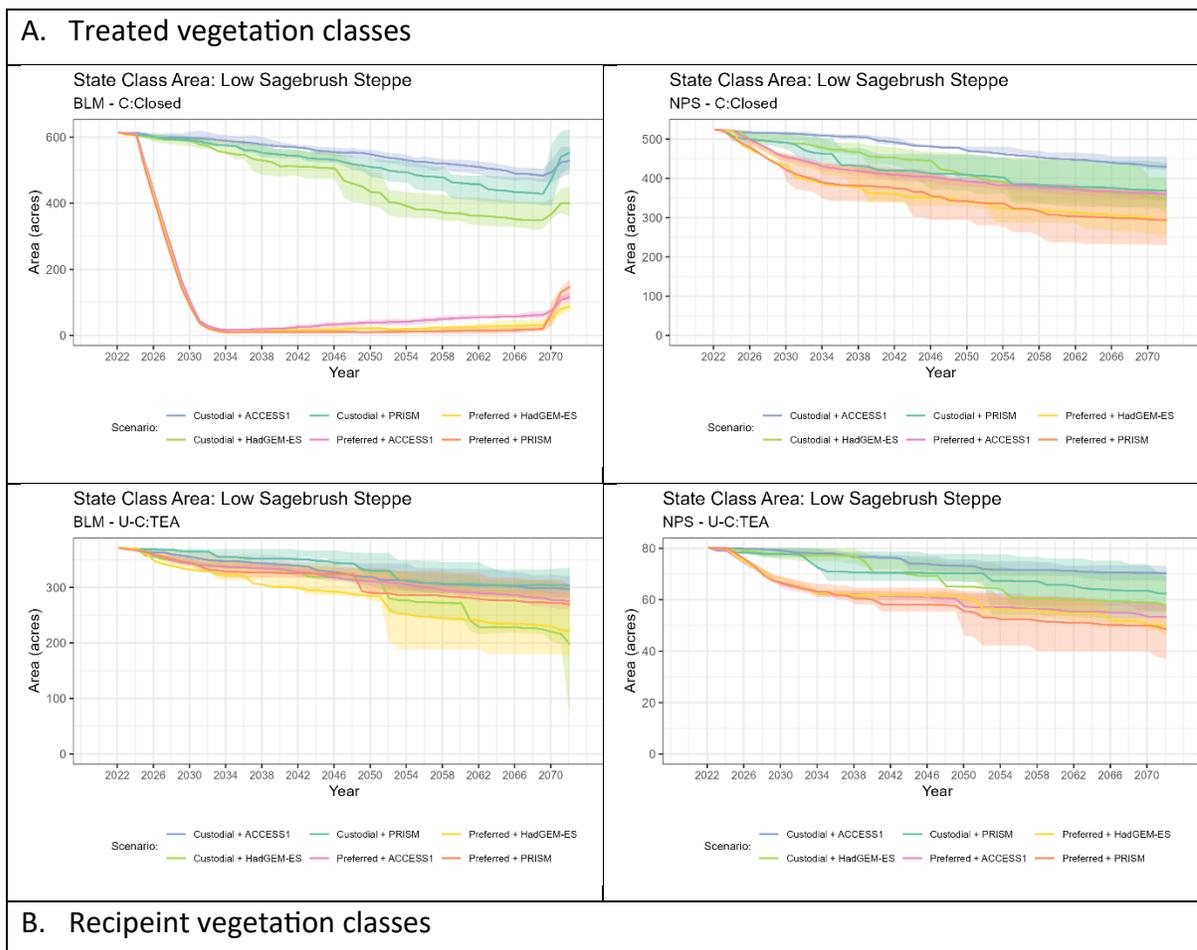


Figure 3.50. Annual cost of treatments in low sagebrush steppe for BLM-managed land and GBNP in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

Prescribed burning reduced the area of the reference late successional class by 600 acres on BLM-managed land and by about 50 acres in GBNP by 2034 in the preferred management scenario (Fig. 3.51A). The reduction was more modest in the tree-encroached class reaching at most 20 acres on both BLM-managed land and GBNP (Fig. 3.51A). The reference early successional class (A:All) was the greatest recipient of burning increasing by 600 acres and at most 100 acres in the preferred management scenario compared to the custodial management scenario, respectively, on BLM-managed land and GBNP (Fig. 3.51B). With decades, succession transitioned the early successional class to the reference mid-successional class (B:Open). Transition from the C:Closed to the A:All class, and succession to the B:Open class was the greatest source of decreased ED. The other recipient class from *prescribed burning* in the U-C:TEA class was the early successional early shrub (U-A:Early-shrub) that increased by at most 25 acres in both BLM-managed land and GBNP (Fig. 3.51B).



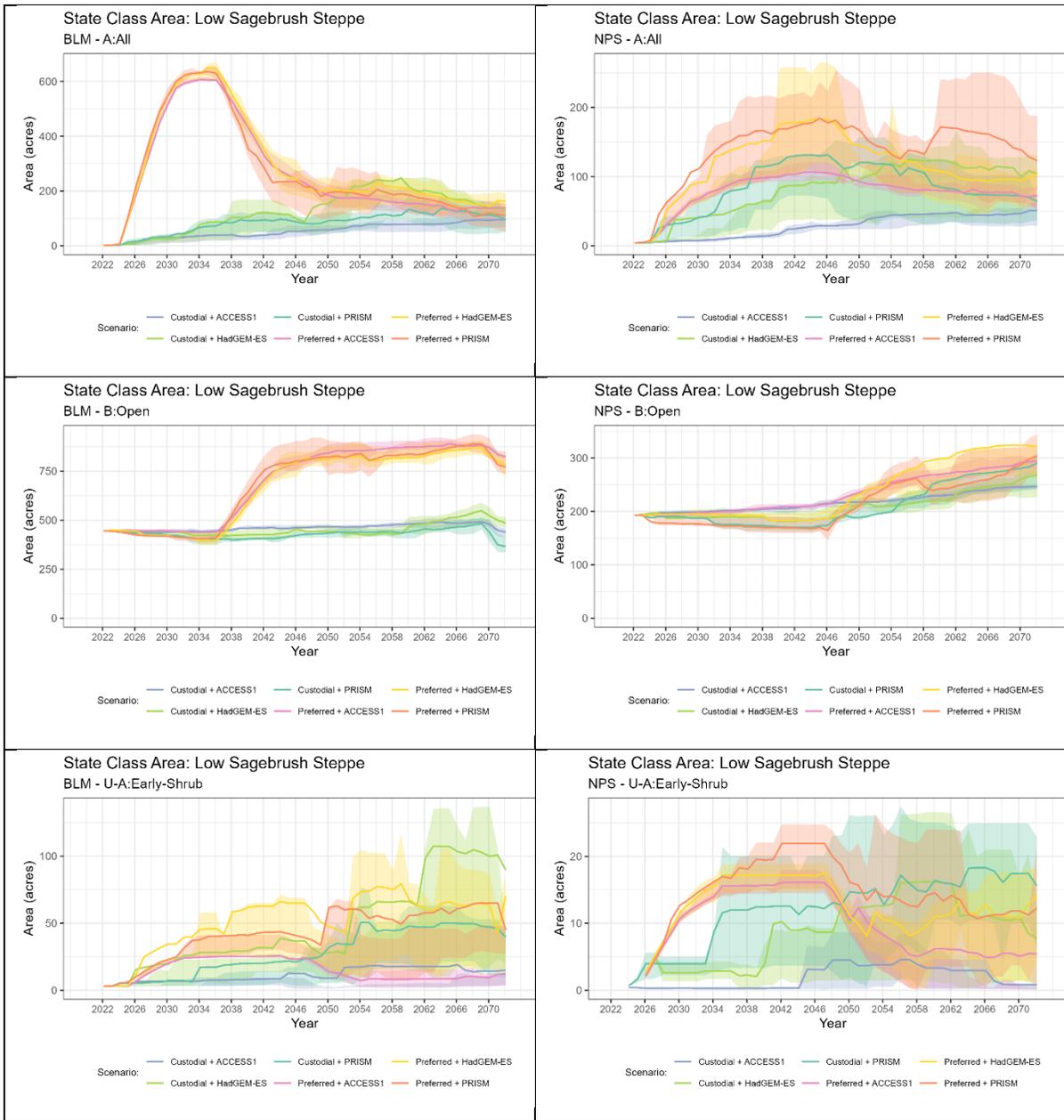


Figure 3.51. Treated vegetation classes (A) and recipient vegetation classes (B) of low sagebrush steppe on BLM-managed land (left panel) and GBNP (right panels) on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.13. Montane Riparian

2022 System acres at 14-m resolution: 1,941

2022 Landscape-wide ED: 32%

Problems or Concerns

We mapped 1,941 acres of montane riparian found in all ownerships. About 650, 664, 568, and 59 acres were mapped, respectively, on BLM-managed land, GBNP, private lands, and USFS-managed land. ED was low at 32%. The observed reference class percentages were surprisingly close to the expected values from the reference condition, except for the under-represented B-Willow:Closed class (23.9% observed *versus* 50% expected).

The uncharacteristic early successional early shrub class (often rabbitbrush) was the most abundant at 16.7% (expected 0%), just about the amount missing from B-Willow:Closed class (Table 3.50). The early shrub class was usually found on incised floodplains. Incision was also mapped in desertified (U-C:Desertified) and inset floodplains (U-A:Inset), mostly found on BLM-managed land and private lands (Table 3.50).

Table 3.50. Vegetation classes of montane riparian expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							1
A:Char2							<0.1
A:Sediment	4	86	0		90	4.6	<0.1
A-Cottonwood :All	92	3	75	1	171	8.8	4
A-Willow:All	8	8	2		18	0.9	5
B-Cottonwood :Closed	107	294	194	48	642	33.1	34

B-Willow:Closed	162	133	169	1	464	23.9	50
C-Cottonwood:Closed	33	58	24	9	124	6.4	6
U-A:Annual Spp		3			3	0.2	0
U-A:Bare Ground	0				0	0.0	0
U-A:Early Shrub	185	63	77		325	16.7	0
U-A:Exotic-Forb-Tree	0		0		1	0.0	0
U-A:Inset	12		4		16	0.8	0
U-C:Desertified	3	1	8		11	0.6	0
U-C:Shrb-Frb Encr	40	14	15	0	71	3.6	0
U-C:TEA	4	1			5	0.3	0

Objectives for Management Actions

The only objective was to reduce ED by recruiting, albeit after succession, into the reference mid-successional willow-dominated B-Willow:Closed class. This was achieved by controlling current or future exotic species and reconnecting the water to its floodplain in incised reaches (Table 3.51). Reconnecting the creeks to their floodplain will inundate all uncharacteristic vegetation classes and initiate a gradual natural recovery. Also requested by partners was the reduction of non-riparian fire-intolerant conifers (a.k.a., FIC), primarily pinyon and juniper, in reference late-successional floodplain classes (U-C:FIC-Closed). This latter class was not mapped in 2023 (TNC was unaware of this condition) but was present in the model, which received chainsaw cutting and pile burning.

Table 3.51. Realized treatment totals (acres) within each period in montane riparian from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Chainsaw and Pile Burning (BLM: \$500/acre; NPS: \$4,000/acre)	Exotic Control (BLM: \$200/acre; NPS: \$225/acre)	Water Table Uplift (BLM & NPS: \$400- \$1,200/acre)	Weed Inventory and Spot Treatment (BLM & NPS: \$115/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres
PRISM				
BLM				
2023-2024	0	0	0	0
2025-2029	2.5-3.6	0.1	4.4-5.6	38-42
2030-2034	0-0.1	0.1-0.4	4.1-5.3	38-43
2035-2039	0	0	0	0
2040-2072	0	0	0	0
NPS				
2023-2024	0	0	0	0
2025-2029	0.5-0.7	0	4.3-6.0	38-42
2030-2034	0.06	0.01	0	39-42
2035-2039	0	0.005	0	98-102
2040-2072	0	0	0	0
ACCESS1				
BLM				
2023-2024	0	0	0	0
2025-2029	2.8-3.8	0.1-0.14	4.2-5.3	39-42
2030-2034	0.02	0.01-0.3	4.5-5.6	39-41
2035-2039	0	0.4-1.1	0	38-41

2040-2072	0	0	0	0
NPS				
2023-2024	0	0	0	0
2025-2029	0.5-0.7	0.005	4.1-5.7	37-41
2030-2034	0.0043	0.005	0	38-42
2035-2039	0	0.02	0	97-102
2040-2072	0	0	0	0
HadGEM-ES				
BLM				
2023-2024	0	0	0	0
2025-2029	2,9-3.5	0.1-0.2	4.5-5.6	39-42
2030-2034	0-0.04	0-0.3	4.6-5.7	38-42
2035-2039	0	0.6-1.5	0	39-42
2040-2072	0	0	0	0
NPS				
2023-2024	0	0	0	0
2025-2029	0.5-0.7	0	4.5-5.4	39-42
2030-2034	0.04	0.004	0	37-42
2035-2039	0	0.02	0	97-102
2040-2072	0	0	0	0

All implementation rates were low in montane riparian. About 4 acres of *chainsaw and pile burning* were applied to fire-sensitive conifers in montane riparian floodplain over 10 years on BLM-managed land (Table 3.51). The same action in GBNP never exceeded a cumulative area of 1 acre. *Exotic control* of known exotic forb and tree patches were barely greater than 1 acre during a 15-year period in BLM-management creeks, whereas the cumulative amount was less than 1 acre in GBNP (Table 3.51). The *water table uplift* action reached 11 acres over 10 years on BLM-managed creeks, which translated into a long riparian distance, and about 5 acres were achieved in 5 years on GBNP (Table 3.51). The *weed inventory and spot spraying* treatment was the most extensively deployed treatment at about 120 acres over 15 years, whereas 180 acres were used on GBNP creeks (Table 3.51).

Treatments had no effects on landscape-wide ED values (Table 3.52), although desired classes changes were observed and later explained (Fig. 58).

Table 3.52. Future ED of montane riparian (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	35% ± 2.8%	35% ± 2.5%
2047	40% ± 1.3%	40% ± 1%
2072	43% ± 1.8%	42% ± 2.1%
ACCESS1		
2035	33% ± 1.6%	33% ± 0.8%
2047	41% ± 1.8%	41% ± 1%
2072	44% ± 1.9%	46% ± 1.7%
HADGEM-ES		
2035	36% ± 3.1%	35% ± 1.8%
2047	40% ± 1.4%	41% ± 2.1%
2072	46% ± 2.3 %	44% ± 2.4%

Cost by year (ST-Sim Results)

The annual cost peaked in 2025 to about \$3,000, then dropped to about \$2,000 by 2030 in both BLM-managed land and GBNP (Fig. 3.52). The \$2,000 annual expenditure was maintained for 5 years on BLM-managed creeks, whereas cost gradually decreased to \$1,000 by year 2034. The latter decrease of cost indicated that the simulation could not find more area for one or more treatments. Only the *weed inventory and spot treatment* contributed cost of about \$1,000 for BLM-managed creeks and \$2,300 for GBNP creeks during the 2035 to 2039 period.

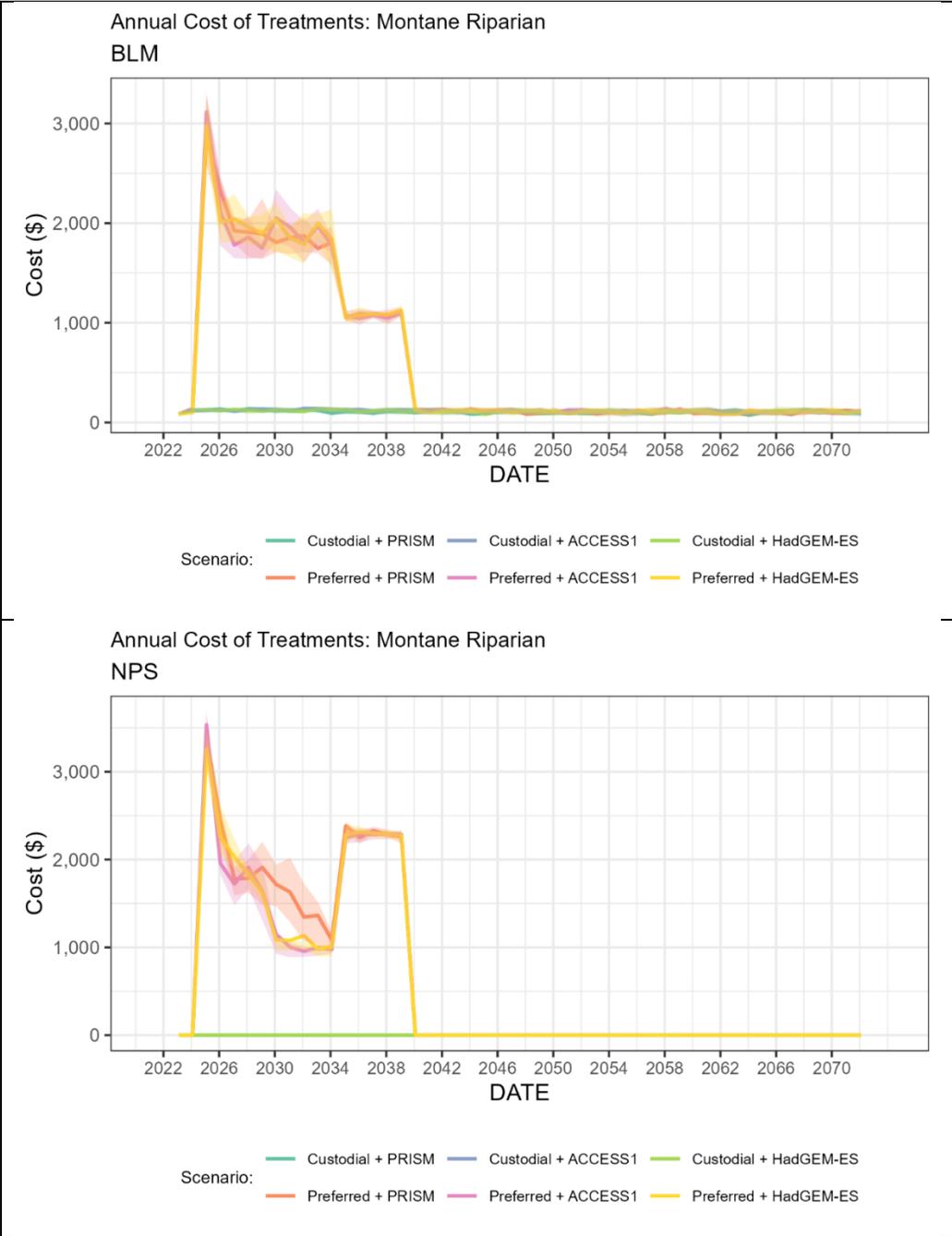


Figure 3.52. Annual cost of treatments in montane riparian for BLM-managed land and GBNP in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

Montane riparian restoration dynamics were complex because few pathways lead directly from uncharacteristic to reference classes. As a result many classes were involved; however, the very low implementation levels used here did not cause even moderate differences between preferred and custodial management scenarios.

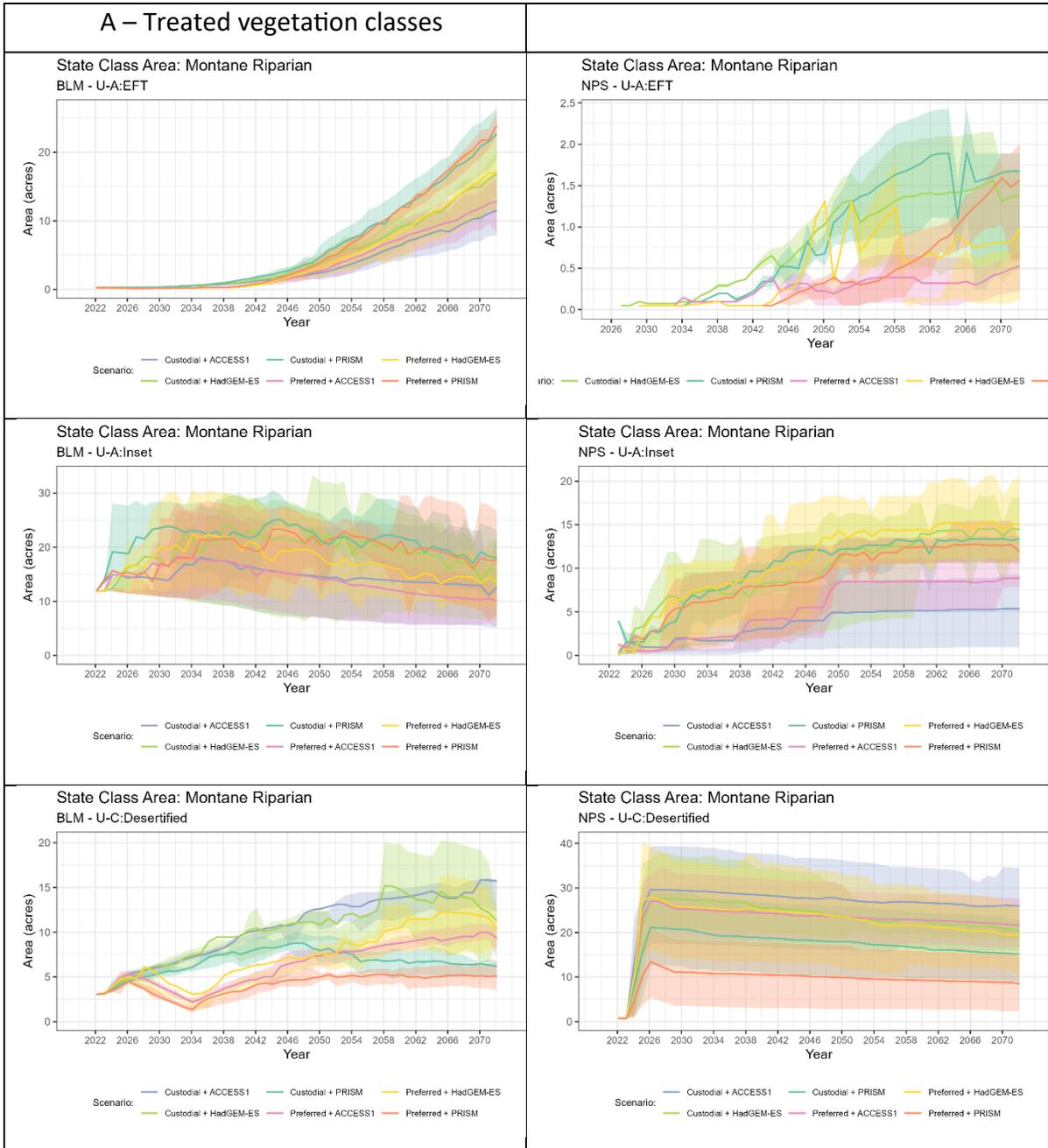
Reconnecting the creeks to their floodplains decreased the area of incised floodplain (U-C:Desertified being the most distinct among many) by at least 5 acres (Fig. 3.53A), with the primary recovery pathway often going through the uncharacteristic native shrub and forb encroached class (U-C:Shrb-Frb-Encr; Fig. 3.53A). This latter class commensurably increased by 5 acres but still contributed to departure because it was uncharacteristic. In the simulations, some acres in the incised floodplains did recover directly to the reference early successional class of willow or cottonwood if perennial shrubs were not dominant (e.g., U-A:Annual Species). Finally, results appeared dependent on climate scenarios as treatment reductions were more effective in the PRISM climate scenario than other climates (Fig. 3.53).

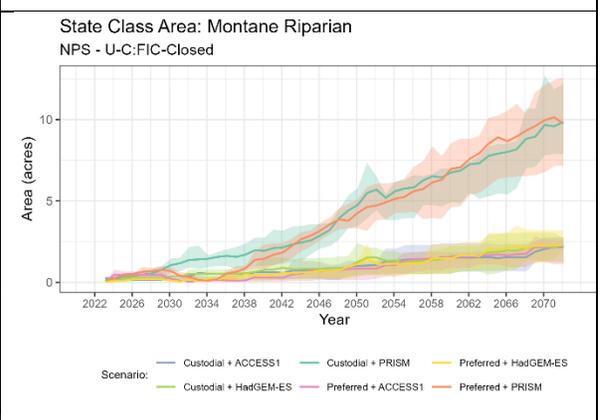
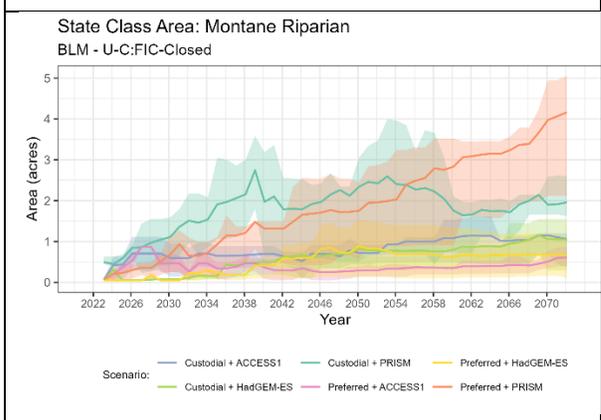
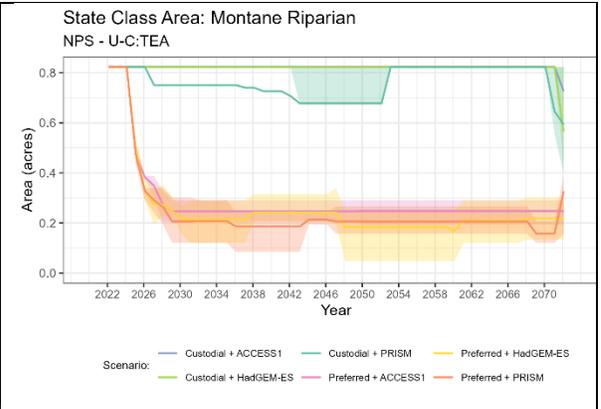
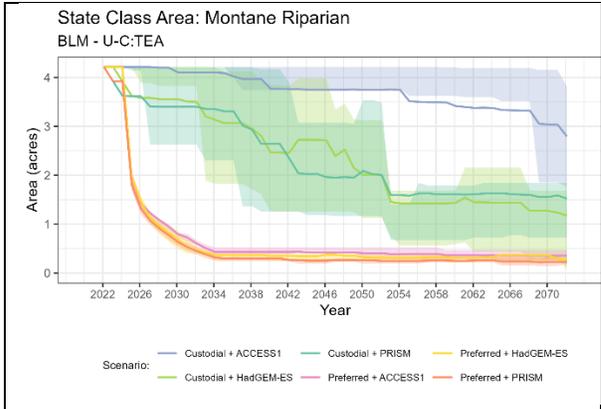
Chainsaw cutting and pile burning conifers in the wet or incised floodplains caused obvious, albeit commensurate with low implementation levels, reductions of wooded acres of the incised tree-encroached class (U-C:TEA) and fire-sensitive conifers (U-C:FIC-Closed; Fig. 3.53A). The U-C:FIC-Closed class transitioned to the reference late-successional cottonwood class (C-Cottonwood:Closed) about 70% of the time and 30% to the early-successional reference cottonwood pathway (A-Cottonwood:All) with *chainsaw cutting of conifers and pile burning*. Both of those reference classes increased by as much as 10 to 20 acres from 2025 to 2030 (Fig. 3.53B).

Both exotic control treatments (*exotic control* and *weed inventory-spot spraying*) were deployed in small amounts, especially on GBNP where total invasion levels were <1 acre (Fig. 3.53A). On BLM-managed land, *exotic control* reduced the area of the exotic forb and tree class (U-A:EFT) class area by <5 acres whereas the area invaded increased with time despite control measures due to the aggressive invasion rate. As a result, the effects of *exotic species control*, which was distributed among both willow classes and the late successional cottonwood class, could not be distinguished from other treatment effects and the background variability. Climate effects were greater than treatment effects because the area of invaded area was consistently less with drier climate (the ACCESS1 climate was drier than the HadGEM-ES climate, which is drier than the PRISM climate; Fig. 3.53).

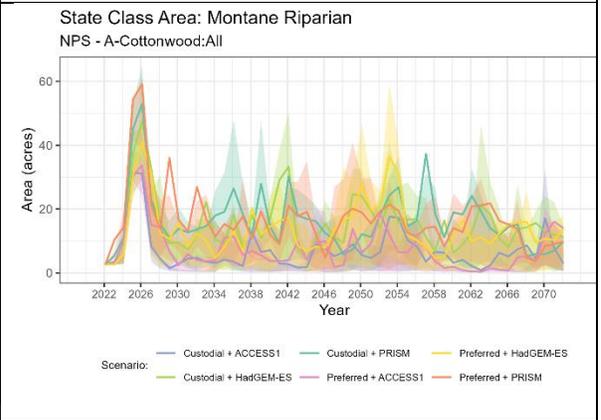
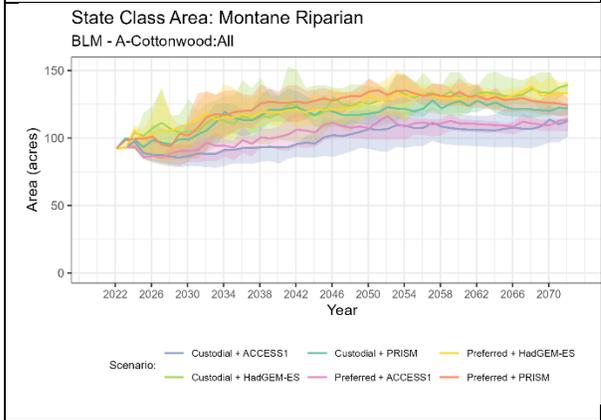
Overall, few acres were treated, yet even with these low levels treatments achieved their goals but often without resulting in reference class increases (e.g., U-C:Shrb-Frb-Encr was the outcome of restoration). These observations explained why ED did not change because the B-Willow:Closed class was not increased. Furthermore, the rapid rise of the area invaded by exotic forbs and trees (U-A:EFT) nearly overwhelmed any other gains.

A – Treated vegetation classes





B – Recipient Classes



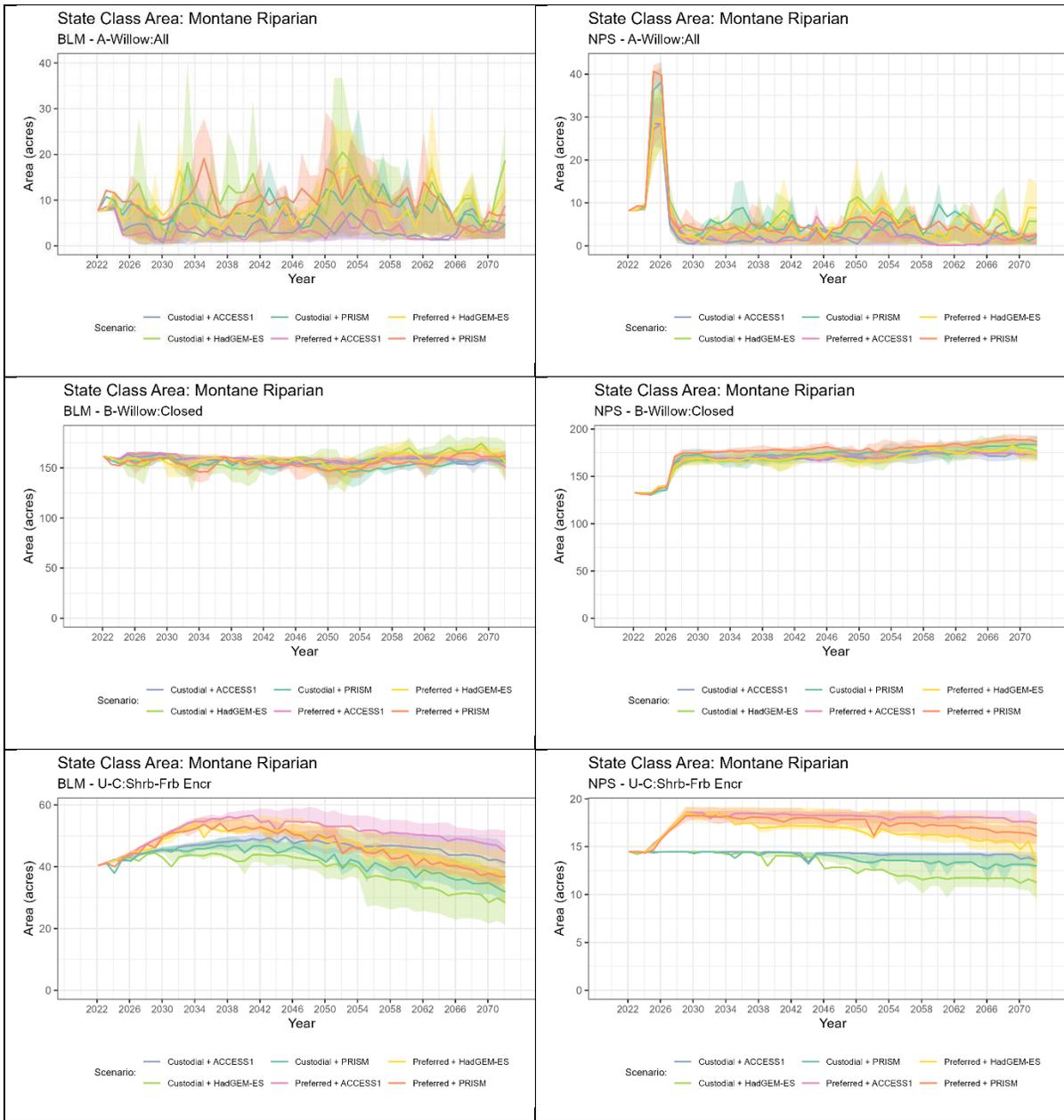


Figure 3.53. Vegetation classes of montane riparian on BLM-managed land (left panel) and GBNP (right panels) on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.14. Montane Sagebrush Steppe - mountain soil

2022 System acres at 14-m resolution: 659

2022 Landscape-wide ED: 41%

Problems or Concerns

Montane sagebrush steppe-mountain was a subalpine shrubland at the low end of moderate departure at 41%. Except for 78 acres on BLM-managed land, this system was all found in GBNP (589 acres). The main problem in this system was the mapped 26% (170 acres) in the reference late-successional open canopy class (D:Open) in GBNP compared to the 2% expected from the reference condition (Table 3.53). The overabundance of the D:Open class matched the under-representation of the reference early successional class (A:All; 6% of total area compared to the 24% expected under reference condition; Table 3.53).

Table 3.53. Vegetation classes of montane sagebrush steppe-mountain expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							3
A:Char2							0
A:All		40			40	6	24
B:Open	72	273			345	52	38
C:Closed	6	72			78	12	32
D:Open		170			170	26	2
E:Closed		10			10	2	1
U-A:Annual Spp		13			13	2	0
U-C:SA		1			1	0	0

Objectives for Management Actions

The only objective was to reduce ED as high-elevation *prescribed burning* could easily move ED to low levels of departures (Table 3.54).

Table 3.54. Realized treatment totals (acres) within each period in montane sagebrush steppe-mountain from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Prescribed Burning - Aerial Ignition (BLM: \$500/acre; NPS: \$4,000/acre)
Years	25 th – 75 th percentiles of total treatment acres
PRISM	
BLM	
2023-2024	0
2025-2029	0
2030-2034	0
2035-2039	0
2040-2072	0
NPS	
2023-2024	0
2025-2029	0
2030-2034	146-151
2035-2039	0
2040-2072	0
ACCESS1	

BLM		
2023-2024		0
2025-2029		0
2030-2034		0
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		0
2030-2034		0
2035-2039		146-151
2040-2072		0
HadGEM-ES		
BLM		
2023-2024		0
2025-2029		0
2030-2034		0
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		0
2030-2034		148-154
2035-2039		0
2040-2072		0

The only treatment was *prescribed burning ignited from helicopter* of classes with trees only on GBNP (Table 3.55). It was assumed that burning would be conducted while *aerial prescribed burning* was applied in adjacent systems. About 150 acres were treated over 5 years.

The single treatment decreased ED by 9-12% in the preferred management scenario compared to the custodial management scenario only for 2035, but barely any differences were observed in 2047 and 2072 (Table 3.55). As a result, ED was lowest in 2035.

Table 3.55. Future ED of montane sagebrush steppe-mountain (% \pm 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED \pm 1 95% Confidence Interval n = 10 replicates	
PRISM	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
2035	39% \pm 3%	26% \pm 2%
2047	34% \pm 2%	32% \pm 4%
2072	42% \pm 4%	40% \pm 5%
ACCESS1		
2035	43% \pm 2%	28% \pm 2%
2047	36% \pm 2%	38% \pm 1%
2072	36% \pm 2%	38% \pm 1%
HADGEM-ES		
2035	39% \pm 3%	25% \pm 2%
2047	37% \pm 3%	37% \pm 3%
2072	44% \pm 3%	41% \pm 4%

Cost by year (ST-Sim Results)

The annual cost was about \$17,500 from 2030 to 2034 and stayed there (Fig. 3.54). This indicated that more area was available for burning after treatment, although these areas might not have been conveniently grouped together for easier ignition.

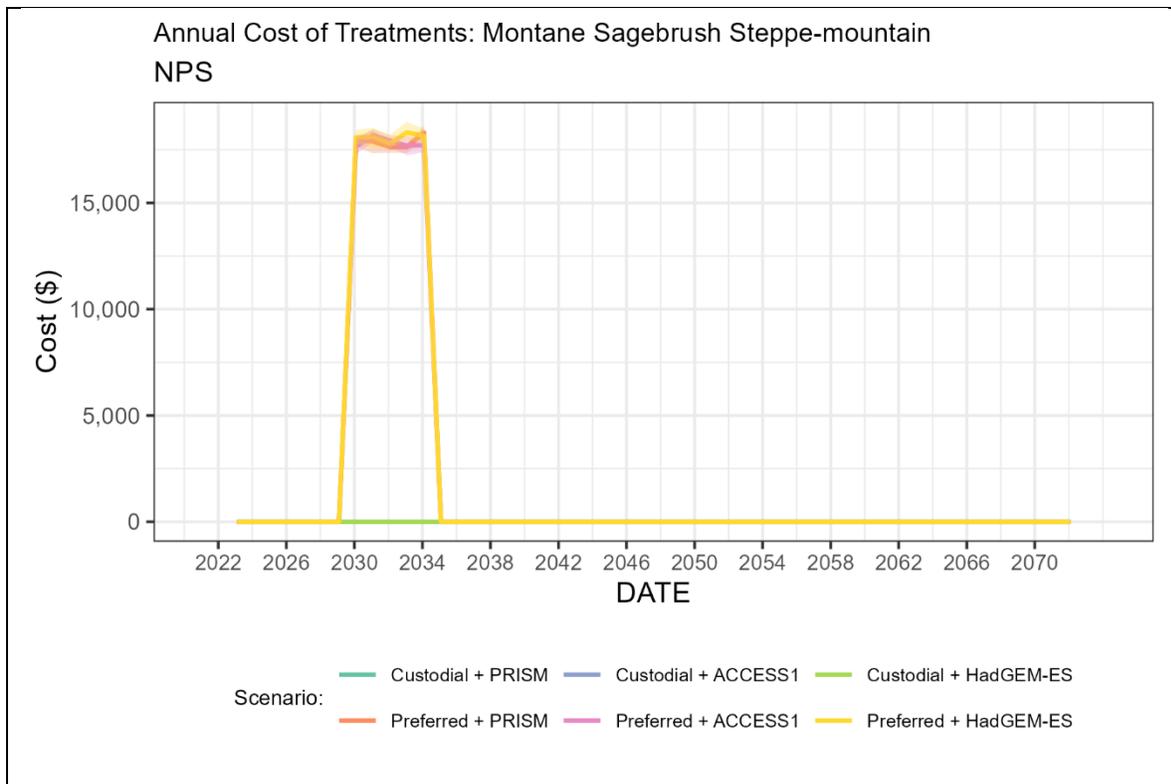


Figure 3.54. Annual cost of treatments in montane sagebrush steppe-mountain GBNP in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES). The line is the mean and error bars are the 25th-75th percentiles.

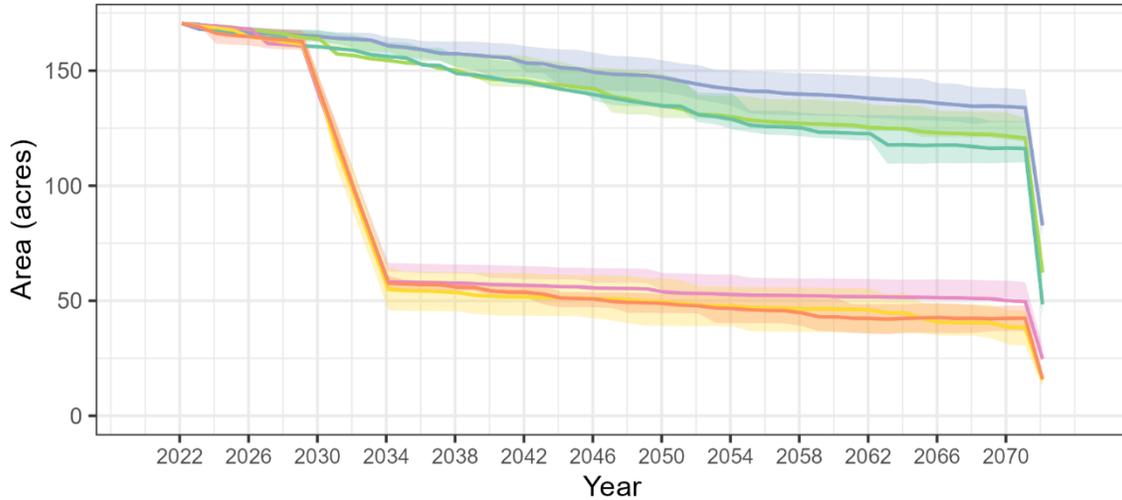
Vegetation Classes (ST-Sim Results):

Aerially ignited prescribed burning in GBNP decreased the area of the reference late-successional open canopy class (D:Open) and the reference late-successional closed canopy class (E:Closed), respectively, by 100 and 5 acres from 2030 to 2034 (Fig. 3.55A). Burning resulted in about 100 acres increase of the reference early successional class also from 2030 to 2034 (A:All; Fig. 3.55B). With time, the area of early successional vegetation (A:All) matured into the reference mid-successional open canopy class (B:Open), which itself had also started succession to the reference treeless late succession closed canopy class in 2045 (C:Closed; Fig. 3.55B). The succession to the C:Closed class, which received no treatment and reached 250 to 400 acres, was the cause for ED increasing in later years in all treatments.

A – Treated vegetation classes

State Class Area: Montane Sagebrush Steppe-mountain

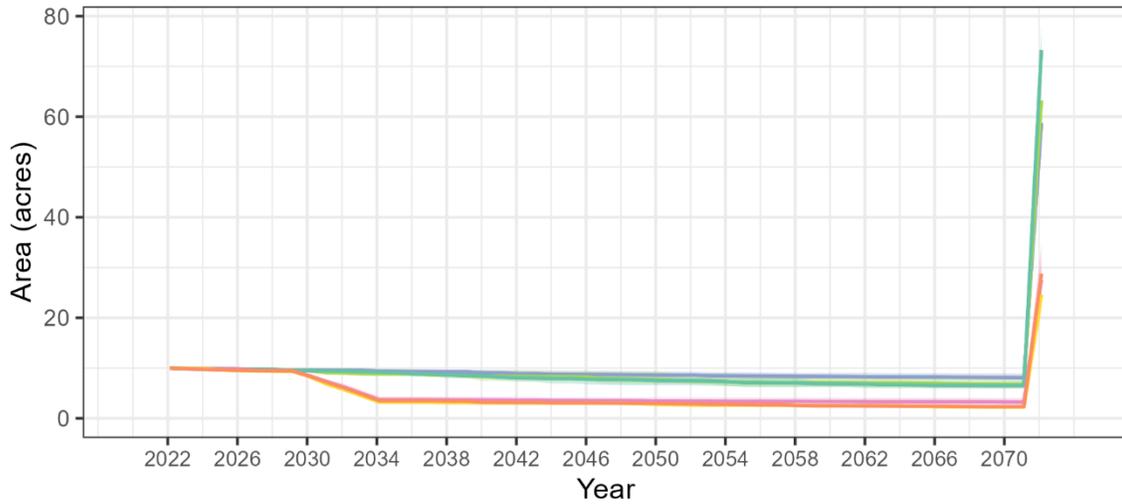
NPS - D:Open



Scenario: Custodial + ACCESS1 Custodial + PRISM Preferred + HadGEM-ES
 Custodial + HadGEM-ES Preferred + ACCESS1 Preferred + PRISM

State Class Area: Montane Sagebrush Steppe-mountain

NPS - E:Closed

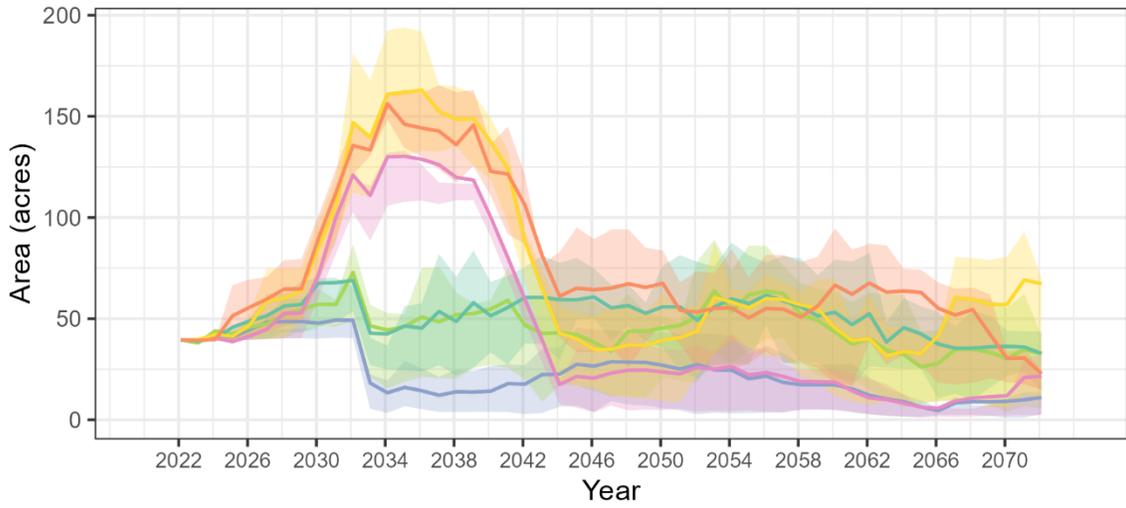


Scenario: Custodial + ACCESS1 Custodial + PRISM Preferred + HadGEM-ES
 Custodial + HadGEM-ES Preferred + ACCESS1 Preferred + PRISM

B – Recipient Classes

State Class Area: Montane Sagebrush Steppe-mountain

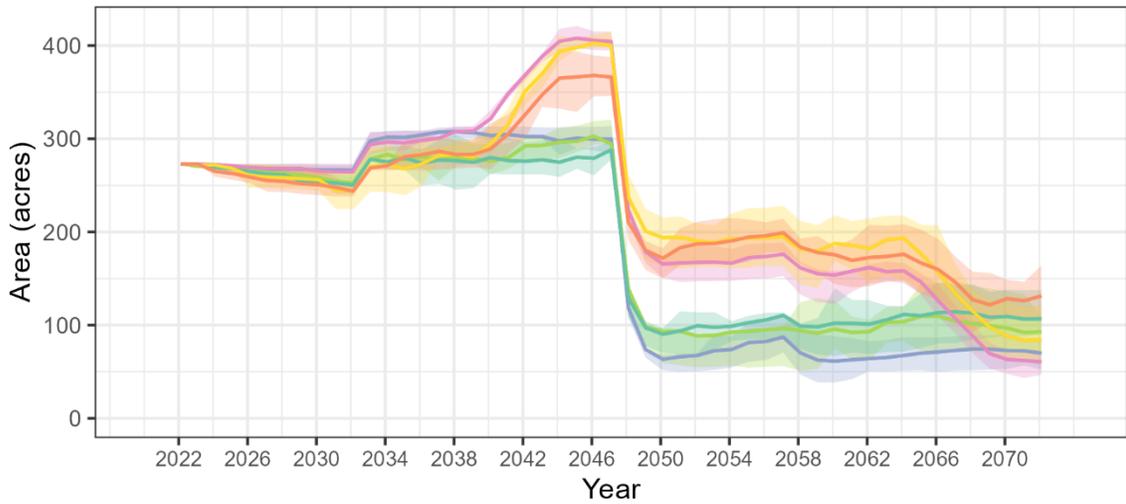
NPS - A:All



Scenario: Custodial + ACCESS1 Custodial + PRISM Preferred + HadGEM-ES
Custodial + HadGEM-ES Preferred + ACCESS1 Preferred + PRISM

State Class Area: Montane Sagebrush Steppe-mountain

NPS - B:Open



Scenario: Custodial + ACCESS1 Custodial + PRISM Preferred + HadGEM-ES
Custodial + HadGEM-ES Preferred + ACCESS1 Preferred + PRISM

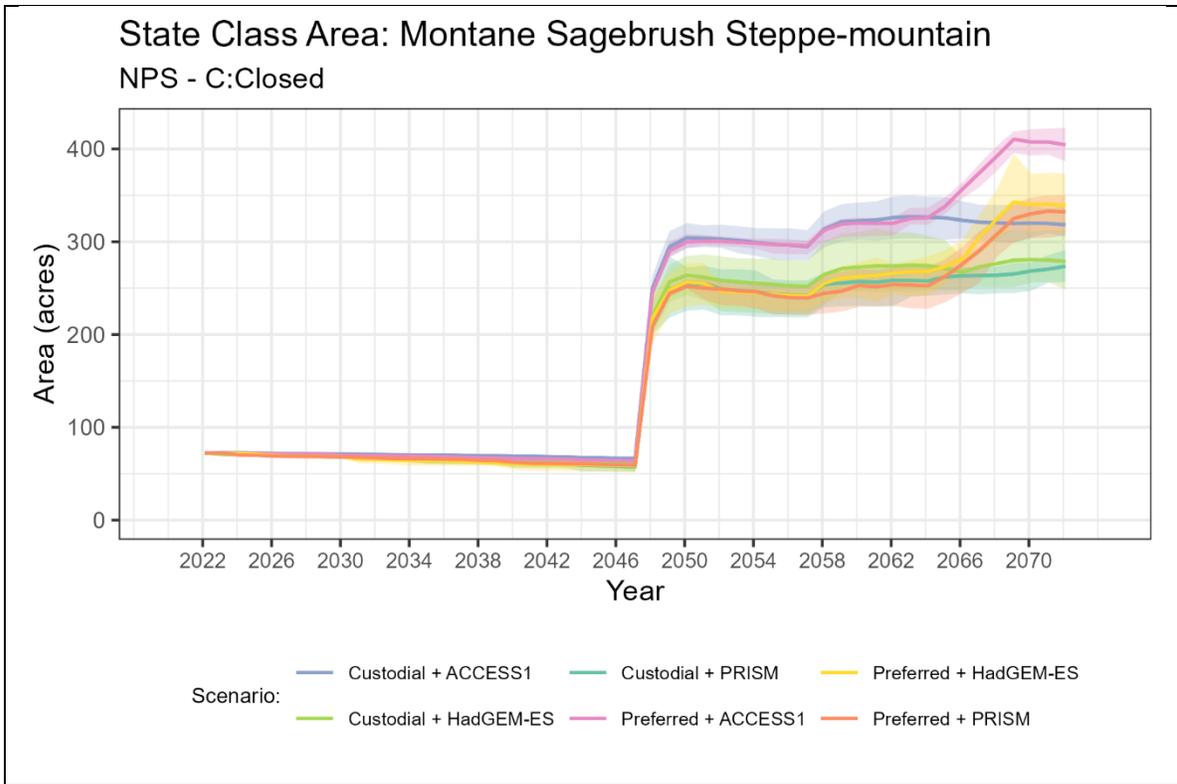


Figure 3.55. Vegetation classes of montane sagebrush steppe-mountain GBNP on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.15. Montane Sagebrush Steppe-upland soil

2022 System acres at 14-m resolution: 36,790

2022 Landscape-wide ED: 74%

Problems or Concerns

Montane sagebrush steppe-upland was commonly found in all ownerships (24,051 acres on BLM-managed land, 12,052 acres on GBNP, 563 acres on private lands, and 115 acres on USFS-managed land). The shrubland was highly departed from the reference condition at 74%.

Several problems caused high departure on both BLM-managed land and GBNP (Table 3.56):

1. Too many young conifers in shrublands (D:Open mapped at 28% compared to 2% expected from the reference condition);
2. Too little of the reference early successional class (3% mapped of A:All compared to 22% expected);
3. Too little of the mid-successional open canopy class (B:Open mapped at 16% compared to 38% expected),
4. Too little of late successional closed canopy class (C:Closed mapped at 4% compared to 31% expected);
5. Eight percent of the uncharacteristic late-successional open canopy with non-native annual species and native grass species (should be 0%);
6. Eighteen percent of the uncharacteristic tree-encroached class with possible nonnative annual species (U-E:TEA; should be 0%); and
7. About 3% of the system’s area dominated by non-native annual species, mostly found on steep slopes of the Strawberry Creek and the Black Fires.

Table 3.56. Vegetation classes of montane sagebrush steppe-upland expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							3
A:Char2							3
A:All	285	667	<1		953	2.6	22
B:Open	3,826	2,008	19	53	5,907	16.1	38
C:Closed	283	1,269		<1	1,553	4.2	31

D:Open	5,716	4,488	218	9	10,431	28.4	2
E:Closed	436	1,081			1,517	4.1	1
U-A:Annual Spp	680	429	11		1,120	3.0	0
U-A:Bare Ground	<1	<1	<1		1	0.0	0
U-A:Early Shrub	6	1	<1	<1	8	0.0	0
U-A:Exotic Forb	41		17	1	60	0.2	0
U-A:SAP	1,208	1,019	4		2,230	6.1	0
U-A:SI	2				2	0.0	0
U-A:SI+AS	0				0	0.0	0
U-A:Unpalat Forb	31				31	0.1	0
U-B:SAP	345	131	5	3	484	1.3	0
U-B:SI	6	6			12	0.0	0
U-B:SI+AS	1			<1	1	0.0	0
U-B:Unpalat Forb	36				36	0.1	0
U-C:Depleted	219	<1	1		220	0.6	0
U-C:SA	103		3	<1	106	0.3	0
U-C:SAP	2,303	6	66	13	2,389	6.5	0
U-C:SI	38	<1	2		40	0.1	0
U-C:SI+AS	1				1	0.0	0
U-C:Unpalat Forb	1				1	0.0	0
U-D:SAP	2,106	667	129	12	2,915	7.9	0
U-D:SI	45	<1	12		57	0.2	0
U-E:TEA	6,333	287	74	24	6,716	18.3	0

Objectives for Management Actions

Three objectives were proposed: reduce ED, protect infrastructure, and prevent excessive sedimentation in creeks after high-severity fires fueled by conifers. GBNP staff housing, Lehmann visitor center, Baker Creek and Lehman campgrounds, and a municipal watershed where surrounded or adjacent to the tree-encroached class of montane sagebrush steppe-upland. Many Bonneville cutthroat trout streams where adjacent to this system in the treed class. Houses and other structures within private inholdings were also in proximity or within the

tree-encroached class on BLM-managed land, especially along Highway 6/50. The system was important to mule deer and elk.

BLM achieved its objectives with *mastication followed by seeding with introduced and native species* to address the reference wooded late-successional class (E:Closed) and the tree-encroached class (U-E:TEA; Table 3.57). *Small tree lopping* was deployed to cut younger conifers in the reference and various uncharacteristic late-successional open canopy classes (D:Open, U-D:SAP, U-D:SI; Table 3.57). It should be noted that only *small tree lopping* in the D:Open class will reduce ED because the other actions either created uncharacteristic seedings with introduced species or transferred acres among uncharacteristic classes, thus not reducing ED.

For GBNP, the use of *ground-ignited prescribed fire* was used in limited amount to transition the reference late-successional open canopy class (D:Closed) to the reference early successional class (A:All), whereas the *chainsaw lopping and scattering* of conifer fuels followed by native species seeding was applied to heavier fuels (E:Closed and U-E:TEA), especially near infrastructure (Table 3.57). These actions should all decrease ED.

An important consideration for reduction of ED is that the total area treated was small compared to the landscape-wide size of the system and outcomes from some actions on the larger BLM-managed land maintained uncharacteristic classes, albeit more desirable ones; therefore, ED was not expected to change appreciably.

Table 3.57. Realized treatment totals (acres) within each period in montane sagebrush steppe-upland from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Chainsaw + Lop + Scatter + Native Seed (NPS: \$365- 500/acre)	Masticate + Seed (BLM: \$577/acre)	Prescribed Burning - Ground Ignition (BLM: \$200- 300/acre; NPS: \$1,134/acre)	Small Tree Lopping (BLM: \$65- \$95/acre; NPS: \$250/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres
PRISM				
BLM				
2023-2024	0	0	0	0
2025-2029	0	146-152	0	772-874
2030-2034	0	493-507	0	13-33

2035-2039	0	489-504	0	8-24
2040-2072	0	0	0	0
NPS				
2023-2024	0	0	0	0
2025-2029	371-380	0	47-53	0
2030-2034	39-51	0	48-52	0
2035-2039	0	0	0	0
2040-2072	0	0	0	0
ACCESS1				
BLM				
2023-2024	0	0	0	0
2025-2029	0	146-152	0	833-892
2030-2034	0	494-506	0	15-37
2035-2039	0	491 -503	0	4-27
2040-2072	0	0	0	0
NPS				
2023-2024	0	0	0	0
2025-2029	371-382	0	47-52	0
2030-2034	39-42	0	48-52	0
2035-2039	0	0	0	0
2040-2072	0	0	0	0
HadGEM-ES				
BLM				
2023-2024	0	0	0	0
2025-2029	0	146-154	0	841-891
2030-2034	0	496-506	0	12-34
2035-2039	0	493-505	0	9-29
2040-2072	0	0	0	0

NPS						
2023-2024		0		0		0
2025-2029		371-380		0		48-51
2030-2034		38-48		0		46-51
2035-2039		0		0		0
2040-2072		0		0		0

ED was consistently 1%-2% smaller in the preferred management than custodial management scenarios; however, several differences were likely not significant as 95% confidence intervals overlapped (Table 3.58). In each climate scenario, ED decreased over time but less in the ACCESS1 climate where the reduced fire activity maintained wooded areas well after the periods of treatment implementation (Table 3.58).

Table 3.58. Future ED of montane sagebrush steppe-upland (% \pm 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED \pm 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	71% \pm 1.5%	70% \pm 0.9%
2047	69% \pm 1.8%	68% \pm 1.4 %
2072	64% \pm 2.1%	63% \pm 1.9%
ACCESS1		
2035	71% \pm 1%	70% \pm 0.7%
2047	71% \pm 1%	70% \pm 0.7%
2072	68% \pm 1.2%	66% \pm 1.1%
HADGEM-ES		
2035	71% \pm 1%	70% \pm 0.9%
2047	68% \pm 1.9%	68% \pm 1.3%
2072	62% \pm 1.9%	63% \pm 1%

Cost by year (ST-Sim Results)

BLM's annual cost started in 2025 at about \$35,000, slightly decreased from 2026 to 2028, and dipped to \$20,000 in 2029 as *small tree lopping* was exhausting accessible areas of young trees (Fig. 3.56). Cost rebounded to \$60,000 from 2030 to 2034 with the increased use of *mastication followed by seeding*. In GBNP, two plateaus of spending reached \$43,000 from 2025 to 2029 and \$47,000 from 2030 to 2034 (Fig. 3.56). The use of *prescribed burning* dominated the cost of restoration despite the variation in the implementation rates of *chainsaw lopping and scattering following by native seeding*.

Vegetation Classes (ST-Sim Results):

While ED was slightly reduced by treatments, vegetation classes responded appreciably to management (Fig. 3.57). On BLM-managed land, climate differences were much greater than treatment effects as small tree lopping only reduced the area of the D:Open class by <200 acres in the PRISM climate by year 2040, but <20 acres in the ACCESS1 climate scenario; however, the D:Open class was 1,000 acres greater in both custodial and preferred management scenarios for the ACCESS1 climate than the other climates by 2060 (Fig. 3.57). Also, the area of this class progressively decreased over time as well for other classes and, as seen later, the non-native annual species class increased substantially over time because of new wildfires (Fig. 3.57). The same patterns with climate and treatment emerged for GBNP; however, treatment differences never exceeded 10-20 acres by 2035.

Small tree lopping was also used in the U-D:SAP, U-D:SA, and U-D:SI classes, whereas treatments were not used in those classes on GBNP. The area of the U-D:SAP class decreased by about 800 acres in the preferred management scenario compared to the custodial management scenario by year 2029 (Fig. 3.57). It was noteworthy that the U-D:SAP class precipitately decreased in the first two years and transitioned to the U-D:SA class; however, this was a model error associated with boot-stage cattle grazing. The area should have remained in U-D:SAP. No such transition occurred in GBNP because livestock grazing was absent from GBNP. Regardless the U-D:SA classes decreased by 600 acres due to small tree lopping (Fig. 3.57). The area of the late successional introduced species seeding class was reduced by 20 acres in the preferred management compared to the custodial management scenario by 2034.

The reference wooded late-successional closed canopy class (E:Closed) was only treated in GBNP where the *chainsaw lopping and scattering following by native species seeding* resulted in an about 500 acres decrease in the preferred management compared to custodial management scenarios (Fig. 3.57). No such change was observed on BLM-managed land where treatments were not used.

Mastication and seeding in the uncharacteristic tree-encroached class (U-E:TEA) on BLM-managed land resulted in at most a 1,000-acre decrease compared to the custodial management scenario by year 2035, although some climate differences were also present (Fig. 3.57). The area of the class progressively decreased over time. Chainsaw operations on GBNP resulted in a 100-acre reduction compared to the custodial management scenario by year 2034. Here, the U-E:TEA class's area did not decrease with time (Fig. 3.57).

The reference early successional class (A:All) increased by about 50 acres in the preferred management scenario compared to custodial management scenario before 2030 only in GBNP where *ground-ignited prescribed burning* was used. Also, when native seeding was used after cutting trees, the native seeding class (U-A: Seeded Native) increased by about 40 acres in the preferred management scenario *versus* the custodial management scenario on GBNP. No differences were noted on BLM-managed land because no treatments would have caused a transition to this class. Instead, the introduced species seeding class (U-A:SI) progressively increased by 60 acres by 2034 because of *BLM mastication followed by seeding* (Fig. 3.57).

As a result of *small tree lopping* in the U-D:SA and U-D:SA classes, the recipient classes U-C:SAP and U-C:SA, respectively, increased by 800 acres and 40 acres (Fig. 3.55). For both classes, the area was greater in the ACCESS1 climate than the PRISM and HadGEM-ES climates.

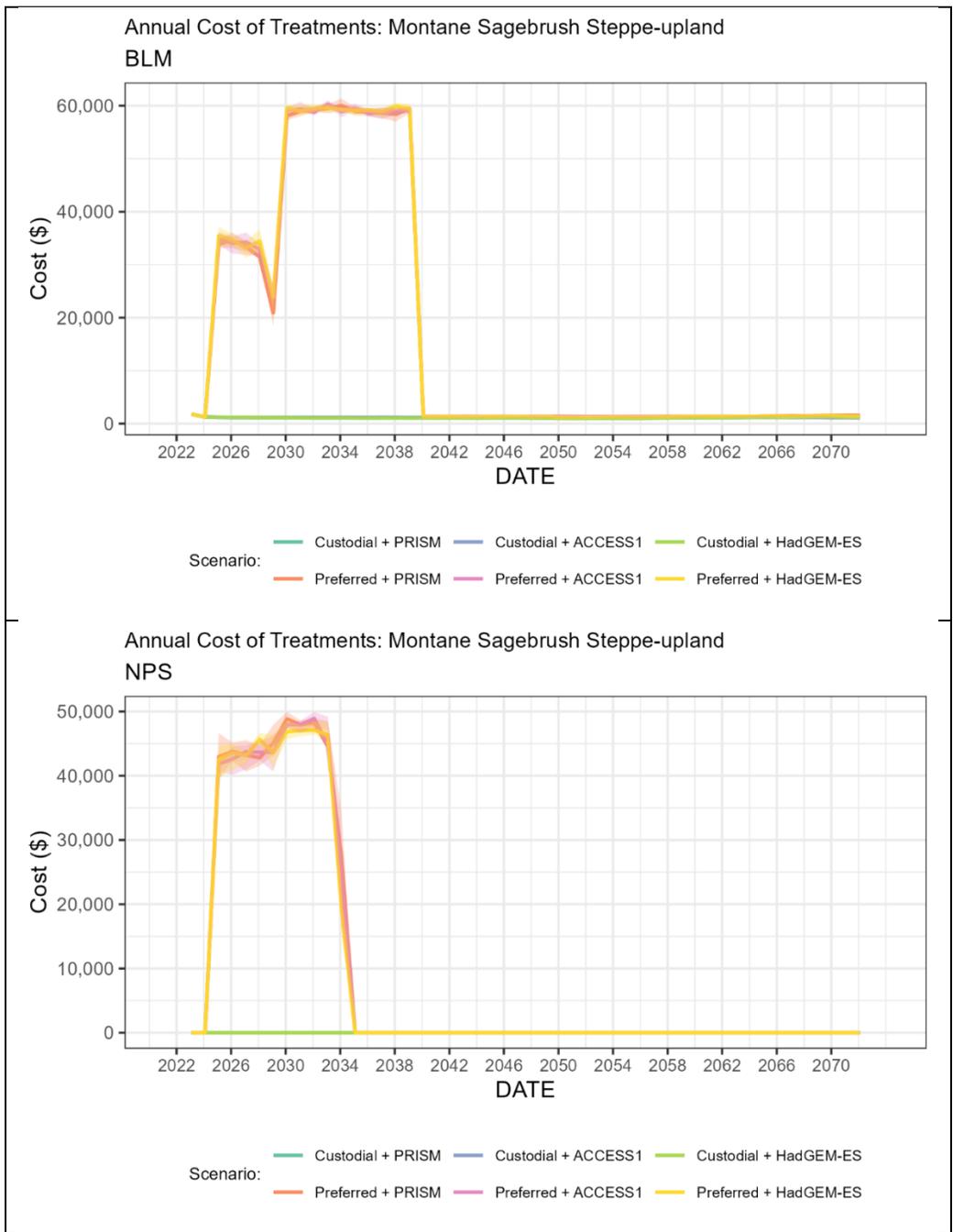
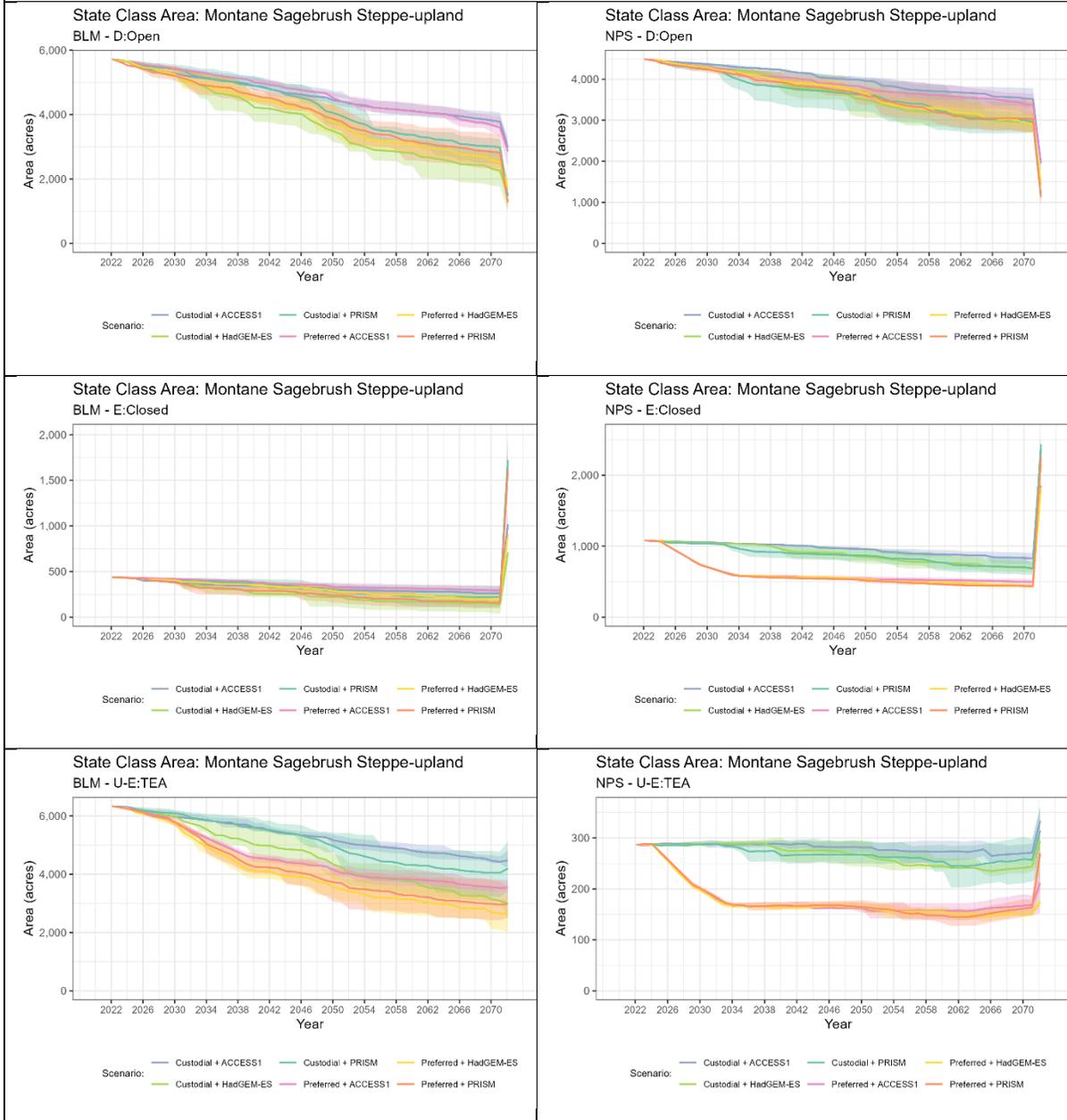
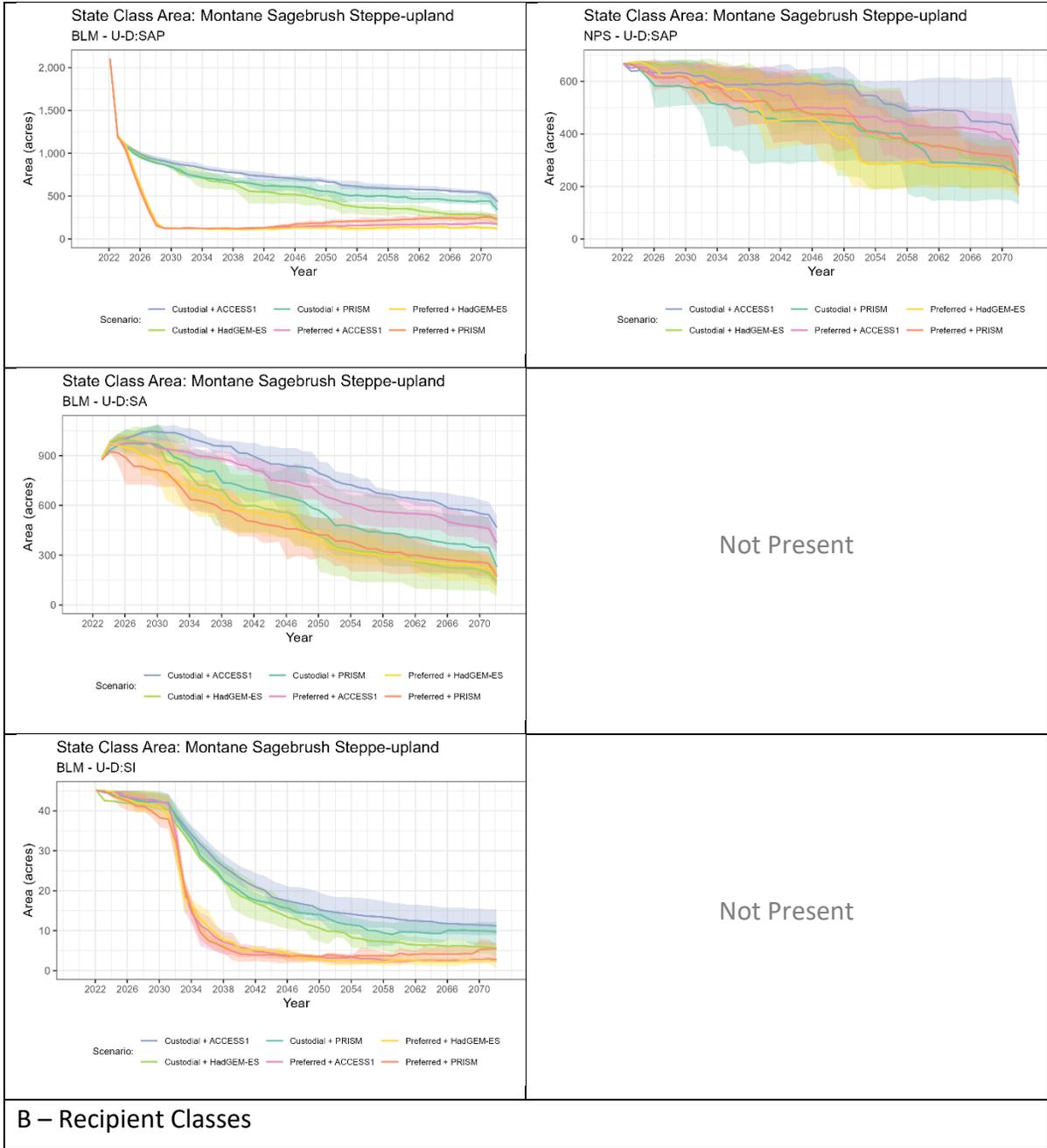
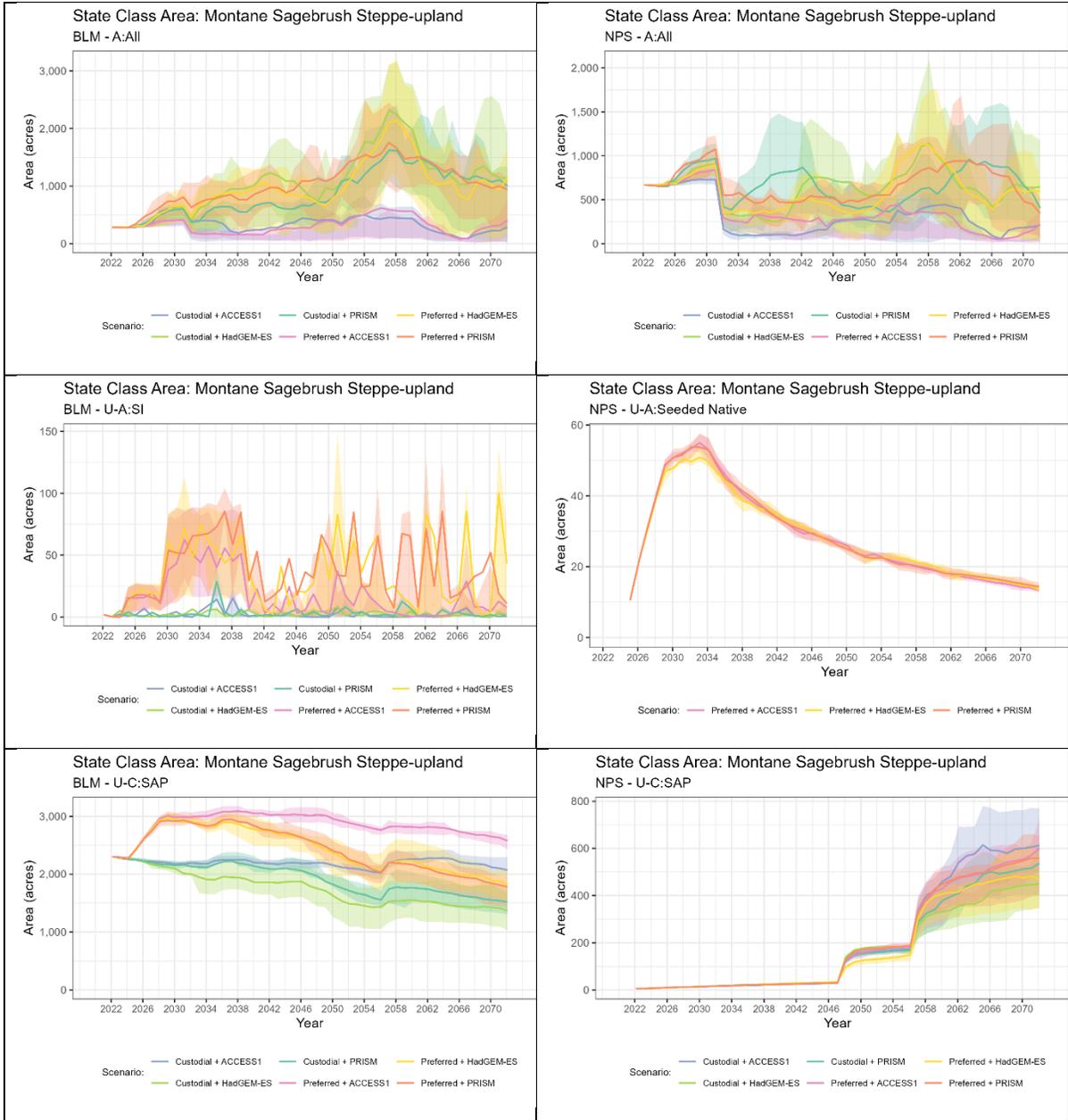


Figure 3.56. Annual cost of treatments in montane sagebrush steppe-mountain for BLM-managed land and GBNP in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

A – Treated vegetation classes







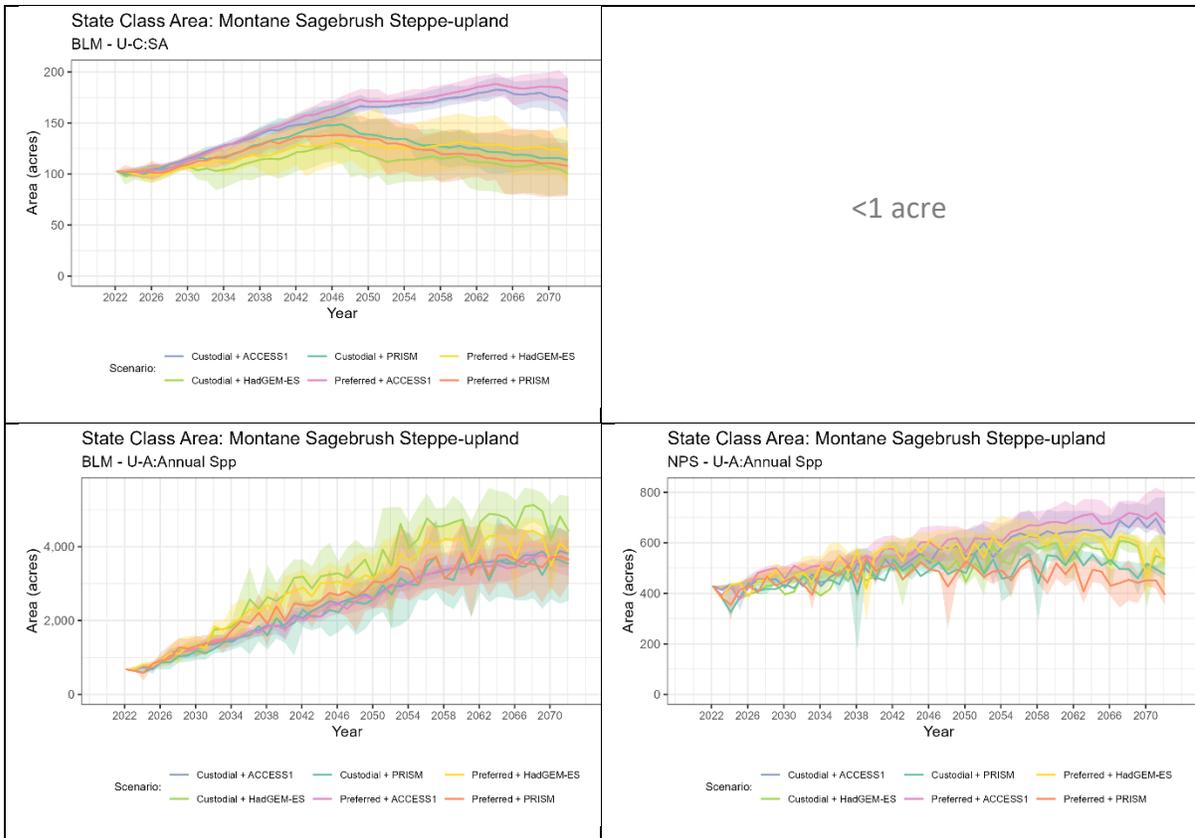


Figure 3.57. Vegetation classes of montane sagebrush steppe-upland on BLM-managed land (left panel) and GBNP (right panels) on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.16. Mountain Shrub

2022 System acres at 14-m resolution: 4,082

2022 Landscape-wide ED: 59%

Problems or Concerns

The 4,082 acres of mountain shrub were moderately departed from the reference condition (59%). Most of the system was on BLM-managed land (3,847 acres), whereas USFS-managed land (116 acres) had more than GBNP (111 acres), which had more than private lands (7 acres). The causes of moderate ED were the over-representation of the reference late successional open class (D:Open; 32% mapped, mostly on BLM-managed land, compared to 2% expected) causing too little area left for the reference late successional closed canopy class (C:Closed; 4.2% observed compared to 53% expected under the reference condition; Table 3.59). Moreover, about 10% of mountain shrub was in the tree-encroached class (U-D:TEA) compared to 0% expected, nearly entirely on BLM-managed land.

Table 3.59. Vegetation classes of mountain shrub expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Other classes were presented in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							3
A:All				9	9	0.2	6
B:Closed	1,839	31	3	17	1,890	46.3	35
C:Closed	101	68		1	170	4.2	53
D:Open	1,277	12	3	12	1,303	31.9	2
U-A:Annual Spp	4				4	0.1	0
U-A:Bare Ground	10		1		10	0.2	0
U-A:Early Shrub	14				14	0.3	0
U-A:SAP	15				15	0.4	0
U-B:SAP	203				203	5.0	0
U-B:SI	1				1	0.0	0
U-C:Depleted	42				42	1.0	0

U-D:SI+AS	4			1	5	0.1	0
U-D:TEA	339	1	0	77	417	10.2	0

Objectives for Management Actions

Both BLM and GBNP decided to apply *aerially ignited prescribed fire* to reduce ED and improve wildlife browse (Table 3.60). The targeted class would be, respectively, the 1,277-acre and 12-acre reference wooded late-successional classes (D:Open) on BLM-managed land and GBNP. *Prescribed burning* would cause a transition to the reference early successional class (A:All), which was initially absent from the landscape, except on USFS-managed land in 2023. Because the treatment was not a priority, it was delayed to 2030-2034 and combined with *aerial prescribed burning* of adjacent and more extensive systems, such as aspen (Table 3.60). By then, more trees would have grown in the late successional class.

Table 3.60. Realized treatment totals (acres) within each period in mountain shrub from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Prescribed Burning - Aerial Ignition (BLM: \$200- 300/acre; NPS: \$1,134/acre)
Years	25 th – 75 th percentiles of total treatment acres
PRISM	
BLM	
2023-2024	0
2025-2029	0
2030-2034	375-426
2035-2039	0
2040-2072	0
NPS	
2023-2024	0
2025-2029	0

2030-2034		21-23
2035-2039		0
2040-2072		0
ACCESS1		
BLM		
2023-2024		0
2025-2029		0
2030-2034		411-430
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		0
2030-2034		21-23
2035-2039		0
2040-2072		0
HadGEM-ES		
BLM		
2023-2024		0
2025-2029		0
2030-2034		410-423
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		0
2030-2034		21-22
2035-2039		0

2040-2072	0
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About 400 acres and 12 acres, respectively, of *prescribed burning* was used on BLM-managed land and GBNP (Table 3.61). ED was consistently lower 3% to 9% (absolute value) in the preferred management scenario than the custodial management scenario and 95% CIs did not overlap (Table 3.61). While ED remained moderately departed over the simulation’s duration, it mostly decreased between the 2035 and 2047 reporting years. No climate effects were observed.

Table 3.61. Future ED of mountain shrub (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	57% ± 0.7%	54% ± 0.8%
2047	47% ± 0.9%	38% ± 1.7%
2072	47% ± 1.7%	42% ± 1.6%
ACCESS1		
2035	56% ± 0.7%	53% ± 0.8%
2047	46% ± 0.5%	37% ± 1%
2072	46% ± 0.5%	37% ± 1%
HADGEM-ES		
2035	56% ± 1.6%	53% ± 0.9%
2047	48% ± 3.9 %	40% ± 2.7%
2072	47% ± 3.5%	43% ± 2.7%

Cost by year (ST-Sim Results)

BLM’s annual cost was at first \$85,000 from 2030 to 2033, then started to decrease by about \$10,000 in 2034, suggesting greater difficulty for ST-Sim to find available areas to treat (Fig. 3.58). The cost to GBNP was a peak of \$7,000 in 2030, which rapidly decrease to <\$100 by 2034.

Given that 12 acres were present in GBNP in 2023, the exhaustion of available area was expected.

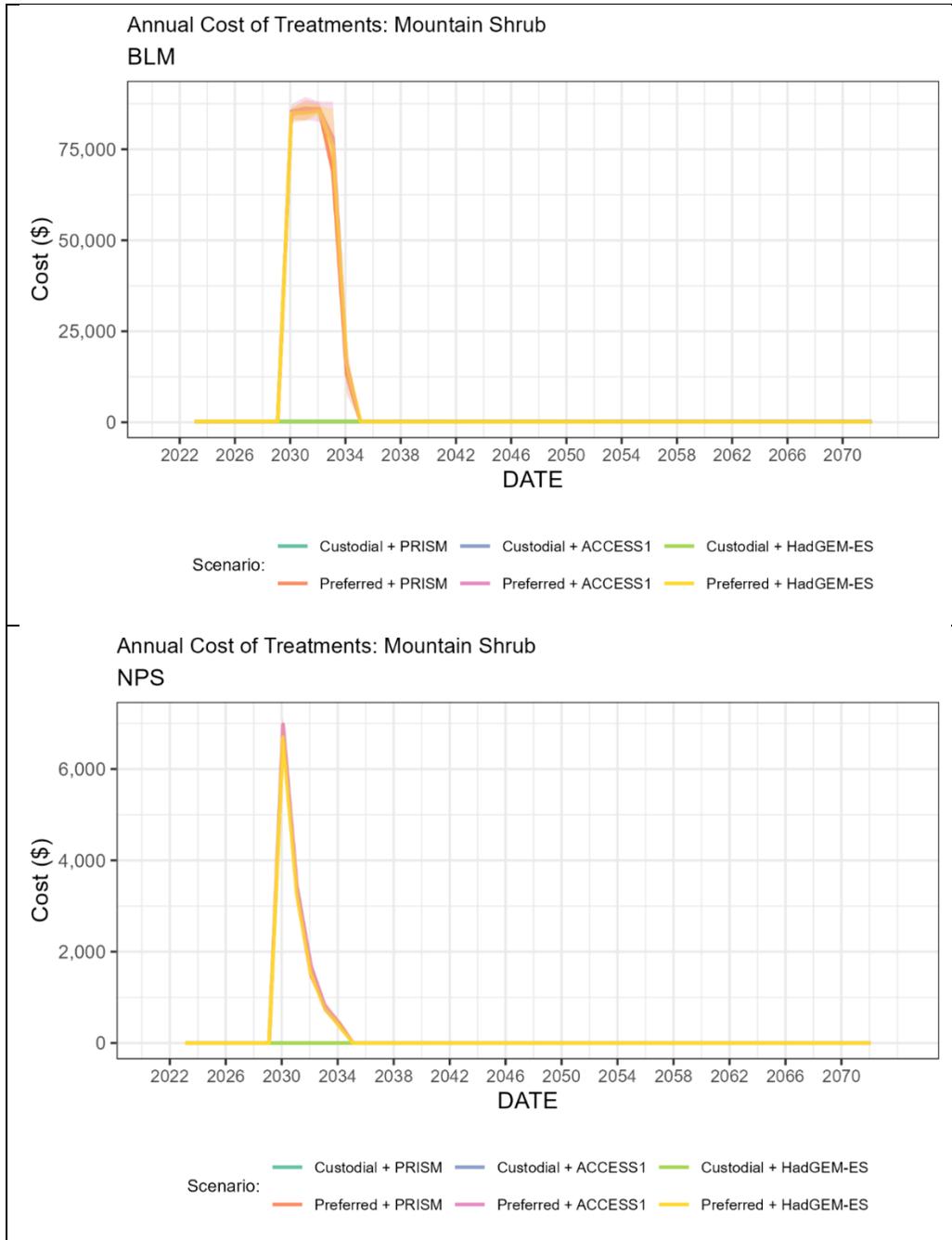


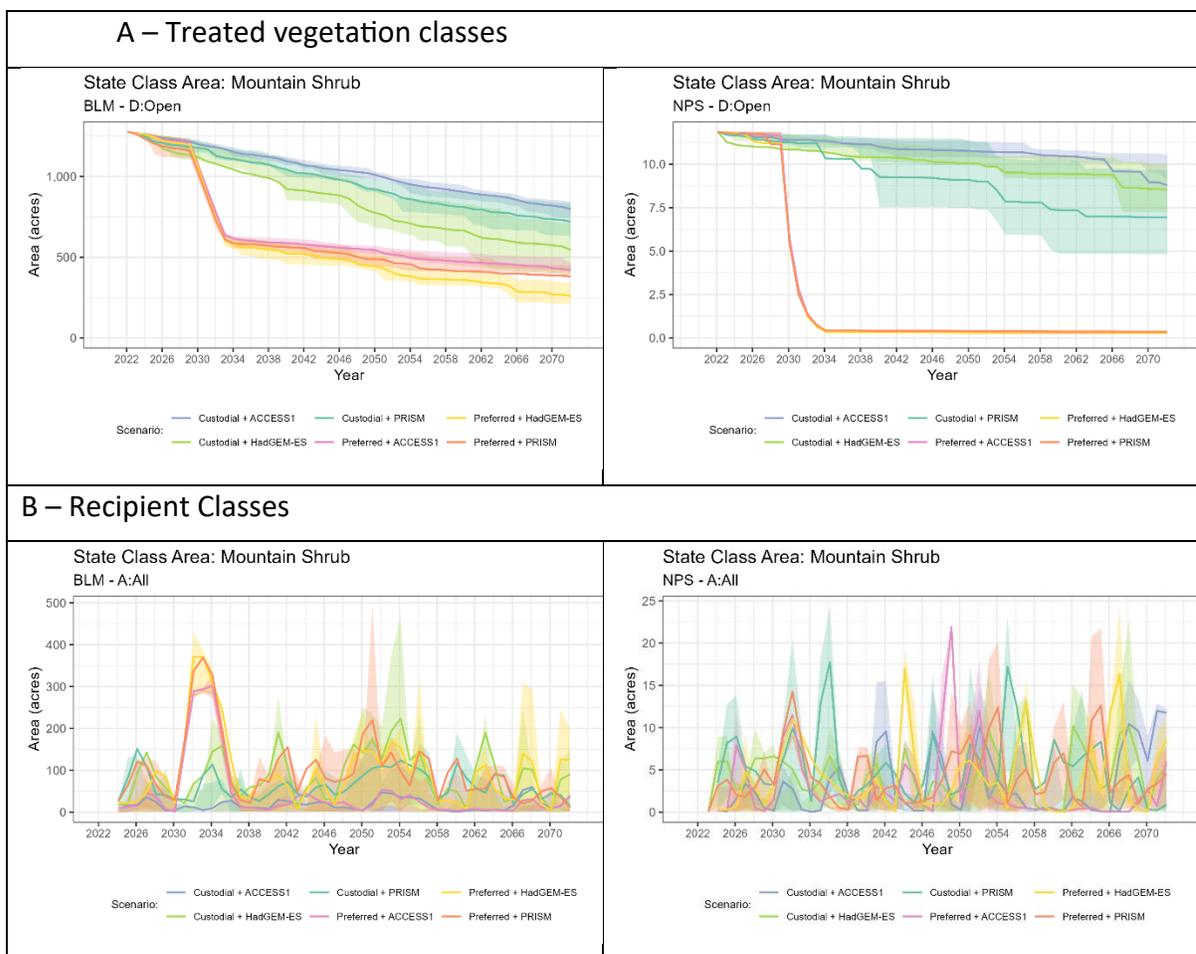
Figure 3.58. Annual cost of treatments in mountain shrub for BLM-managed land and GBNP in the South Snake Range. Cost only applied to the preferred management combined with each of three future

climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

While ED was slightly reduced by treatments, *aerial-ignited prescribed burning* had large effects on target classes. The reference late successional open canopy class (D:Open) was reduced, respectively, by about 500 acres and 11 acres from 2030 to 2034 in BLM-managed land and GBNP (Fig. 3.59A). Therefore, the D:Open class was nearly eliminated in GBNP.

In response to burning, the reference early successional class (A:All) increased, respectively, by 300 to 350 acres and 10-12 acres from 2030 to 2034 in BLM-managed land and GBNP (Fig. 3.59B). This pulse of young mountain shrubland matured to the reference mid-successional closed canopy class (B:Closed) five years later in both ownerships, which itself matured into the already present area reference late successional closed canopy class (C:Closed; Fig. 3.59B).



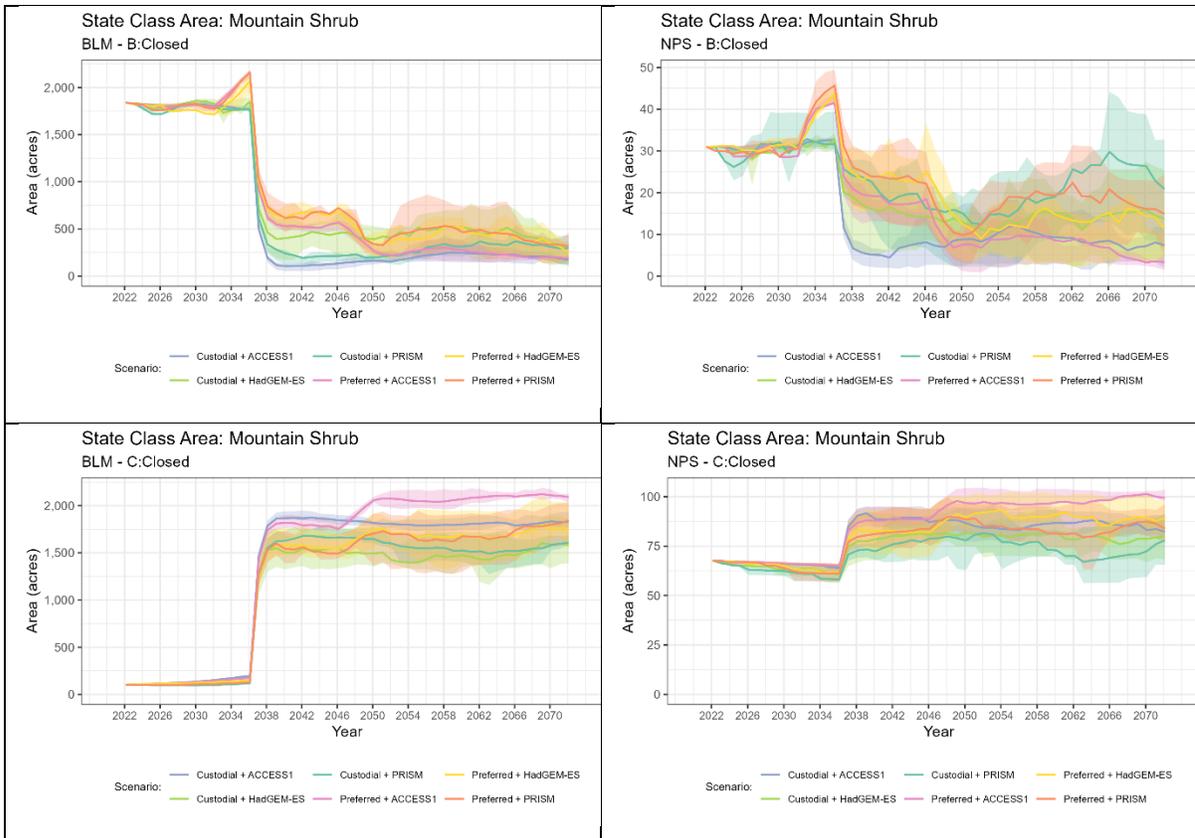


Figure 3.59. Vegetation classes of mountain shrub on BLM-managed land (left panel) and GBNP (right panels) on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.17. Ponderosa Pine

2022 System acres at 14-m resolution: 530

2022 Landscape-wide ED: 51%

Problems or Concerns

Ponderosa pine covered 530 acres in the landscape. About 308 acres were located on BLM-management land, 218 acres were mapped in GBNP, and the remaining 3 acres were on private lands. The system was moderately departed from reference conditions at 51%, although estimates of non-spatial ED for small systems was likely biased (not a problem for spatially explicit; ED Hann and Strom 2003; Steele et al. 2006; Provencher et al. 2024). The distribution of class areas was near reference conditions on BLM-managed land because of the Philips Ranch Fire; however, the late-successional closed canopy class (C:Closed) was too abundant on GBNP (137 acres) whereas the late-successional open canopy class was underrepresented at 12 acres (Table 3.62). Too much area of the reference early successional class (A:All) and the older closed canopy class (C:Closed) were the primary sources of moderate departure; however, only the C:Closed could be treated.

Table 3.62. Vegetation classes of ponderosa pine expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							0
A:All	122	57			179	34	8
B:Closed	7	6	0		13	2	6
B:Open	34	6			40	8	26
C:Closed	5	137	2		143	27	2
C:Open	142	12			154	29	57

Objectives for Management Actions

The primary objective was to reduce ED by transitioning area from the late-successional closed canopy class to the late-successional open canopy class. Because ponderosa pine was distributed in patches, therefore not easily prescribed burned, *chainsaw cutting of fuels ladders to open canopies followed by pile burning* was expected to feasibly lower ED if achieved in

sufficient area (Table 3.63). Another programmatic objective was the *collection of pinecones* for seed storage.

Table 3.63. Realized treatment totals (acres) within each period in ponderosa pine from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Chainsaw + Pile Burning (BLM: \$500/acre NPS: \$4,000/acre)	Pinecone Collection (BLM & NPS: \$1,000/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres
PRISM		
BLM		
2023-2024	0	6.6-7.1
2025-2029	0	1.8-2.5
2030-2034	0.5-1.0	0
2035-2039	0	0
2040-2072	0	0
NPS		
2023-2024	0	49-50
2025-2029	5.9-6.2	18-21
2030-2034	0	0
2035-2039	0	0
2040-2072	0	0
ACCESS1		
BLM		
2023-2024	0	6.6-6.9

2025-2029	0	1.6-2.3
2030-2034	0.5-0.9	0
2035-2039	0	0
2040-2072	0	0
NPS		
2023-2024	0	49-51
2025-2029	5.6-6.1	19-21
2030-2034	0	0
2035-2039	0	0
2040-2072	0	0
HadGEM-ES		
BLM		
2023-2024	0	6.6-6.8
2025-2029	0	1.6-2.2
2030-2034	0.5-0.6	0
2035-2039	0	0
2040-2072	0	0
NPS		
2023-2024	0	49-50
2025-2029	5.5-6.0	18-21
2030-2034	0	0
2035-2039	0	0
2040-2072	0	0

Small area (<1 acre) of *chainsaw cutting followed by pile burning* was used on BLM-managed land in the 2030-2034 period, which was consistent with the small area of the closed canopy classes (Table 3.63). About 10 times more of the same treatment (5.5-6.2 acres) was used five years earlier from 2025-2029 in GBNP (Table 3.63). *Pinecone collection* was conducted from 2023 to 2034 in both BLM-managed land and GBNP, respectively, at rates of about 6.7 acres and 50 acres. The rates of implementation of *chainsaw and pile burning* were lower from 2025

to 2029 at about 1.8 acres and 20 acres, respectively, in BLM-managed land and GBNP (Table 3.63).

ED was consistently 3% to 6% (absolute values) lower in the preferred management scenario than custodial management scenario until the 2047 reporting year; however, differences vanished after the last 25 years (2072 reporting year) without management (Table 3.64). This degradation points to the need for maintenance management. ED decreased over time reaching lower values, even achieving low departure in the ACCESS1 and HadGEM-ES climates, at the end of simulations in 2072 (Table 3.64). ED stayed in the moderate departure range, albeit at the low end (39%), in the PRISM climate (Table 3.64).

Table 3.64. Future ED of ponderosa pine (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	46% ± 2.5%	40% ± 0.5%
2047	44% ± 2.3%	40% ± 0.6%
2072	39% ± 2.2%	39% ± 3.4%
ACCESS1		
2035	43% ± 1.3%	37% ± 0.5%
2047	38% ± 1.4%	35% ± 0.8%
2072	25% ± 1.4%	25% ± 1.0%
HADGEM-ES		
2035	44% ± 1.6%	38% ± 0.9%
2047	41% ± 1.9%	37% ± 1.1%
2072	29% ± 4.2%	29% ± 3.2%

Cost by year (ST-Sim Results)

BLM's annual cost did not exceed \$350 with a first peak of expenses (\$350) for *pinecone collection* in 2030 (Fig. 3.60). A second period of minor expenses (<\$75) were incurred from 2030 to 2034 for *chainsaw cutting and pile burning*. Only a few pixels were treated on BLM-

managed land. Considerably more expenses (about \$22,000) were calculated in GBNP in mostly 2025 for both *pinecone collection* and thinning fuel ladders in closed canopy classes (Fig. 3.60).

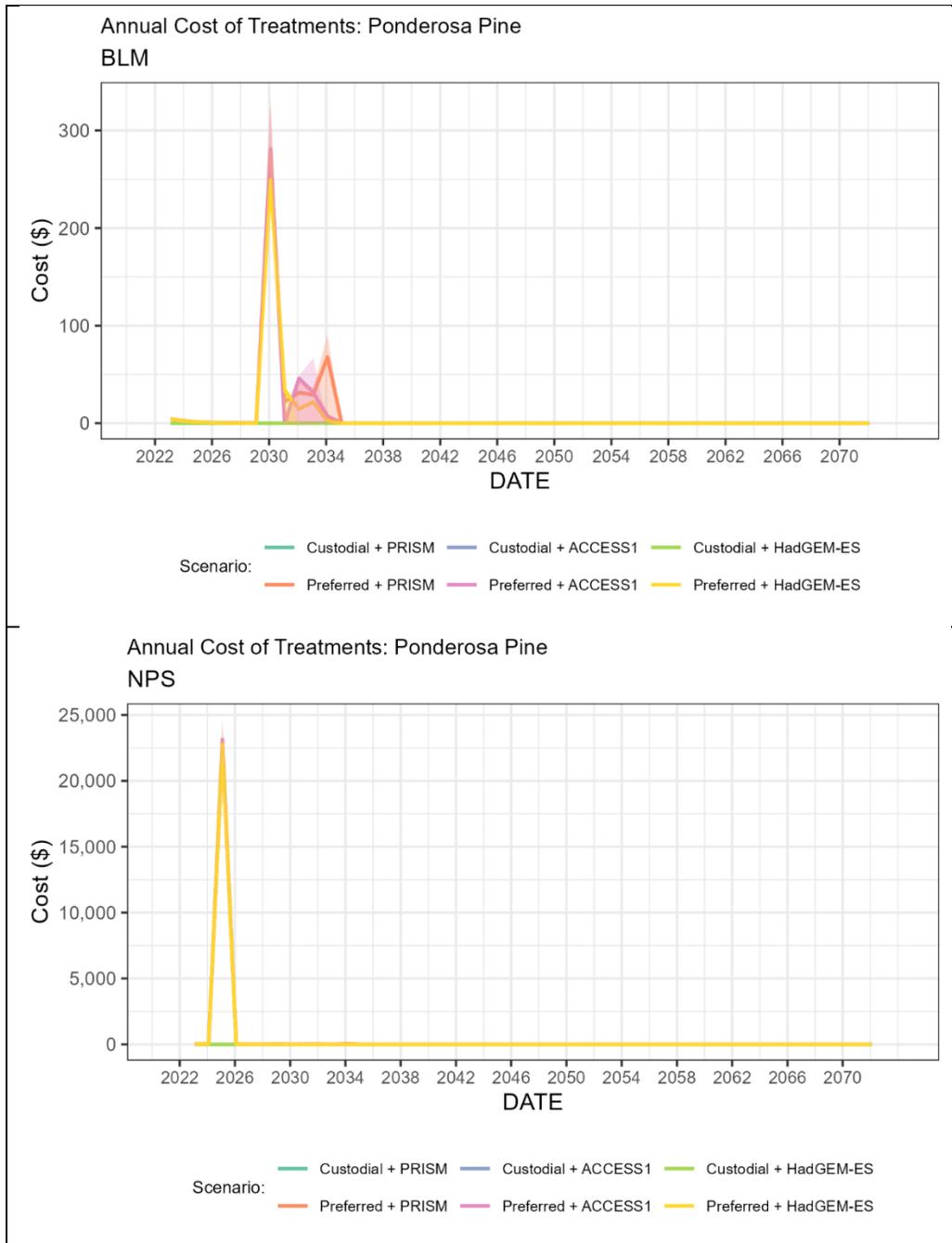


Figure 3.60. Annual cost of treatments in ponderosa pine for BLM-managed land and GBNP in the South Snake Range. Cost only applied to the preferred management combined with each of three future

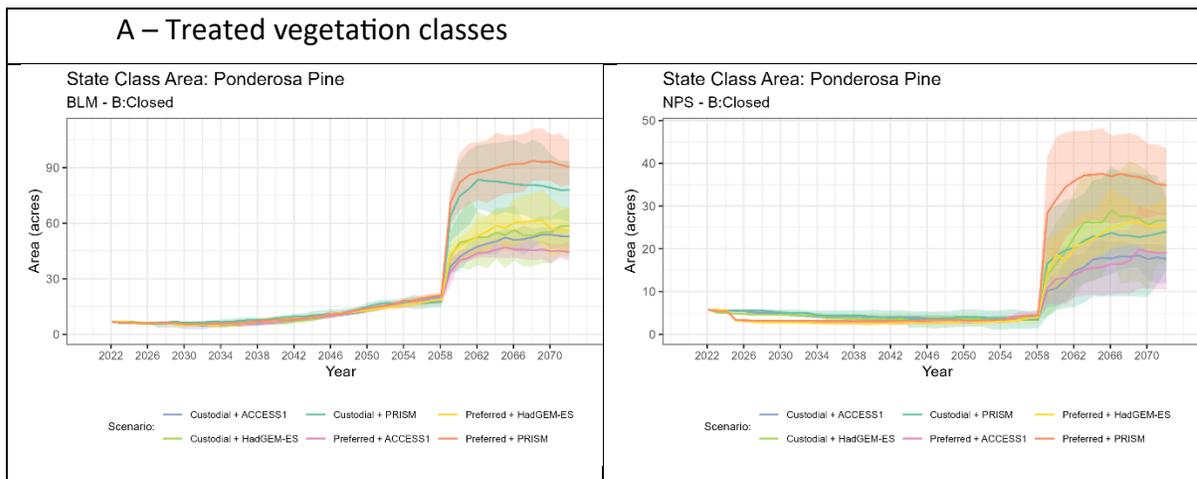
climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

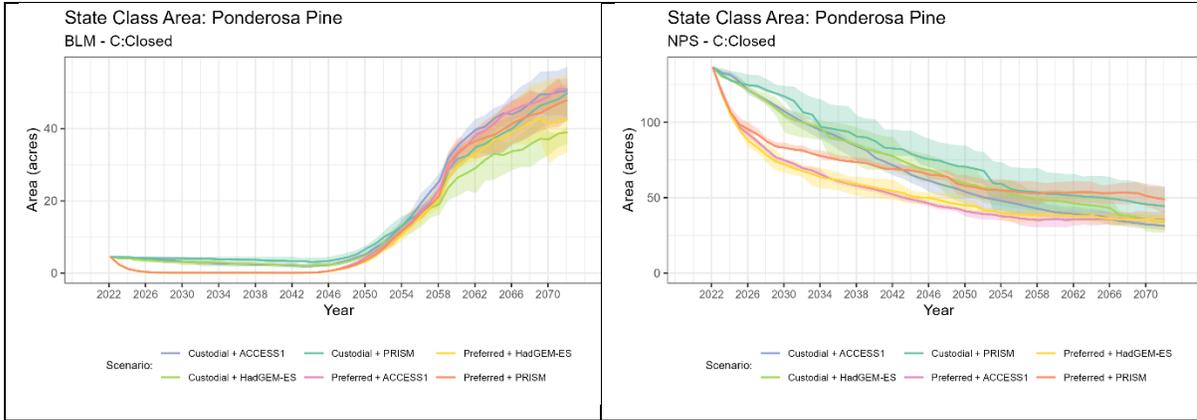
Vegetation Classes (ST-Sim Results):

The effect of *chainsaw cutting and pile burning* was mostly observed in the reference late-successional closed canopy class (C:Closed) where the treatment decreased class area by about 2 acres and 25 acres in the preferred versus custodial management scenarios, respectively, on BLM-managed land and GBNP by 2026 to 2030 (Fig. 3.61A). Only a few acres were treated in the reference mid-successional closed canopy class (B:Closed). Interestingly, the area of the preferred management scenario became more abundant than the custodial management scenario after 25 years of no treatment as observed after 2048; therefore, continued management is important to keep closed canopy classes in check (Fig. 3.61A). This result alone would substantially decrease ED.

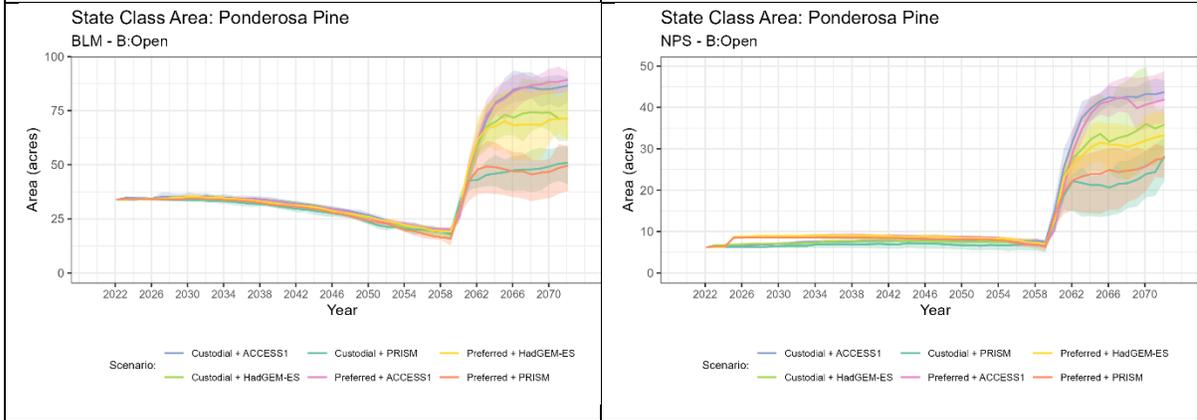
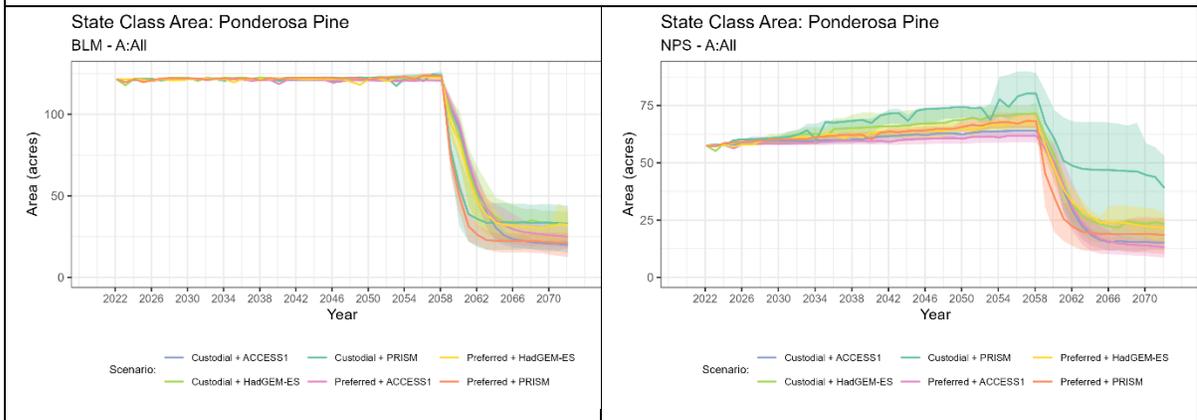
Treatment effects were more noticeable in the reference late-successional open-canopied classes (C:Open) than mid-successional open-canopied class (Fig. 3.61B). The most pronounced treatment was found for GBNP with a steady increase of about 25 acres compared to a few acres in other open canopy classes in both ownerships. Overall, the small investment into ponderosa pine was successful, especially for GBNP.

Another quirk of results was the sudden increase of the B:Open class in 2058 because of succession from the reference early successional class (A:All; Fig. 3.61B). This result can be seen from the equally sudden decrease of the A:All class during the same period.





B – Recipient Classes



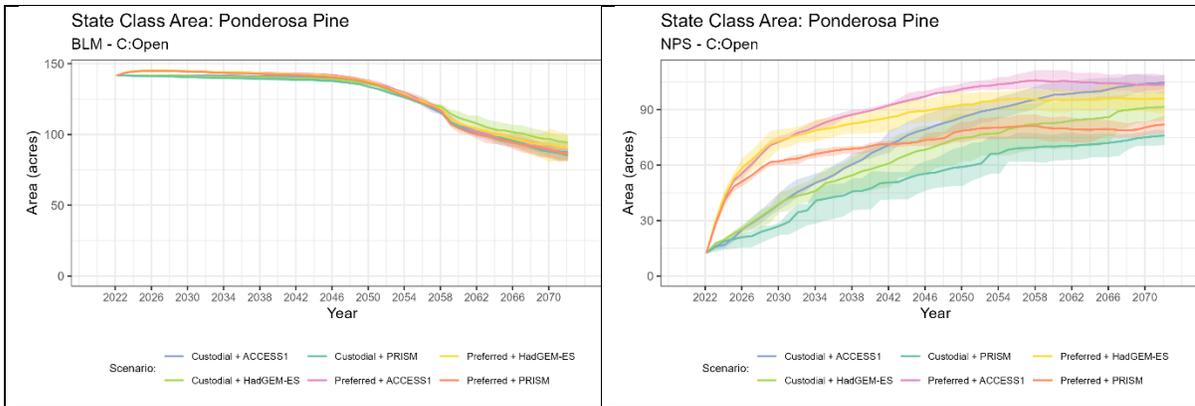


Figure 3.61. Vegetation classes of ponderosa pine on BLM-managed land (left panel) and GBNP (right panels) on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.18. Riparian Ponderosa Pine

2022 System acres at 14-m resolution: 454

2022 Landscape-wide ED: 39%

Problems or Concerns

The 454 acres of the system was about equally distributed in BLM-managed land and GBNP but absent from private lands and USFS-managed land. ED was at the low end of moderate departure. Too much area was in the reference early successional class (A:All; 56.4%) and mid-successional open canopy class (B:Open; 21.3%), respectively, compared to the reference condition (respectively, 35% and 7%; Table 3.65). Too little area was in the reference mid-successional closed canopy class (B:Closed; 5.2%), reference late-successional closed canopy class (C:Closed; 6.1%), and reference late-successional open canopy class (C:Open; 7.9%), respectively, compared to the reference condition at 17%, 17%, and 25% (Table 3.65). In other words, older classes were under-represented likely due to past high severity wildfires or historic logging.

Table 3.65. Vegetation classes of riparian ponderosa pine expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							1
A:All	124	132			256	56.4	35
B:Closed	7	17			23	5.2	17
B:Open	47	49			96	21.3	7
C:Closed	15	13			28	6.1	17
C:Open	33	3			36	7.9	25
U-A:Annual Spp	2				2	0.5	0
U-A:FIC-All	11				11	2.5	
U-B:FIC-Closed	1				1	0.1	

Objectives for Management Actions

While BLM and GBNP can only wait for saplings (A:All) to age into trees, management objectives were to *thin trees and pile burn* a small amount of closed canopy classes, *collect pinecones* for seed storage, and *track and control exotic noxious weeds* (Table 3.66). Tree thinning might *increase* ED by reducing even more the area of closed canopy trees, already below the reference percentages (Table 3.66). However, opening the canopy of closed classes might reduce the likelihood of stand-replacing wildfire killing legacy pines in waterways.

Table 3.66. Realized treatment totals (acres) within each period in riparian ponderosa pine from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Chainsaw & Pile Burning (BLM: \$500/acre NPS: \$4,000/acre)	Pinecone Collection (BLM & NPS: \$1,000/acre)	Weed Inventory & Spot Spraying (BLM & NPS: \$115/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres
PRISM			
BLM			
2023-2024	0	9-11	0
2025-2029	0	23-26	4.3-5.7
2030-2034	12-23	0	4.3-5.3
2035-2039	0.2-5.8	0	4.5-5.8
2040-2072	0	0	0
NPS			
2023-2024	0	9.6-10.3	0
2025-2029	5.4-7.2	24-26	4.2-5.7
2030-2034	0	9.4-11.3	4.1-5.6
2035-2039	0	0	4.5-6.1
2040-2072	0	0	0

ACCESS1				
BLM				
2023-2024	0		10-11	0
2025-2029	0		24-26	4.1-5.6
2030-2034	18-24		0	4.2-5.5
2035-2039	0.8-4.1		0	4.4-5.8
2040-2072	0		0	0
NPS				
2023-2024	0		9.5-10.4	0
2025-2029	5.7-7.0		23-24	4.7-6.0
2030-2034	0.1-0.9		8.6-10.8	4.6-5.7
2035-2039	0.1-0.5		0	4.2-5.7
2040-2072	0		0	0
HadGEM-ES				
BLM				
2023-2024	0		9.3-10.6	0
2025-2029	0		24-27	4.3-5.6
2030-2034	16-25		0	4.2-5.6
2035-2039	0.5-2.9		0	4.0-5.4
2040-2072	0		0	0
NPS				
2023-2024	0		9.4-10.9	0
2025-2029	5.9-7.1		24-26	4.3-5.7
2030-2034	0-0.8		9.1-10.5	4.3-5.4
2035-2039	0.1-0.8		0	4.3-5.8
2040-2072	0		0	0

Chainsaw cutting followed by pile burning would be the largest contributor to change in ED (Table 3.67). About 22 acres of this action was applied from 2030 to 2039 on BLM-managed land and about 7 acres were implemented in GBNP from 2025 to 2039, although mostly from 2025 to 2029. More than 39 acres of *pinecone collection* were conducted from 2023-2029 on BLM-managed land and 2023 to 2034 in GBNP (Table 3.67). *Detecting exotic noxious plant species and spot spraying* was applied in steady amount (about 5 acres) from 2025 to 2039 (Table 3.67). This action should be continued until the entire system is surveyed regardless the area of exotic species present.

As predicted, ED was larger (worse) by 2-4% (absolute value) in the preferred management scenario than the custodial management scenario in most years and scenarios, except for the ACCESS1 climate on reporting years 2047 and 2072 (Fig. 3.67). Increased ED was a consequence of reducing the area of already under-represented classes. The 95% confidence intervals did not overlap; therefore, differences were significant.

Table 3.67. Future ED of riparian ponderosa pine (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	31% ± 1.0%	35% ± 0.6%
2047	30% ± 2%	32% ± 4%
2072	38% ± 5%	41% ± 6%
ACCESS1		
2035	32% ± 0.6%	35% ± 0.5%
2047	48% ± 4%	45% ± 3%
2072	58% ± 3%	57% ± 3%
HADGEM-ES		
2035	32% ± 0.7%	35% ± 1.0%
2047	35% ± 5%	37% ± 4%
2072	43% ± 6%	44% ± 5%

Cost by year (ST-Sim Results)

BLM's annual cost peaked at \$10,000 in 2030 but then dropped to negligible amounts from 2031 to 2039 (Fig. 3.62). Cost peaked at \$22,000 in 2025 in GBNP (Fig. 3.62). As with BLM, cost greatly diminished and persisted until 2029. Chainsaw cutting and pile burning was the primary source of expenditures.

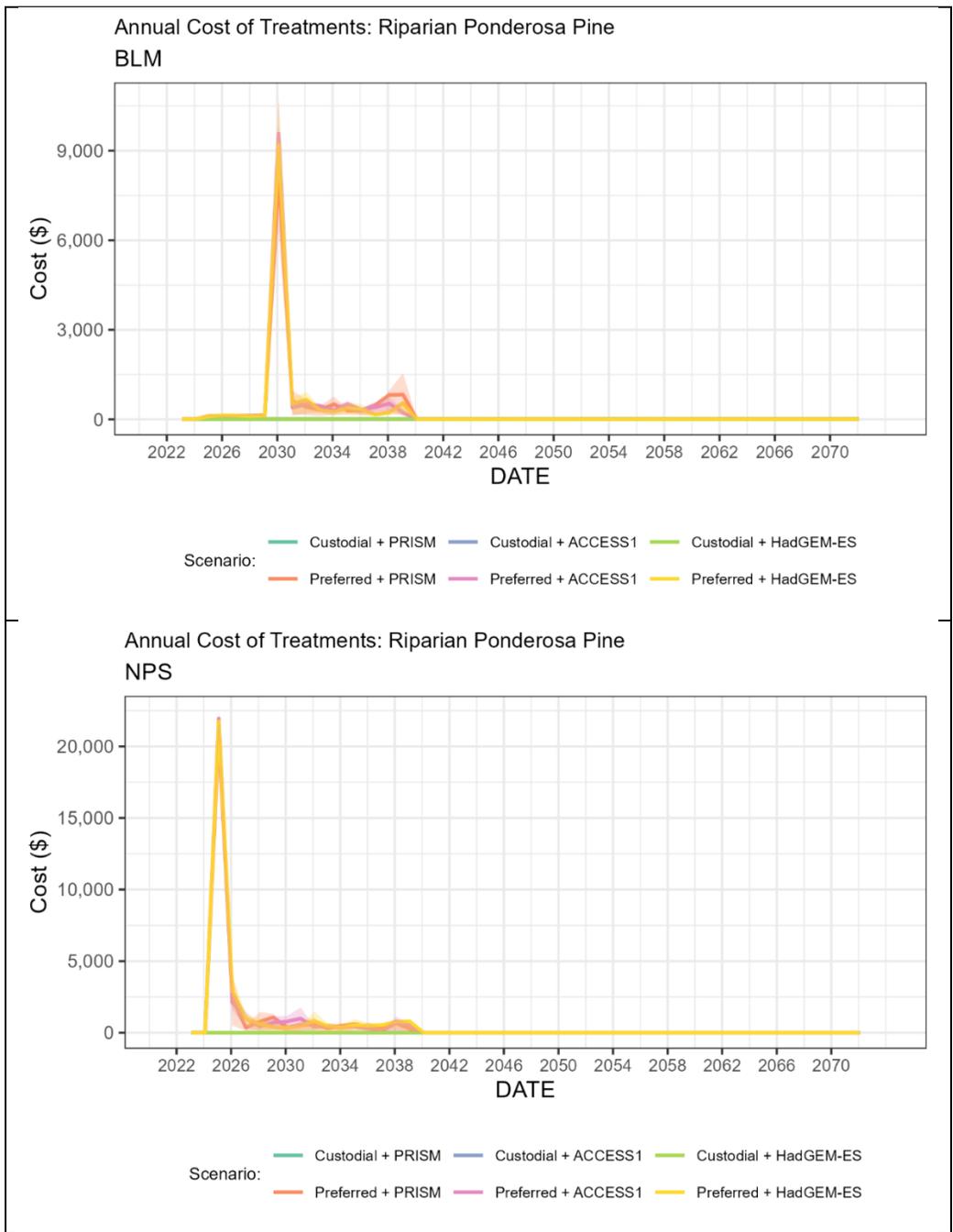
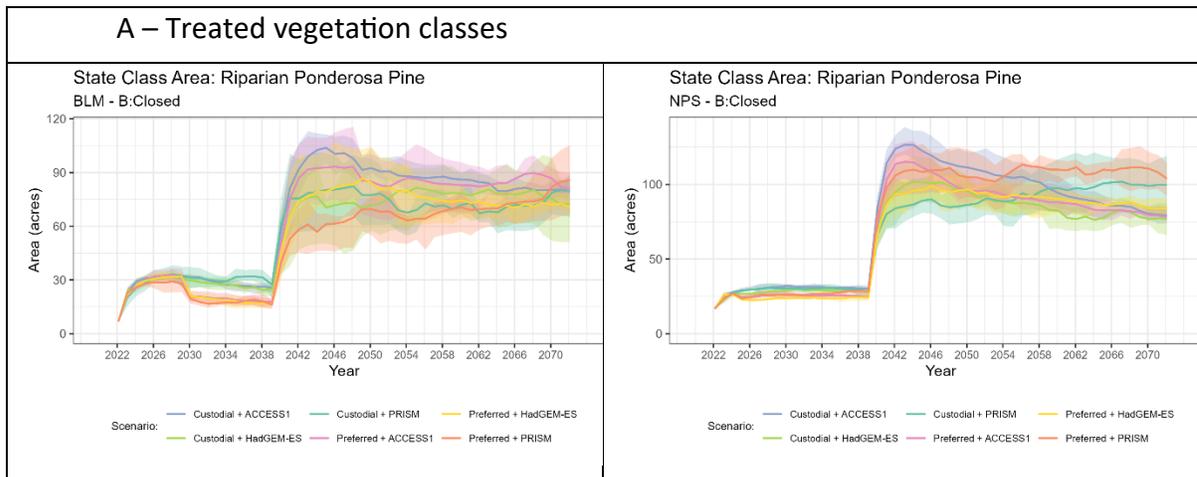


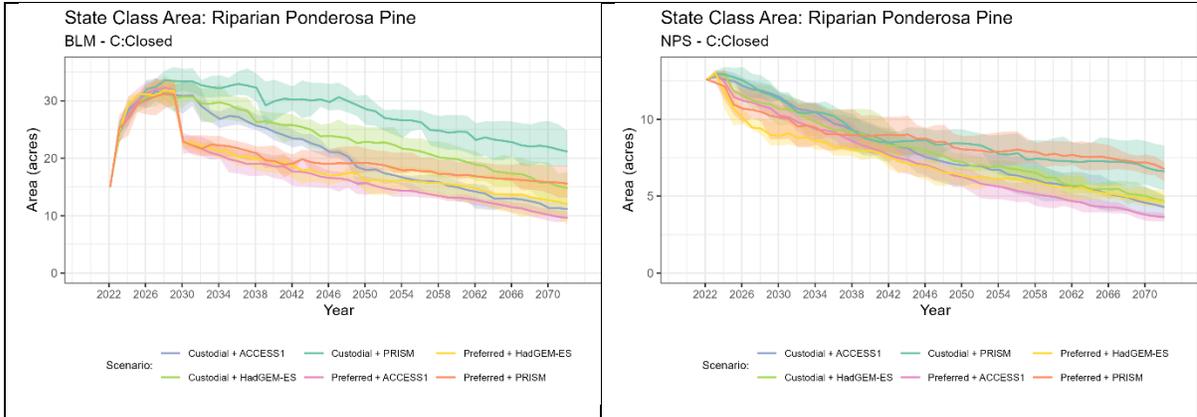
Figure 3.62. Annual cost of treatments in riparian ponderosa pine for BLM-managed land and GBNP in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

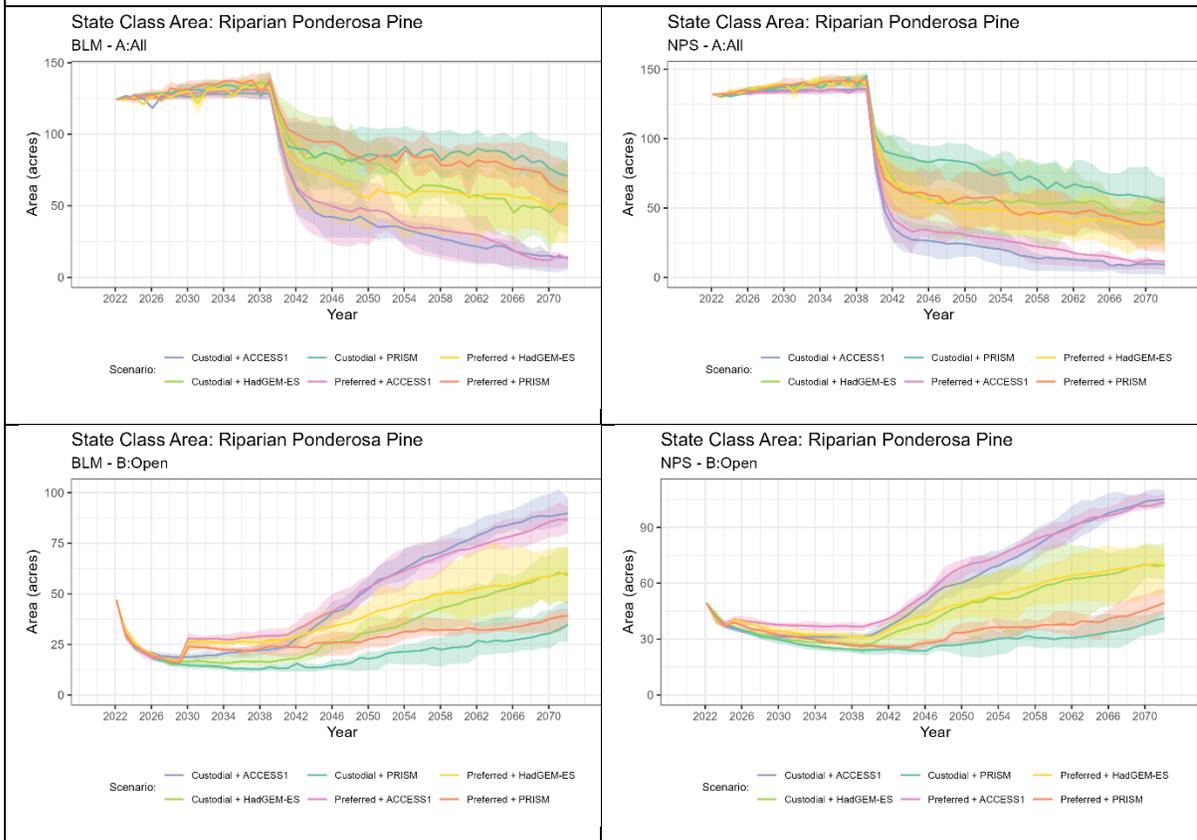
Chainsaw cutting and pile burning reduced the area of the closed canopy classes (B:Closed and C:Closed). The area of both classes decreased by about 10 acres in the preferred management scenario compared to the custodial management scenario in 2030 on BLM-managed land (Fig. 3.63A). The effect persisted until succession from the early successional class caused a large increase in the B:Closed class starting in year 2028 (Fig. 3.63B). In GBNP, reductions of the mid-successional and late-successional closed canopy classes (B:Closed and C:Closed) were barely perceptible at 1-2 acres (Fig. 3.63A).

As a result of treatment, both B:Open and C:Open classes increased, respectively, by the same areas of reduction observed in the B:Closed and C:Closed classes (Fig. 3.63B). Over years, the area of mid successional and late successional classes open-canopied classes increased consistently. While the increase of the C:Open class allowed the class's area to approach reference condition (25%), the same increase of the B:Open class was exceeding the reference condition (7%), thus making ED worse. Open canopies reduce the chances of high-severity fire adjacent to streams, therefore, agencies might have a desired future condition that is different from the reference condition.





B – Recipient Classes



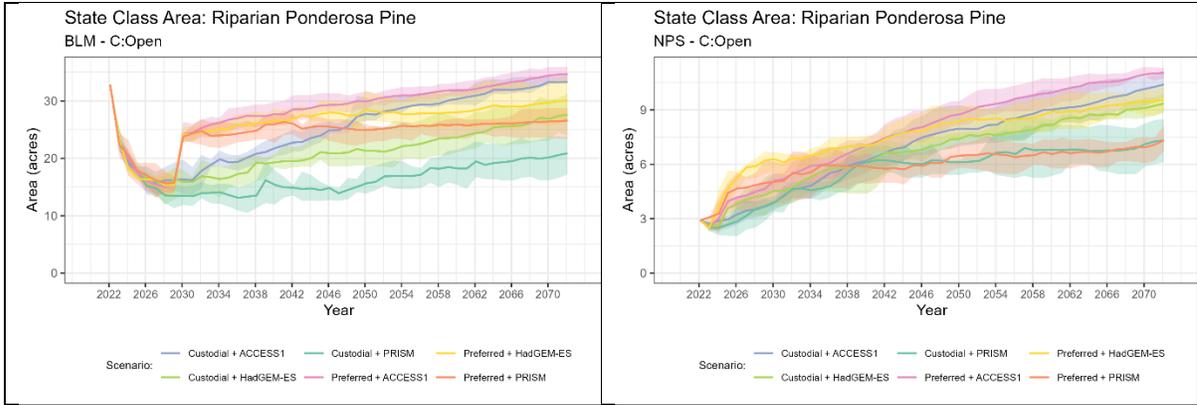


Figure 3.63. Vegetation classes of riparian ponderosa pine on BLM-managed land (left panel) and GBNP (right panels) on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.19. Saline Meadow

2022 System acres at 14-m resolution: 4,628

2022 Landscape-wide ED: 47%

Problems or Concerns

The 4,629 acres of saline meadow were primarily found on BLM-managed land (1,903 acres) and private lands (2,724 acres), with one surprising acre at middle elevation on USFS-managed land (Table 3.68). The main problems with the system were the dominance of the depleted meadow class (U-C:Depleted; 30.8%) and the reference late successional class (C:Open; 24.3%) compared to the reference condition proportion (12%). Also, there was not enough of the reference mid-successional class (B:Closed; 40.6%) compared to the reference condition (87%; Table 3.68). The exotic forb classes were minimal but expected to increase.

Table 3.68. Vegetation classes of saline meadow expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:All	4		3		7	0.1	1
B:Closed	370		1,511		1881	40.6	87
C:Open	443		682		1125	24.3	12
U-A:Exotic Forb	0		21		21	0.5	0
U-A:Pasture	15	<1	154		169	3.7	0
U-A:SAP	<1		<1		<1	<0.01	0
U-C:Depleted	1,071		353	1	1425	30.8	0

Objectives for Management Actions

Saline meadow was not a priority system. The maintenance objective was to *control exotic forbs* in a tiny area of BLM-managed land and in the future (Table 3.69). Total implementation area was less than 1.2 acres from 2025 to 2029.

Table 3.69. Realized treatment totals (acres) within each period in saline meadow from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Exotic Control (BLM: \$200/acre; NPS: \$225/acre)
Years	25 th – 75 th percentiles of total treatment acres
PRISM	
BLM	
2023-2024	0
2025-2029	0.4-0.7
2030-2034	0
2035-2039	0
2040-2072	0
NPS	
2023-2024	0
2025-2029	0
2030-2034	0
2035-2039	0
2040-2072	0
ACCESS1	
BLM	
2023-2024	0
2025-2029	0.3-1.2
2030-2034	0
2035-2039	0
2040-2072	0

NPS		
2023-2024		0
2025-2029		0
2030-2034		0
2035-2039		0
2040-2072		0
HadGEM-ES		
BLM		
2023-2024		0
2025-2029		0.4-1.0
2030-2034		0
2035-2039		0
2040-2072		0
NPS		
2023-2024		0
2025-2029		0
2030-2034		0
2035-2039		0
2040-2072		0

Exotic control had no effect on ED given large overlapping 95% confidence intervals, although ED was slightly and consistently larger in the preferred *versus* custodial management scenarios (Table 3.70). ED increased from moderately to highly departed from 2035 to the 2072 reporting year (Table 3.70).

Table 3.70. Future ED of saline meadow (% \pm 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED \pm 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	56% \pm 11%	58% \pm 11%
2047	53% \pm 6%	59% \pm 8%
2072	69% \pm 7%	70% \pm 6%
ACCESS1		
2035	67% \pm 9%	61% \pm 9%
2047	71% \pm 9%	73% \pm 8%
2072	71% \pm 9%	72% \pm 8%
HADGEM-ES		
2035	59% \pm 11%	60% \pm 10%
2047	59% \pm 7%	58% \pm 8%
2072	67% \pm 7%	67% \pm 8%

Cost by year (ST-Sim Results)

BLM's annual cost plateaued at \$1,200 from 2025 to 2029, after which exotic control was stopped (Fig. 3.64). Despite the small amount of area to treat, the cost plateau shows no exhaustion of the U-A:Exotic Forb class.

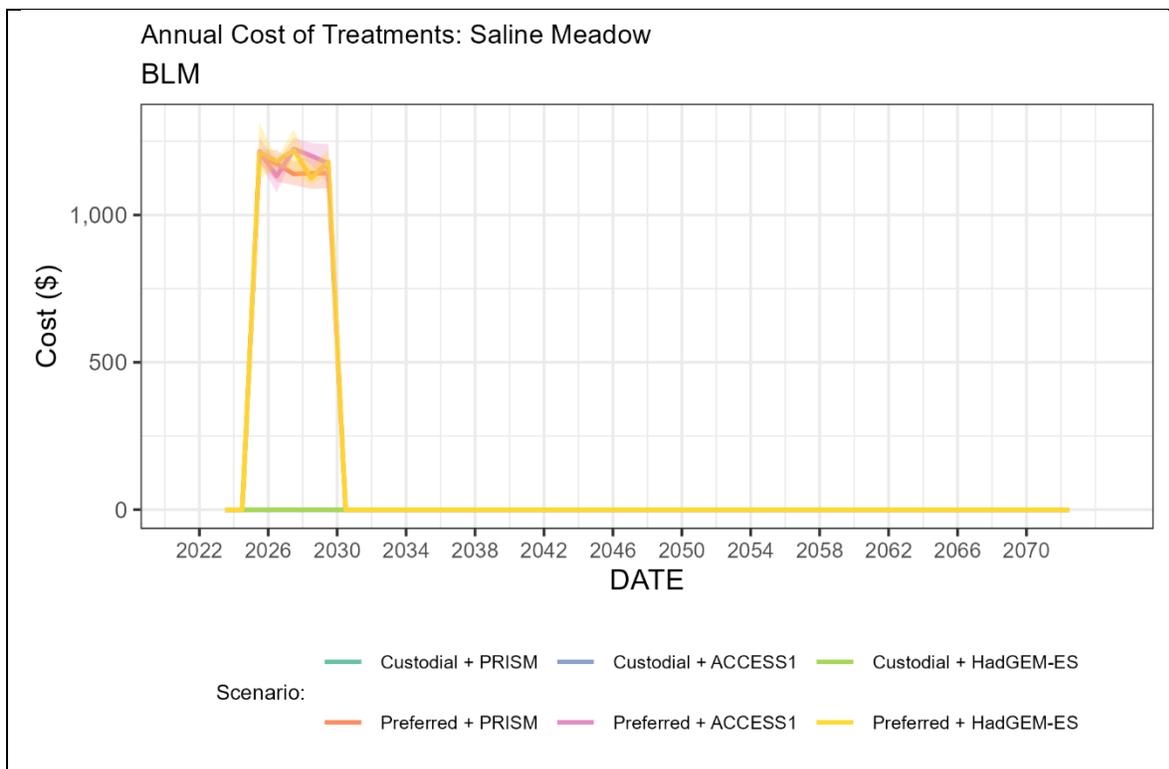


Figure 3.64. Annual cost of treatments in saline meadow for BLM-managed land in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

Exotic control reduced the area of the U-A:Exotic Forb class late in the simulations but not perceptibly at the time of implementation (Fig. 3.65). This interesting result likely happened because the invasion of uninvaded area can have an exponential increase if adjacent areas were invaded; therefore, small initial differences in invaded area in 2023 could translate into future noticeable differences. For the PRISM climate, there was about 50 acres less in the preferred management scenario than the custodial management scenario, whereas the difference was about 100 acres for the ACCESS1 climate in 2072 (Fig. 3.65).

The area of the U-A:Exotic forb class increased from near zero acres to 200 to 400 acres by year 2072 (Fig. 3.65). ED increased because of this trend in invaded area. This large increase was at the expense (i.e., invasion) of the declining reference mid-successional closed class; however, the area of the U-A:Exotic Forb class that was successfully treated resulted in more of the B:Closed class (Fig. 3.65). This result indicated the value of early intervention and the need for sustained exotic species control.

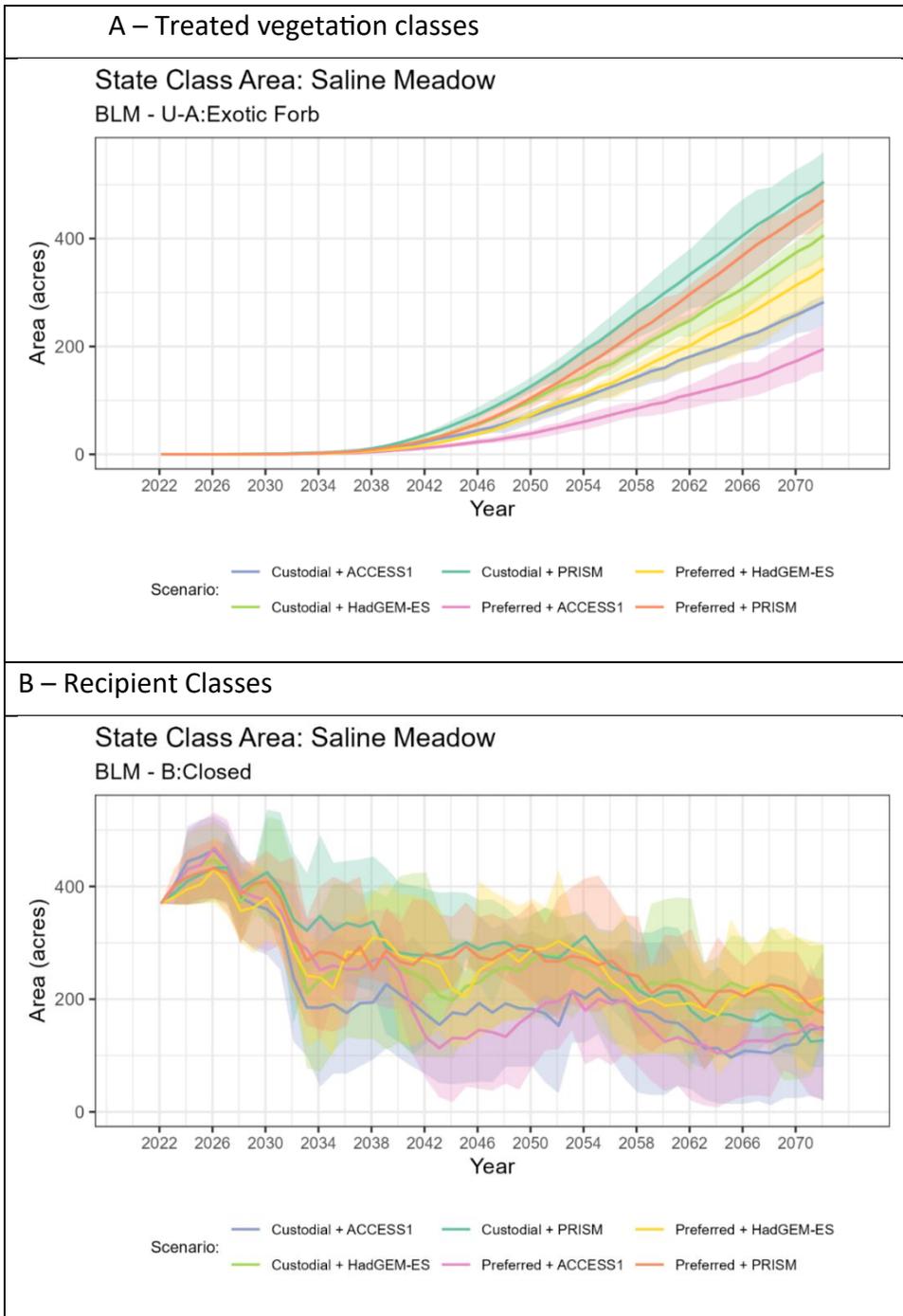


Figure 3.65. Vegetation classes of saline meadow on BLM-managed land on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.20. Stansbury Cliffrose

2022 System acres at 14-m resolution: 802

2022 Landscape-wide ED: 25%

Problems or Concerns

The 802 acres of Stansbury cliffrose were at low departure from reference condition (ED = 25%; Table 3.71). The system was on BLM-managed land (399 acres) and USFS-managed land (402 acres; Table 3.71). The percentages of class areas' on USFS-managed land were close to the reference condition and included no uncharacteristic classes (Table 3.71). The system contained 28 acres of uncharacteristic classes on BLM-managed land and the reference late-successional open canopy class was dominant at 266 acres that caused too much area of the class (65.3%) compared to the reference condition (44%; Table 3.71).

Table 3.71. Vegetation classes of Stansbury cliffrose expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							1
A:Char2							1
A:All	6			3	10	1.2	10
B:Closed	99			141	239	29.8	44
C:Open	266		<1	258	524	65.3	44
U-A:Annual Spp	1				1	0.1	
U-B:SAP	18				18	2.3	
U-C:Depleted	1				1	0.2	
U-C:SAP	1				1	0.1	
U-C:TEA	7				7	0.9	

Objectives for Management Actions

The only objective for Stansbury cliffrose was to reduce the area dominated or co-dominated by pinyon and juniper for improvement of wildlife habitat on BLM-managed land, such as mule deer and bighorn sheep. *Small tree lopping* and *chainsaw thinning* were proposed; however, *chainsaw thinning* applied to the reference late-successional class (C:Open) was accidentally turned off for BLM. Also, *small tree lopping* was only supposed to be used in the U-C:Depleted and U-C:SAP classes, but was not implemented because all 2 acres of these classes were in an excluded areas (wilderness, domestic sheep wintering grounds, and so on). Therefore, no treatments were implemented, and no cost was incurred in Stansbury cliffrose.

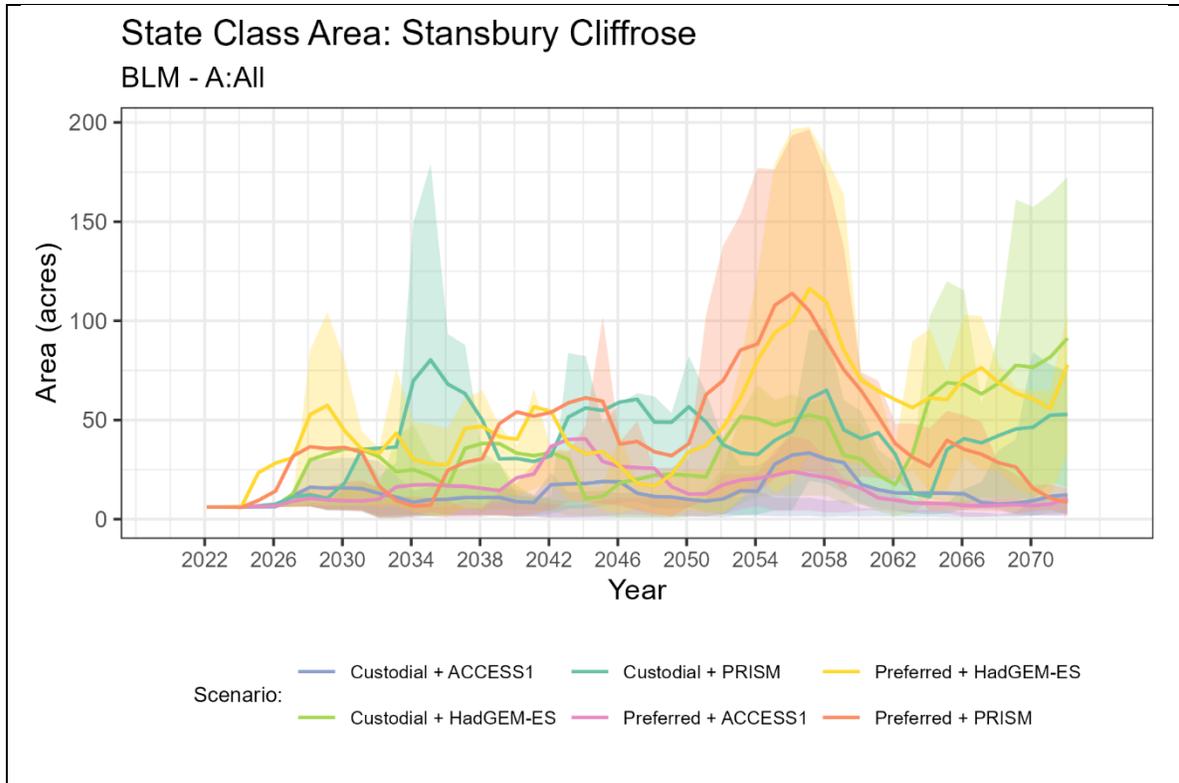
Even without treatments Stansbury cliffrose remained in the low ED range between 16% and 28% with no statistical differences between management scenarios (Table 3.72). Slightly lower ED values were achieved under the ACCESS1 climate in most reporting years.

Table 3.72. Future ED of Stansbury cliffrose (95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	23% ± 1%	23% ± 4%
2047	19% ± 3%	20% ± 4%
2072	19% ± 4%	21% ± 4%
ACCESS1		
2035	21% ± 3%	22% ± 2%
2047	16% ± 2%	18% ± 4%
2072	19% ± 3%	18% ± 4%
HADGEM-ES		
2035	21% ± 5%	20% ± 4%
2047	20% ± 7%	16% ± 3%
2072	28% ± 9%	27% ± 9%

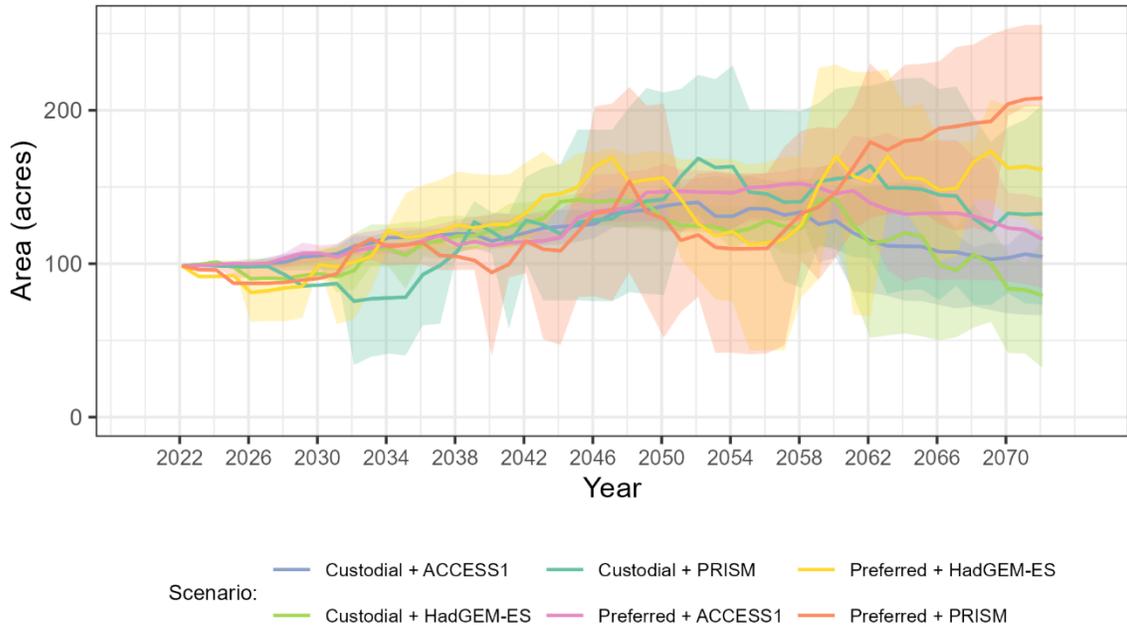
Vegetation Classes (ST-Sim Results):

Without any treatment, the reference early and mid-successional classes (A:All and B:Closed) increased, doubling for several management and climate scenarios, and the late-successional open canopy class decreased (Fig. 3.76). Contributing to higher departure, however, was the increase of the uncharacteristic tree-encroached class (U-C:TEA) from 5 acres in 2023 to three to four times that amount by 2072. These results suggest treatments might not be needed to keep Stansbury cliffrose close to the reference condition or in good condition for palatable browse.



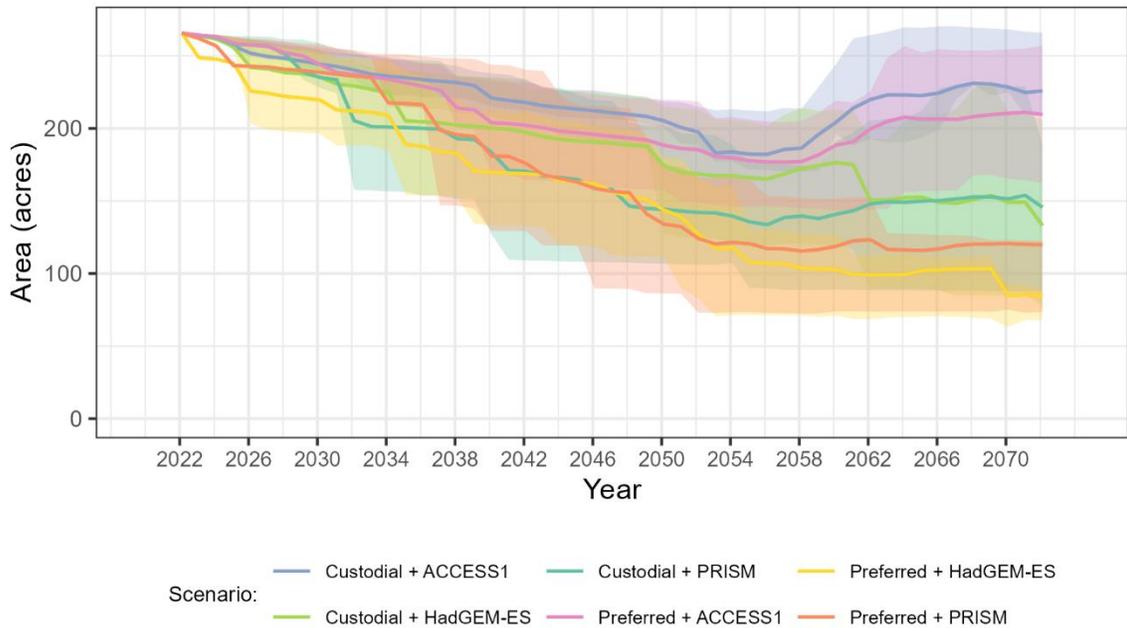
State Class Area: Stansbury Cliffrose

BLM - B:Closed



State Class Area: Stansbury Cliffrose

BLM - C:Open



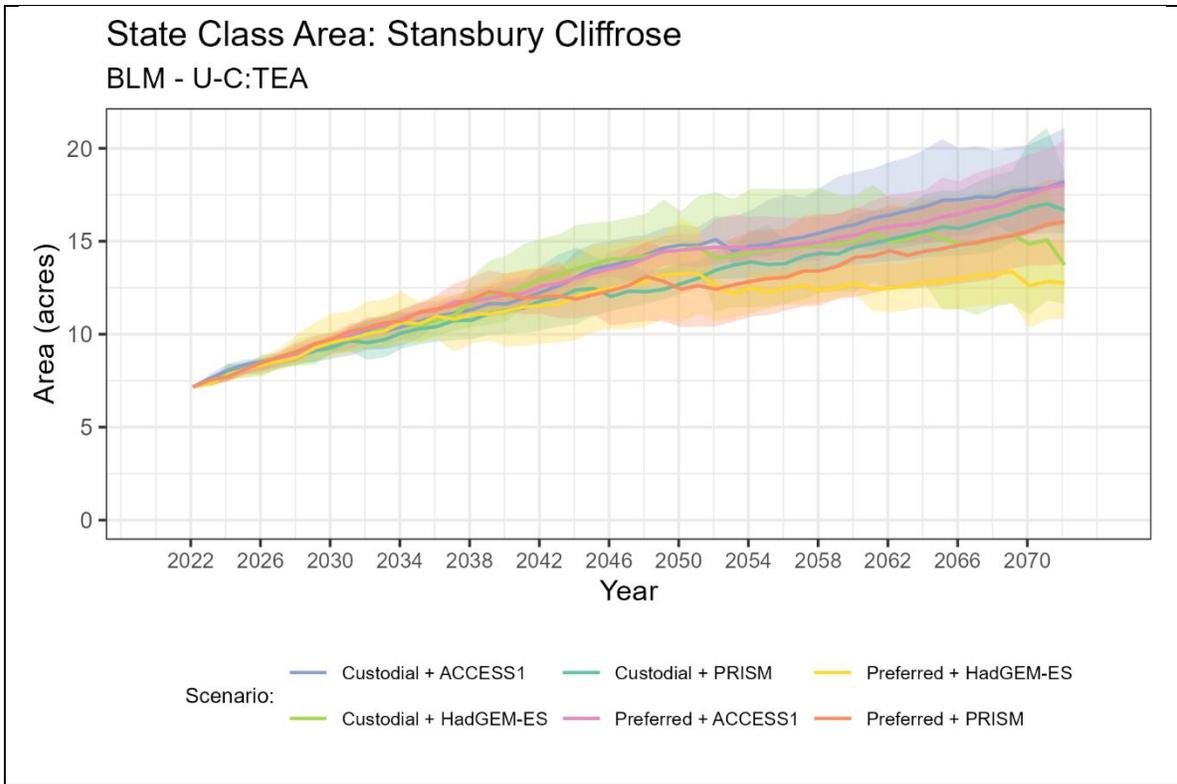


Figure 3.76. Vegetation classes of Stansbury cliffrose on BLM-managed land on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.21. Wet Meadow

2022 System acres at 14-m resolution: 1,875

2022 Landscape-wide ED: 51%

Problems or Concerns

Wet meadows covered 1,875 acres predominantly located on private land (1,473 acres), whereas 211 acres and 191 acres, respectively, were on BLM-managed land and GBNP (Table 3.73). Wet meadow was moderately departed from the reference condition (51%). Forty-six percent was in the reference mid-successional closed canopy class (B:Closed), compared to the 94% expected in the reference condition, and 43% of wet meadows were introduced species seedings on private land (692 acres) and 114 acres on BLM-managed land (Table 3.73). No seedings were mapped in GBNP. Additionally, 5% of meadows were in the uncharacteristic shrub and forb encroached class and another 5%, mostly in GBNP, of the reference late successional open canopy class (C:Open; Table 3.73).

Table 3.73. Vegetation classes of wet meadow expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:All		1			1	0	3
B:Closed	63	84	711	<1	858	46	94
C:Open	0	92	6		99	5	3
U-A:Exotic Forb	0		10		10	1	0
U-A:Hummocked	2		1		3	0	0
U-A:SI	114		692		806	43	0
U-C:Desertified	<1		2		2	<1	0
U-C:Shrb-Frb Encr	31	10	50		91	5	0
U-C:TEA	1	5	<1		6	<1	0

Objectives for Management Actions

The primary objective was to increase the area of the B:Closed by reducing the areas of the late-successional classes (e.g., C:Open, U-C:Shrb-Frb Encr, and U-C:TEA) on BLM-managed land

and GBNP. It was unlikely the introduced species seedings would be restored to native species meadows. Both *ground-ignited* and *aerial prescribed burning*, preferably when used in adjacent areas, were proposed to accomplish this objective (Table 3.74). The other objectives were to *control exotic forbs* (Exotic Control treatment) and restore incisions (U-C:Desertified class) to a meadow reconnected to the water table (*Water Table Uplift* treatment; Table 3.74).

Table 3.74. Realized treatment totals (acres) within each period in wet meadow from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Exotic Control (BLM: \$200/acre; NPS: \$225/acre)	Prescribed Burning - Aviation (BLM: \$250/acre; NPS: \$1,134/acre)	Prescribed Burning - Ground (BLM: \$250/acre; NPS: \$1,134/acre)	Water Table Uplift (BLM & NPS: \$400-\$1,200/ acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres
PRISM				
BLM				
2023-2024	0	0	0	0
2025-2029	1.6-2.6	49-53	48-52	4.2-5.5
2030-2034	0.9-1.5	0	0	0
2035-2039	0.7-1.6	24-26	23-26	9-11
2040-2072	0	0	0	0
NPS				
2023-2024	0	0	0	0
2025-2029	0	0	23-26	3-4
2030-2034	0	0	0	0
2035-2039	0	23-26	23-26	0
2040-2072	0	0	0	0
ACCESS1				

BLM					
2023-2024	0	0	0	0	
2025-2029	1.7-2.3	48-52	49-52	4.2-5.8	
2030-2034	0.8-1.4	0	0	0	
2035-2039	0.8-1.5	23-26	24-26	9.1-11.1	
2040-2072	0	0	0	0	
NPS					
2023-2024	0	0	0	0	
2025-2029	0	0	23-26	3.2-4.2	
2030-2034	0	0	0	0	
2035-2039	0	24-27	23-27	0	
2040-2072	0	0	0	0	
HadGEM-ES					
BLM					
2023-2024	0	0	0	0	
2025-2029	1.4-2.0	48-51	49-52	4.4-5.7	
2030-2034	0.7-1.5	0	0	0	
2035-2039	0.6-1.4	23-26	24-26	9.0-11.0	
2040-2072	0	0	0	0	
NPS					
2023-2024	0	0	0	0	
2025-2029	0	0	24-26	3.3-4.2	
2030-2034	<0.1	0	0	0	
2035-2039	0	23-27	24-26	0	
2040-2072	0	0	0	0	

Exotic forb control was rarely used in GBNP whereas no more than 2 acres were implemented in any 5-year period on BLM-managed land regardless of climate scenarios (Table 3.74). About 50 acres and 25 acres, respectively, of *aerially ignited prescribed burning* were conducted on BLM-

management land during the 2025-2029 and 2035-239 periods, whereas 25 acres were deployed in GBNP only during the 2035-2039 period (Table 3.74). For BLM-managed land, the same rates of implementation were used with *ground ignited prescribed burning* for the same periods. About 25 acres of *ground ignited prescribed burning* were also used in GBNP during the 2025-2029 and 2035-2039 period. No *prescribed burning* was done from 2030 to 2034. About 5 and 10 acres of *water table uplift* devices (a.k.a., *PALS*), respectively, were placed in incisions during the 2025-2029 and 2035-2039 periods, in BLM-managed meadows (Table 3.75). About 3.6 acres of these flow and debris devices were built during the 2025-2029 period in GBNP (Table 3.74). Climate differences on implementation rates were not observed.

In all years and climates, the preferred management scenario's EDs were 1%-3% smaller than for the custodial management scenario (Table 3.75); however, 95% confidence intervals overlapped. This indicated a consistent, but weak treatment effect. The highest ED values were observed in the ACCESS1 climate (Table 3.75).

Table 3.75. Future ED of wet meadow (% ± 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED ± 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	57% ± 1%	56% ± 2%
2047	61% ± 1%	58% ± 1%
2072	70% ± 1%	67% ± 1%
ACCESS1		
2035	64% ± 3 %	62% ± 2%
2047	70% ± 2 %	68% ± 3%
2072	79% ± 2%	77% ± 2%
HADGEM-ES		
2035	61% ± 3%	59% ± 3%
2047	65% ± 3%	63% ± 2%
2072	71% ± 2%	68% ± 3%

Cost by year (ST-Sim Results)

BLM's annual cost plateaued twice: about \$11,500 from 2025 to 2029 and \$7,500 from 2035 to 2039 (Fig. 3.77). There were no signs of class depletion because cost did not decrease within periods. Two plateaus in the same periods were also estimated for GBNP both ranging from \$17,500 to \$18,000 (Fig. 3.77).

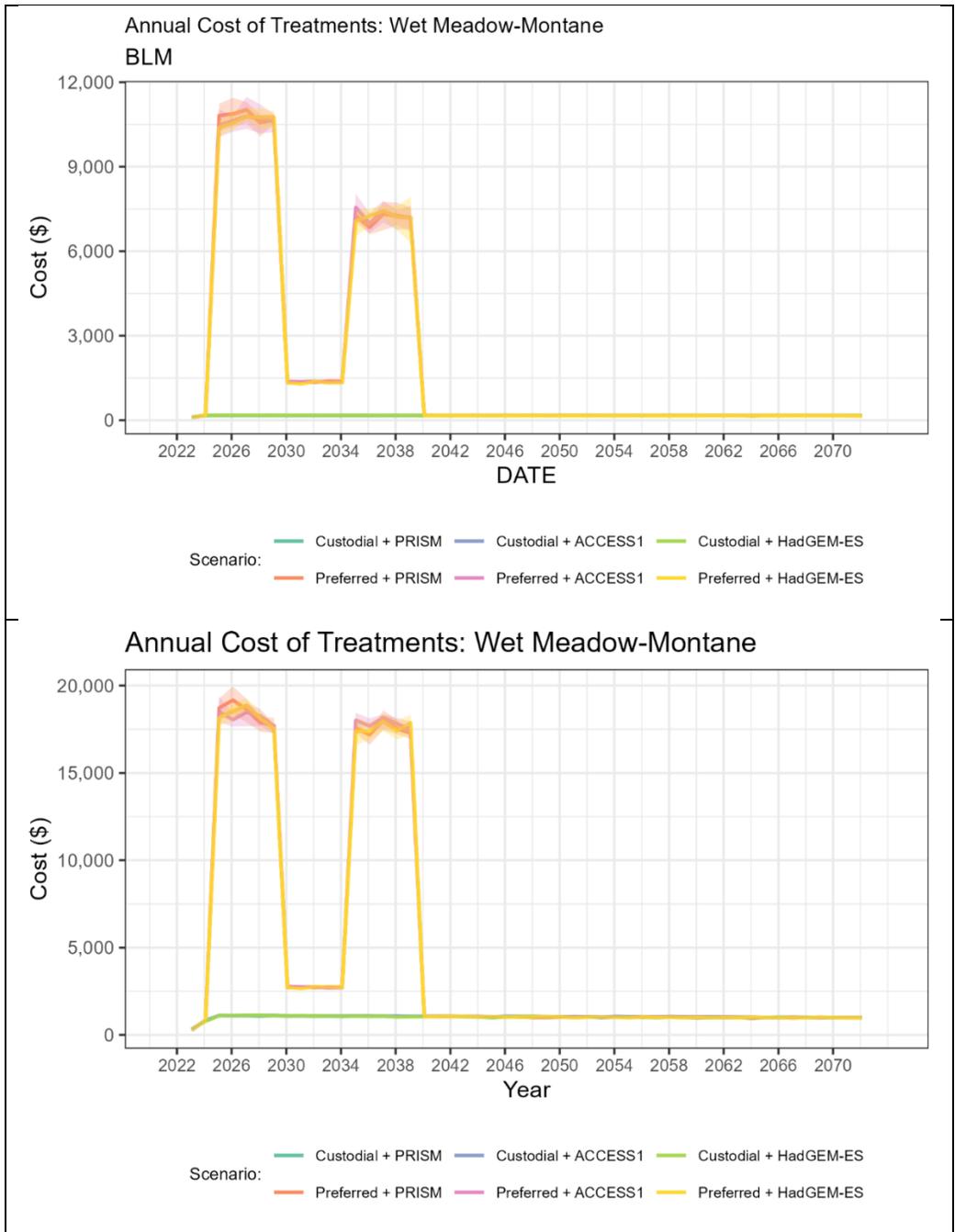


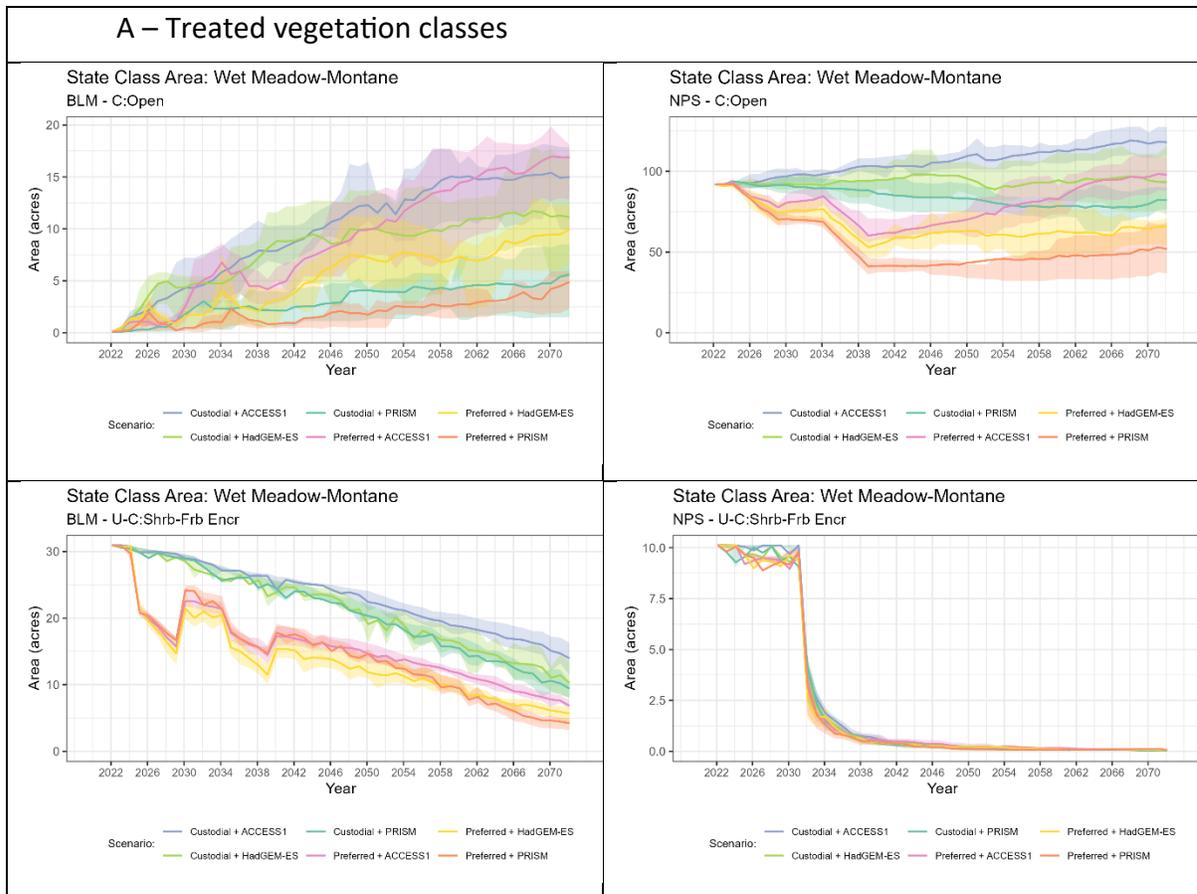
Figure 3.77. Annual cost of treatments in wet meadow for BLM-managed land and GBNP in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

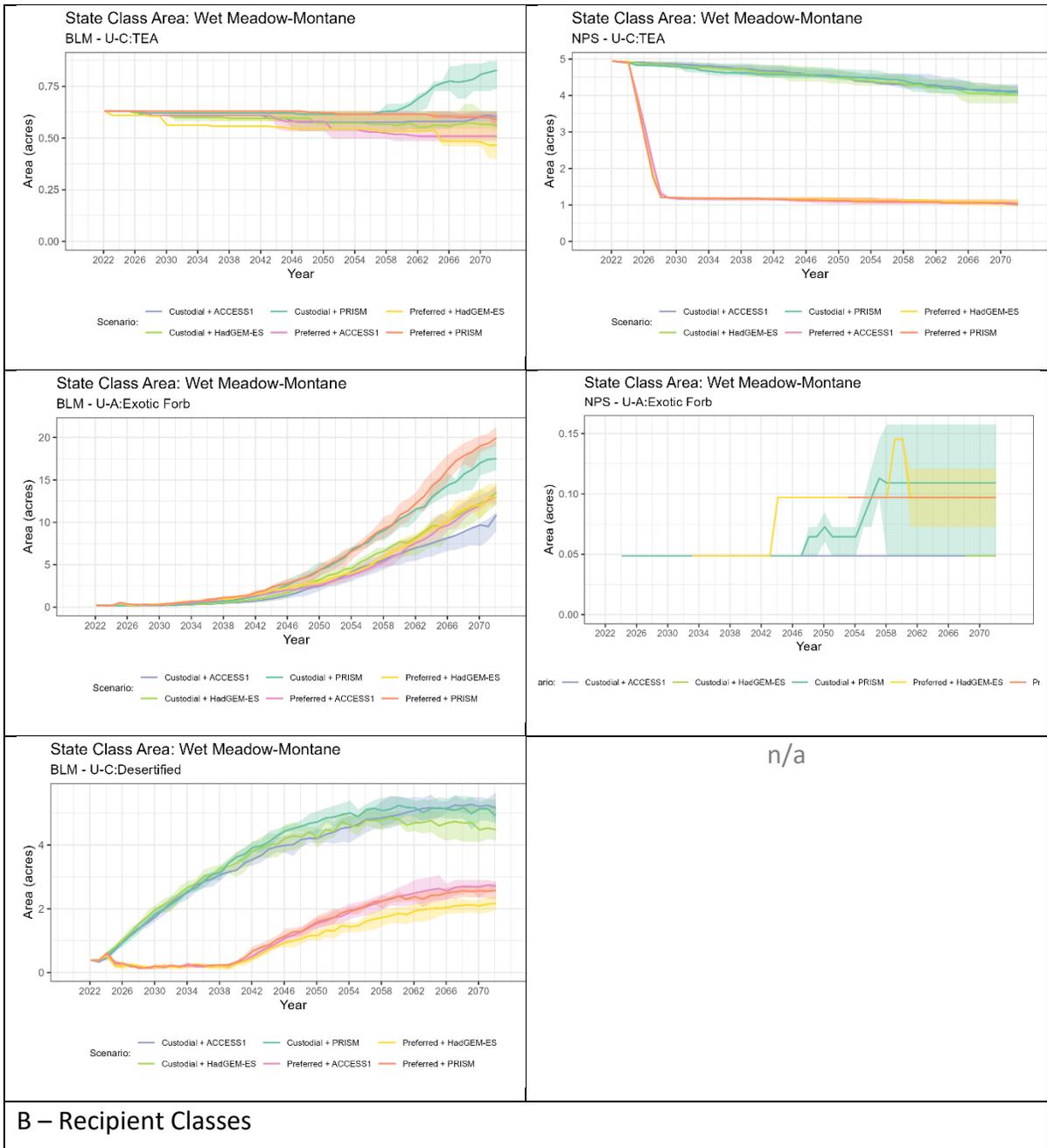
Vegetation Classes (ST-Sim Results):

The *exotic control* treatment was not used in GBNP because exotic forbs were nearly absent, whereas effects were not perceptible during the periods of implementation on BLM-managed land (Fig. 3.78A). On BLM-managed land, the area of the exotic forb class increased steadily after the last period of implementation starting in 2040. No such increase was found on GBNP.

The strongest treatment effects were with both types of *prescribed burning* with obvious, albeit small (<15 acres), dips in area of the late-successional C:Open, U-C:Shrb-Frb Encr, and U-C:TEA classes with woody species in the preferred management scenario compared to the custodial management scenario during the 2025 to 2029 and 2034-2039 burning periods for both BLM-managed land and GBNP (Fig. 3.78A). The reference early successional class (A:All) increased by the same area as recipient of burning (Fig. 3.78B). With succession, the area of the A:All class matured into the reference mid-successional class (B:Closed; Fig. 3.78), which would lower ED.

The *water table uplift* treatment was only used in BLM-managed meadows where it decreased the desertified class by 2 acres starting in 2025 (Fig. 3.78A). Those two acres imperceptibly contributed to the A:All class. This action also reduced ED.





B – Recipient Classes

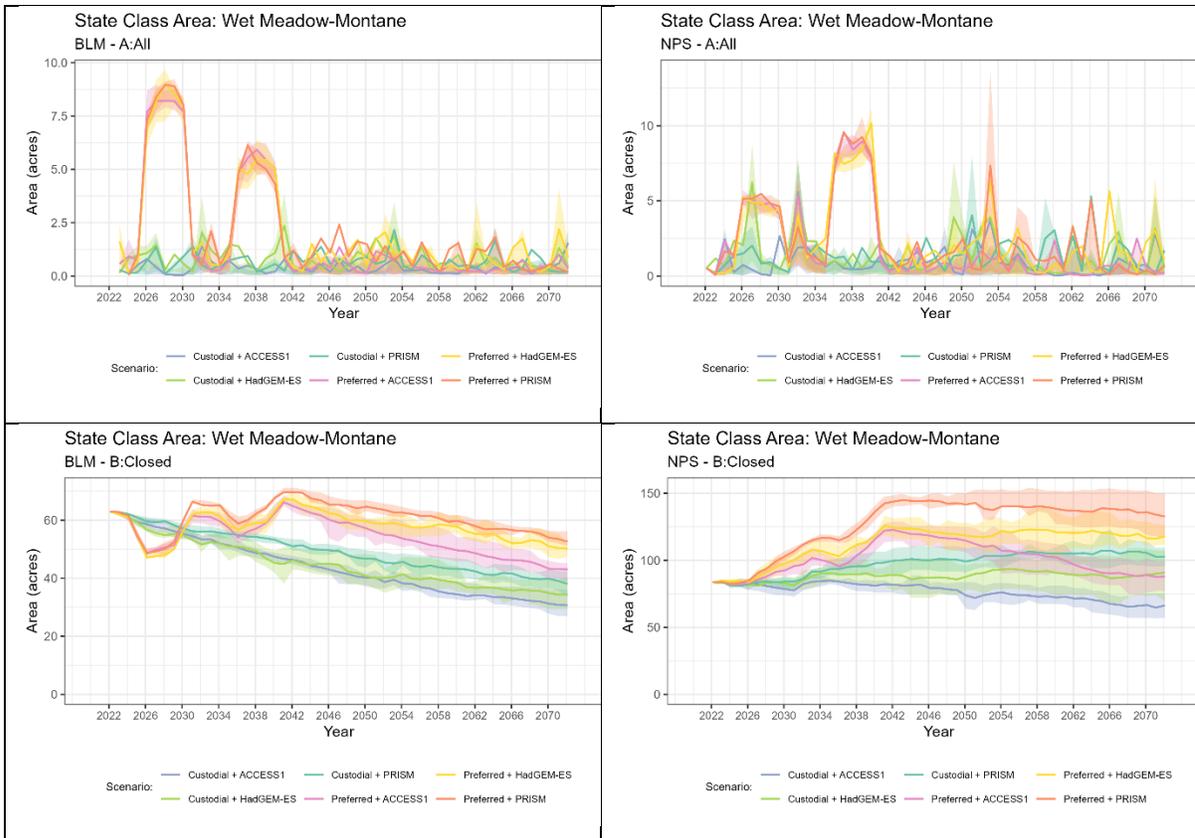


Figure 3.78. Vegetation classes of wet meadow on BLM-managed land (left panel) and GBNP (right panels) on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.2.22. Wyoming Big Sagebrush - upland soil

2022 System acres at 14-m resolution: 15,990

2022 Landscape-wide ED: 99%

Problems or Concerns

Wyoming big sagebrush's 15,990 acres were very highly departed from reference conditions (ED = 99%). Less than 3% of the system was in any reference vegetation classes, which were dominated by late-successional classes with trees instead of classes dominated by shrubs as expected from the reference condition. Most of the system was on BLM-managed land with the nearly all the rest of the system on private lands (Table 3.76). Less than 1 acre was mapped on both GBNP and USFS-managed land (Table 3.76). Three uncharacteristic classes, all late-successional without trees, dominated the source of departure in decreasing order of area: shrubs with non-native annual species and perennial grasses (U-C:SAP at 3,868 acres), depleted shrubland (i.e., <5% cover of herbaceous understory; U-C:Depleted at 3,598 acres), and shrub with only non-native annual species (U-C:SA at 3,368 acres; Table 3.76). At 999 acres, the tree-encroached shrubland with potential non-native annual species class (U-E:TEA) was the next in importance, followed by the mid-successional shrubs with non-native annual species and perennial grass species (U-B:SAP at 858 acres), the non-native annual species dominant class (U-A:Annual Species) at 604 acres, and late-successional shrubland with young conifers, non-native annual species, and perennial grass (U-D:SAP; Table 3.76).

Table 3.76. Vegetation classes of Wyoming big sagebrush-upland expressed in current area (acres), current class percentage of entire system, and percentage of each class in the reference condition. Classes with no areas were not shown. All classes in the system were listed in Appendix 1.

Class	BLM Area (acres)	NPS Area (acres)	Private Area (acres)	USFS Area (acres)	Total Area (acres)	Percent of Total in 2022	Reference Condition (a.k.a., NRV) % of Total
A:Char1							1
A:Char2							1
A:All							18
B:Open	61				61	0.4	34
C:Closed	53				53	0.3	34
D:Open	176		3		179	1.1	0
E:Closed	101				101	0.6	11

U-A:Annual Spp	604	<1	324		928	5.8	0
U-A:Bare Ground	11		13		23	0.1	0
U-A:Early Shrub	371		176	<1	548	3.4	0
U-A:Exotic Forb	72		25		97	0.6	0
U-A:SAP	21		7		29	0.2	0
U-A:SI			0		0	0.0	0
U-A:SI+AS			3		3	0.0	0
U-B:SAP	858		74	1	933	5.8	0
U-B:SI+AS	32		3		36	0.2	0
U-C:Depleted	3598	<1	226		3824	23.9	0
U-C:SA	3368		266		3634	22.7	0
U-C:SAP	3812		33		3845	24.0	0
U-C:SI+AS	186				186	1.2	0
U-D:SAP	400		33		433	2.7	
U-D:SI	1		1		2	0.0	
U-E:TEA	999	<1	75		1073	6.7	

Objectives for Management Actions

BLM's primary objectives were to reduce the cover of the U-A:Annual species class (from 604 acres) by replacing it with perennial species seedings and reduce the cover of tree-encroached shrubland (U-E:TEA, 999 acres) and seed the treated areas (Table 3.77). Because introduced species will be used in seedings, these actions will not change ED compared to doing nothing. These actions should have multiple desirable outcomes of reducing the risk of high-severity fires, lowering the fire frequency fueled by non-native annual species at lower elevations, improve wildlife browse, and improve livestock forage.

Table 3.77. Realized treatment totals (acres) within each period in Wyoming big sagebrush-upland from 2023 to 2072. Three future climates were (PRISM, ACCESS1, and HadGEM-ES).

	Herbicide + Imazapic Spraying + Introduced Species Seeding (BLM: \$237/acre)	Masticate + Introduced Species Seeding (BLM: \$577/acre)
Years	25 th – 75 th percentiles of total treatment acres	25 th – 75 th percentiles of total treatment acres
PRISM		
BLM		
2023-2024	0	0
2025-2029	0	0
2030-2034	622-872	743-755
2035-2039	0	62-159
2040-2072	0	0
NPS		
2023-2024	0	0
2025-2029	0	0
2030-2034	0	0
2035-2039	0	0
2040-2072	0	0
ACCESS1		
BLM		
2023-2024	0	0

2025-2029		0		0
2030-2034		457-771		741-757
2035-2039		0		177-202
2040-2072		0		0
NPS				
2023-2024		0		0
2025-2029		0		0
2030-2034		0		0
2035-2039		0		0
2040-2072		0		0
HadGEM-ES				
BLM				
2023-2024		0		0
2025-2029		0		0
2030-2034		562-876		746-757
2035-2039		0		93-136
2040-2072		0		0
NPS				
2023-2024		0		0
2025-2029		0		0
2030-2034		0		0
2035-2039		0		0
2040-2072		0		0

The treatment of *seeding introduced species followed by spraying imazapic* (a.k.a., Plateau™) in the U-A:Annual Species class was only applied during the 2030-2034 period for a total of >400 to <780 acres (Table 3.77). The *mastication of trees followed by seeding of introduced species* was conducted from 2030 to 2034 at about 750 acres and from 2035 to 2039 within a broad range of 62 to 202 acres (Table 3.77).

As predicted, treatments had no effects on ED. ED was 98% in all scenarios, years, and climates (Table 3.78).

Table 3.78. Future ED of Wyoming big sagebrush-upland (% \pm 1 95% Confidence Interval, n = 10). Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

	ED \pm 1 95% Confidence Interval n = 10 replicates	
	CUSTODIAL MANAGEMENT	PREFERRED MANAGEMENT
PRISM		
2035	98% \pm <0.1%	98% \pm <0.1 %
2047	98% \pm 0.1%	98% \pm 0.1%
2072	98% \pm <0.1%	98% \pm 0.1%
ACCESS1		
2035	98% \pm 0.1%	98% \pm 0.1%
2047	98% \pm 0.2%	98% \pm 0.1%
2072	98% \pm 0.2%	98% \pm 0.1%
HADGEM-ES		
2035	98% \pm 0.1%	98% \pm <0.1%
2047	98% \pm <0.1%	98% \pm 0.1%
2072	98% \pm 0.1%	98% \pm 0.2%

Cost by year (ST-Sim Results)

BLM's annual cost was about \$120,000 from 2030 to 2034, and then dropped after 2035 until 2038 (Fig. 3.79). The sudden drop of cost suggested that simulations could not find more area to masticate (Fig. 3.79).

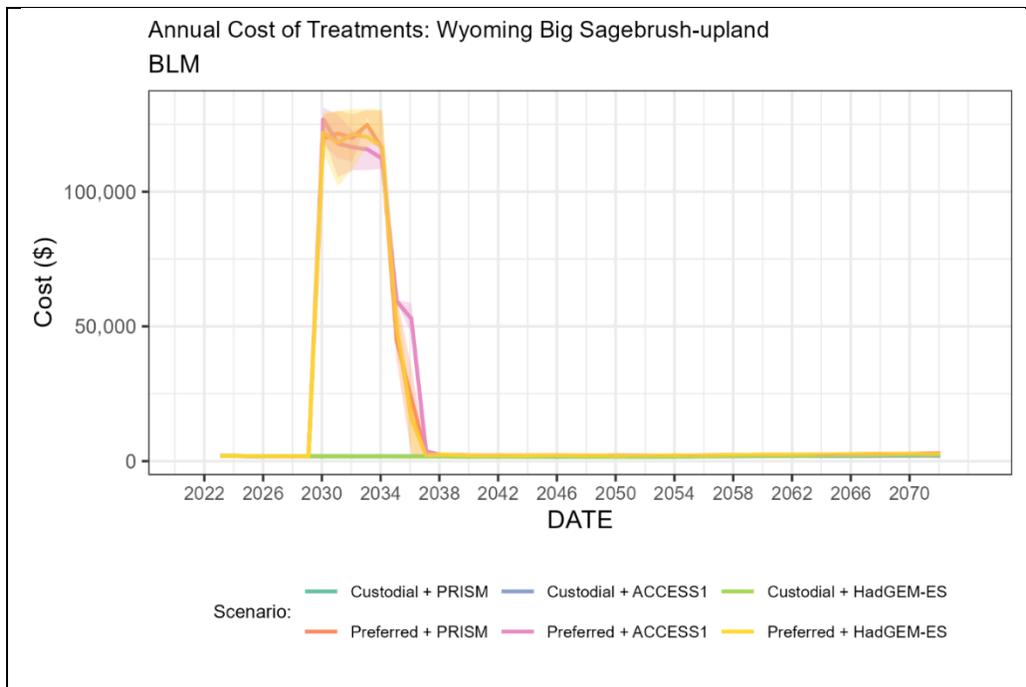


Figure 3.79. Annual cost of treatments in Wyoming big sagebrush-upland for BLM-managed land in the South Snake Range. Cost only applied to the preferred management combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) The line is the mean and error bars are the 25th-75th percentiles.

Vegetation Classes (ST-Sim Results):

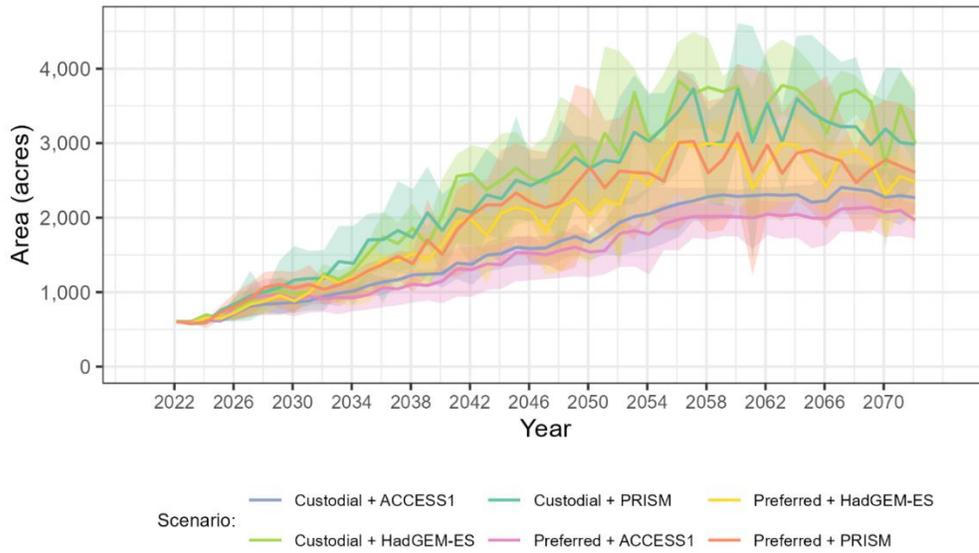
Seeding and spraying imazapic in the non-native annual species class (U-A:Annual Species) decreased the area in the preferred management scenario compared to the custodial management scenario by 2039 (Fig. 3.80A). The difference was as much as 400 to 500 acres for the PRISM climate in 2039, but barely 100 acres for the ACCESS1 climate (Fig. 3.80A). Interestingly, while the area of the U-A:Annual Species class increased in all scenarios over time, the difference between the preferred management and custodial management scenarios widened with time.

The *mastication of conifers and seeding* treatment eliminated the tree-encroached class (U-E:TEA) resulting in an about 900 acres drop in the preferred management scenario compared to the custodial management scenario (Fig, 3.80A).

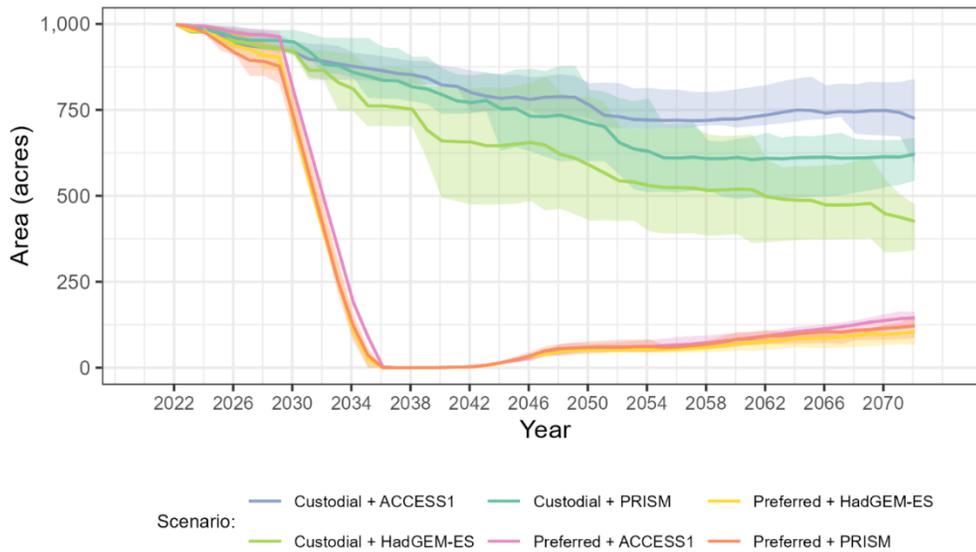
Both treatments caused the early successional introduced species seeding (U-A:SI) to increase from 0 to about 1,000 acres by 2040 (Fig. 3.80). Succession within the seeded pathways caused the U-A:SI class to decrease and the mid-succession seeded class to increase (U-B:SI). Starting around 2040, succession and droughty climate from the ACCESS1 LOCA caused greater transition from the U-A:SI (i.e., lower area) to the U-B:SI class (i.e., larger area) than for the other climates Fig. 3.80B).

A – Treated vegetation classes

State Class Area: Wyoming Big Sagebrush-upland
BLM - U-A:Annual Spp



State Class Area: Wyoming Big Sagebrush-upland
BLM - U-E:TEA



B – Recipient Classes

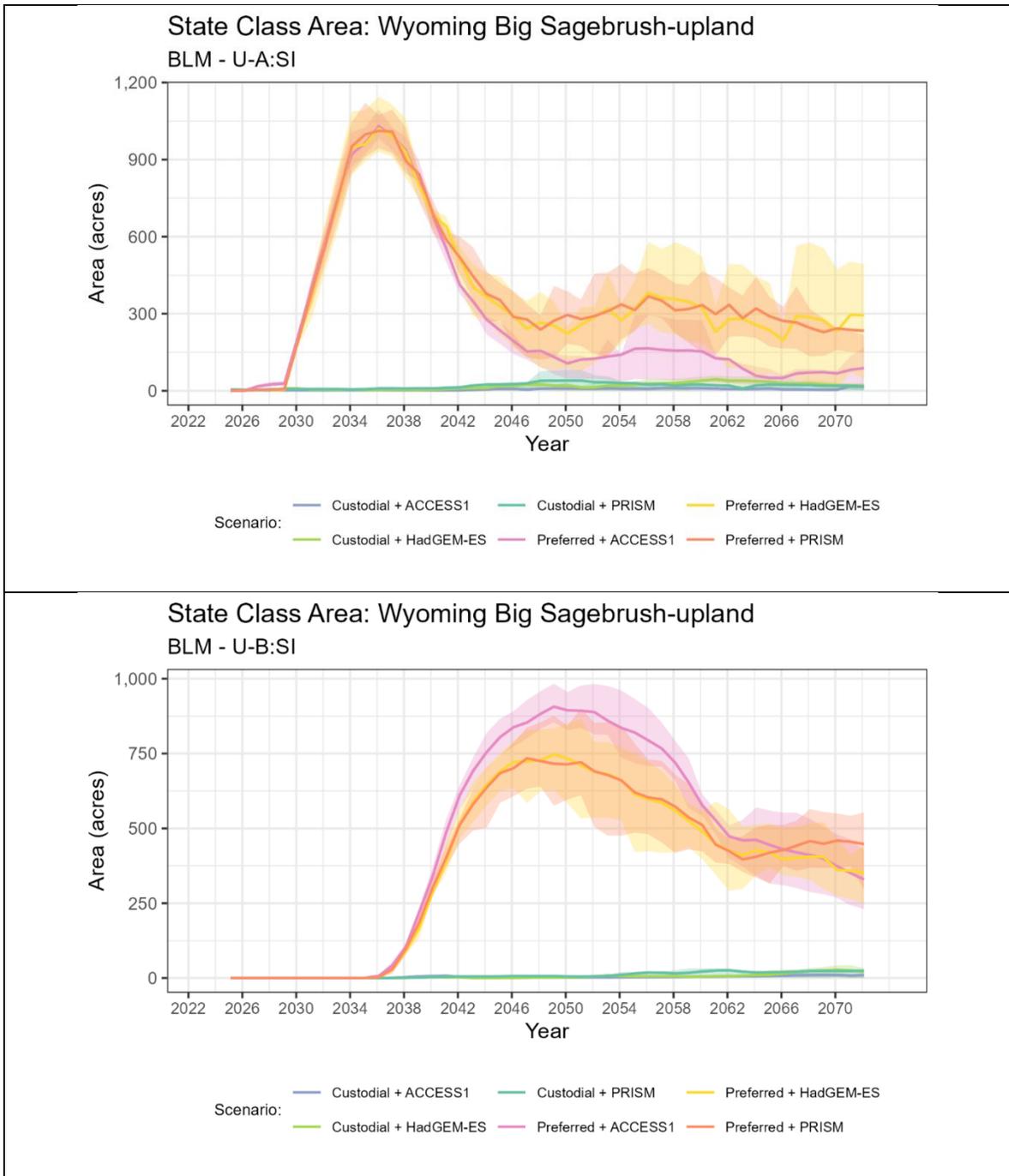


Figure 3.80. Vegetation classes of Wyoming big sagebrush-upland on BLM-managed land on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates. The line is the mean and error bars are the 25th-75th percentiles.

3.3. Landscape-wide Disturbance Frequency Maps

This section is to inform land managers about the locations of wildfires (first figure shown below) and treatments expressed as a frequency of the number of events totaled over 50 years and averaged among 10 replicates at each pixel. Areas with higher frequencies of a treatment would provide stronger justification for proposed action on federal land because the simulation criteria were repeatedly satisfied. Treatment maps were ranked from largest to smallest in total area treated. For each treatment, we listed the ecological systems concerned. Higher frequencies of wildfires, especially at low elevations where mean fire return intervals would be longer in the absence of non-native annual species, displayed areas for proactive fuels management using seeding (if the precipitation zone allowed it), herbicides, or fuel breaks designed to minimize build-up of non-native fine fuels.

3.3.1. Wildfire

Wildfire frequency explained much of the dynamics of this entire study (Fig. 3.81). The strongest factor was climate (within a row of Fig. 3.81). The PRISM climate had the highest wildfire frequencies, followed by the HadGEM-ES climate, which was not too different from the PRISM climate, whereas the ACCESS1 climate showed substantially less wildfire frequency (Fig. 3.81). The eastern rim just outside GBNP on BLM-managed land was the area of highest fire activity where non-native annual species were dominant or abundant in the understory of shrublands. The mouth of Strawberry Creek, in the 2026 Strawberry Fire, was a good example (Fig. 3.81). In the models, drier climate caused less fire under the assumption that drought decreased fine fuels accumulation.

Treatment within each climate between the preferred management and custodial management scenarios consistently achieved small reductions on the size and frequency of all zones with higher fire frequencies (Fig. 3.81). These multiple reduction of fire frequencies were more noticeable in the PRISM and HadGEM-ES climates.

3.3.2. Treatments

Small tree lopping was deployed more than any other treatment mostly at middle elevations (Fig. 3.82). Average implementation levels ranged from 2,787.1 (27,871 acres across times and replicates/10 replicates) (ACCESS1 climate) to 2,827.7 acres for the PRISM and HadGEM-ES climates during simulations (Fig. 3.82). The distribution of this action followed the shrubland rim generally outside GBNP at the toe of the mountains and just below it where pinyon and juniper occurred as young trees on the eastern and western slopes and in hilly shrublands on both sides of Highway 50/6 and outside wilderness areas on the southern border of the AOI (Fig. 3.82). The economical action was used in antelope bitterbrush with black sagebrush and with montane big sagebrush, black sagebrush, low sagebrush semi-desert, and montane sagebrush steppe on upland soil. No climate differences were observable (Fig. 3.82).

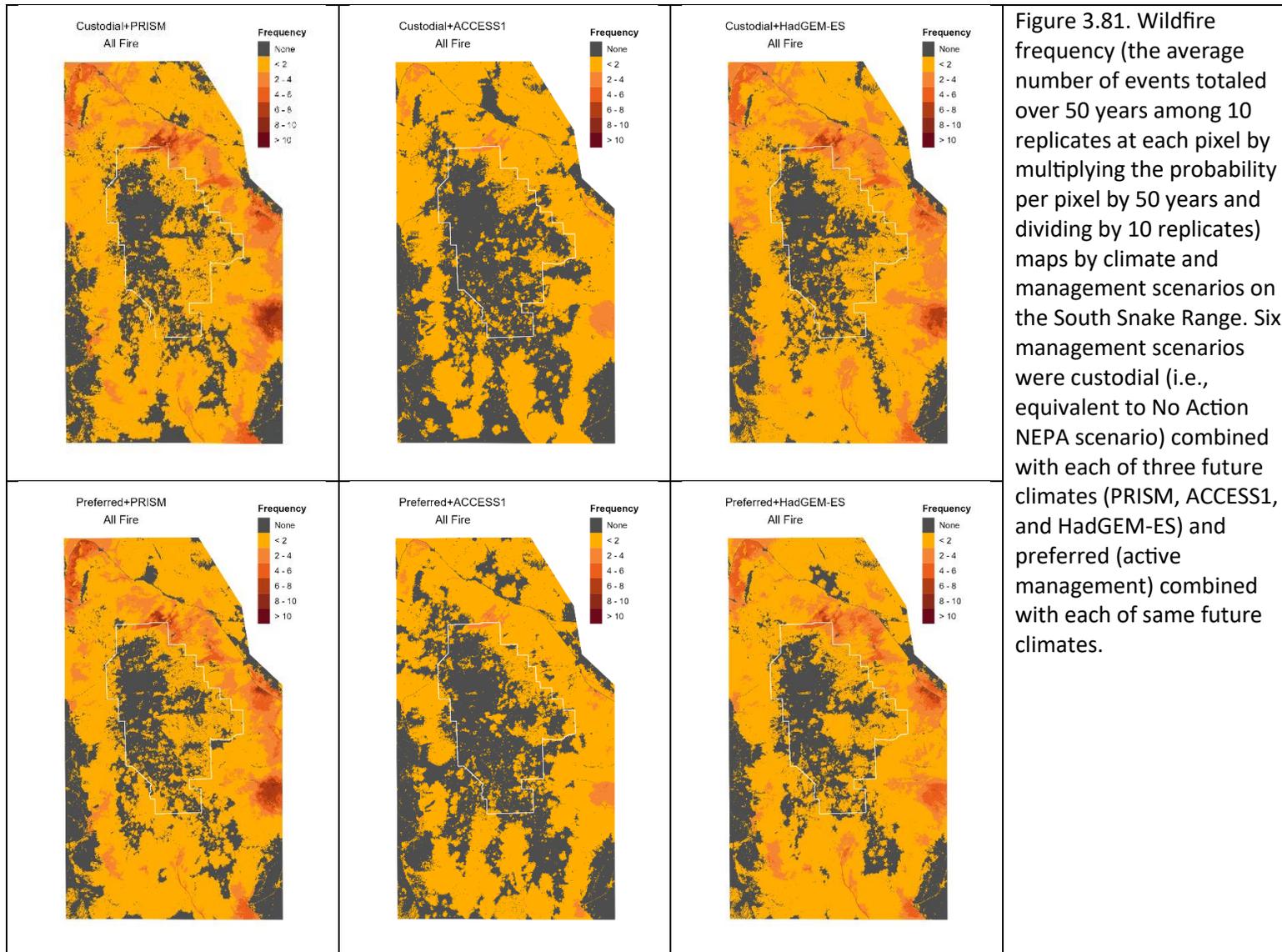


Figure 3.81. Wildfire frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate and management scenarios on the South Snake Range. Six management scenarios were custodial (i.e., equivalent to No Action NEPA scenario) combined with each of three future climates (PRISM, ACCESS1, and HadGEM-ES) and preferred (active management) combined with each of same future climates.

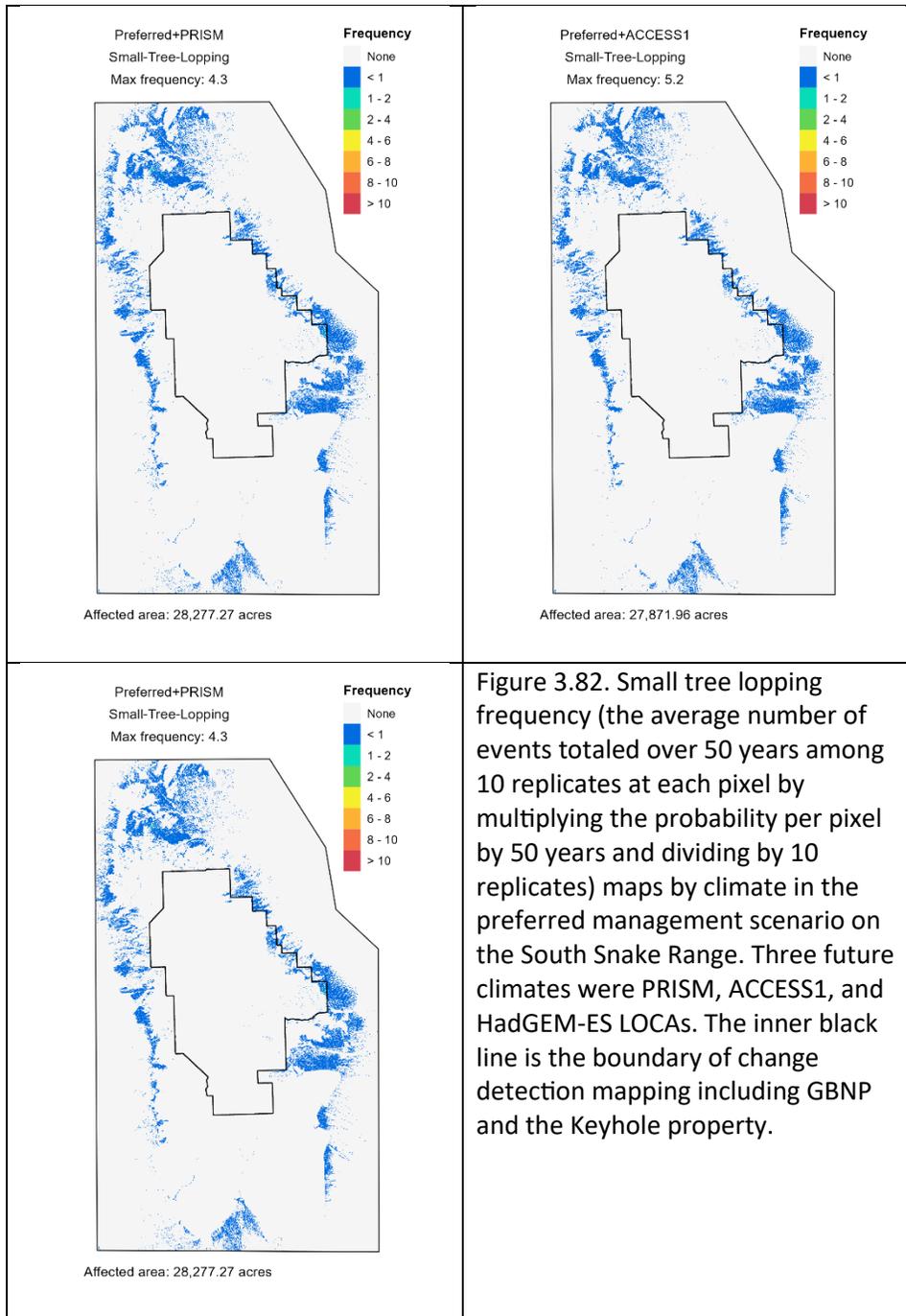


Figure 3.82. Small tree lopping frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

The second largest restoration action was seeding introduced and native perennial species and spraying imazapic (Plateau®) to inhibit germination of dormant annual species seed in areas dominated by non-native annual species on BLM-managed land. This treatment's extent ranged from 1,610.2 acres (ACCESS1) to 1,789.4 acres (PRISM climate; Fig. 3.83). Application was from middle to the lowest possible elevations where seeding was still possible (i.e., above the mixed salt desert and greasewood flats). Only black sagebrush and Wyoming big sagebrush – upland received Herbicide-Plateau+Seed. Slight climate effects were observed on the west slope south

of Mt. Washington on BLM-managed land where the frequency of the treatment was lower in the ACCESS1 climate than other climates (Fig. 3.83).

Prescribed burning ignited from a helicopter was the third most widespread treatment (ranging from 1,083.7 acres under HadGEM-ES climate to 1,102.7 acres for PRISM climate) that was found two precipitation zones (> 14-inch precipitation zone) above small tree lopping and mastication followed by seeding in the upper-montane and subalpine zone (Fig. 3.84). Most of the treated area was inside GBNP, with the rest in the Windy Peak area for BLM-managed land. Many systems received aerially ignited prescribed burning: aspen woodland, aspen-mixed conifer, aspen-subalpine conifer, dry wet meadow, limber-bristlecone pine-mesic, low sagebrush steppe, montane sagebrush steppe-mountain soil, mountain shrub, and wet meadow. We did not detect climate differences (Fig. 3.84).

Mastication of trees followed by introduced and native species seeding was the fourth most deployed action (Fig. 3.85). Implementation levels ranged from 1,016.4 acres (ACCESS1) to 1,078.1 acres (HadGEM-ES). The action's footprint was like that of small tree lopping except thinner, absent from the AOI's southern border, and added at higher elevations outside the northern border of GPNP (Figs. 3.80 *versus* 3.85). This action was not used in GBNP. Higher elevations support more mesic sites with denser and likely larger trees where masticators proved efficient. The treatment was used in antelope bitterbrush with black sagebrush and with mountain big sagebrush, black sagebrush, low sagebrush semi-desert, montane sagebrush steppe on upland soil, and Wyoming big sagebrush on upland soil. Very small frequency differences could be observed such as 1) less implementation on the north-central border (just east of USFS-managed land) in the ACCESS1 climate compared to others and 2) less implementation on the eastern slope between the Black Fire and Big Spring Ranch in the HadGEM-ES climate than other climates (Fig. 3.85).

The next treatment was mastication followed by native species seeding, but it was implemented at one third the area of the next highest treatment. The range of area treated was from 549.9 (PRISM climate) to 591.0 acres (ACCESS1 climate; Fig. 3.86). The spatial distribution of this treatment was similar to that of masticate+seed; however, masticate+native seed was also deployed in GBNP because a native species mixture was used. The action was used in antelope bitterbrush-black sagebrush, black sagebrush, and montane sagebrush steppe-upland soil. We could not observe differences among climates (Fig. 3.86).

Mowing sagebrush followed by introduced and native species seeding was only applied in black sagebrush from low to middle elevations over a range of 523.5 acres (PRISM climate) to 551.8 acres (ACCESS1 climate; Fig. 3.87). Except for hilly shrublands on both sides of Hwy 50/6 east of Sacramento Pass, the action was deployed on lower alluvial fans at the periphery of the AOI (Fig. 3.87). No climate differences were observed.

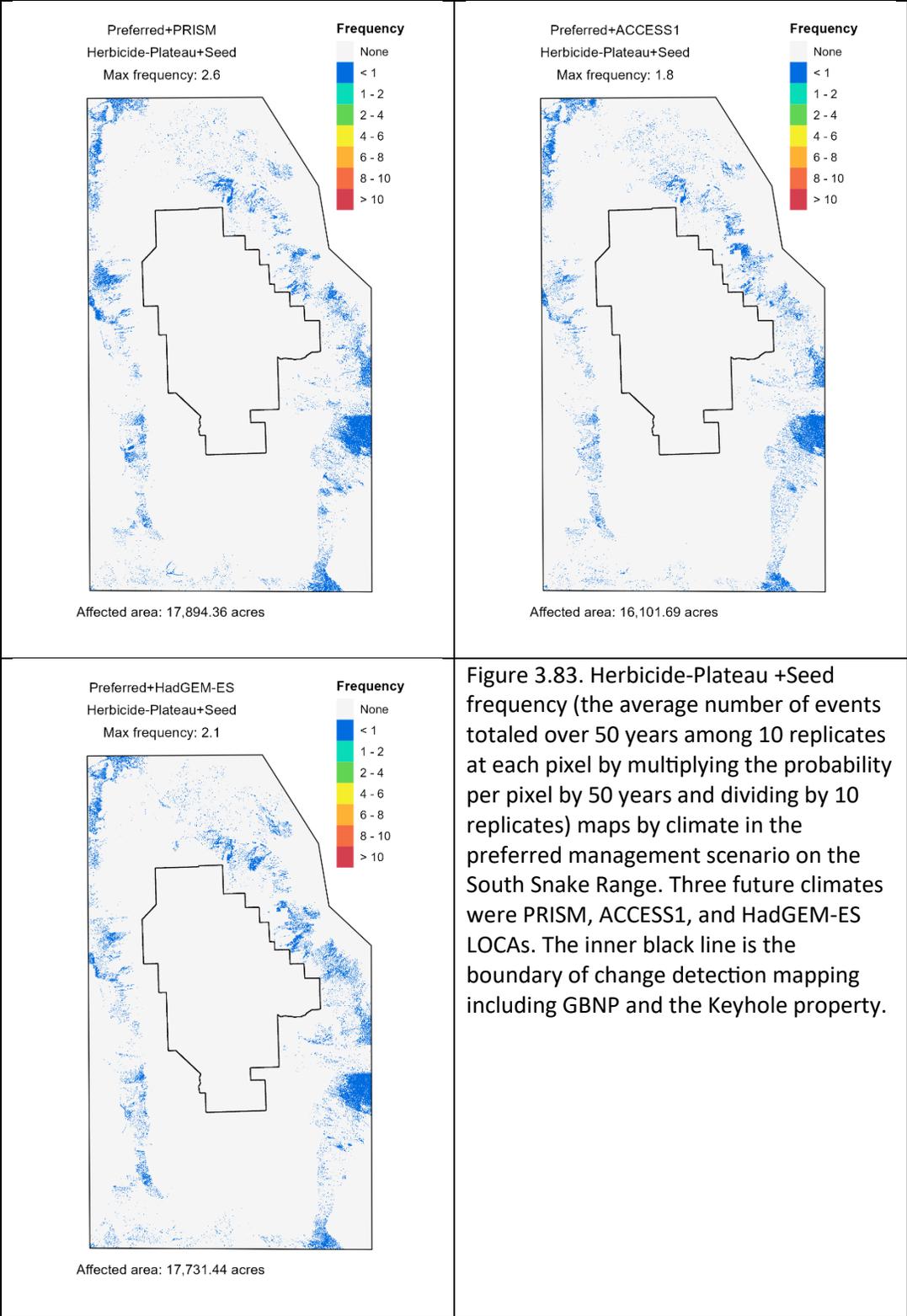


Figure 3.83. Herbicide-Plateau +Seed frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

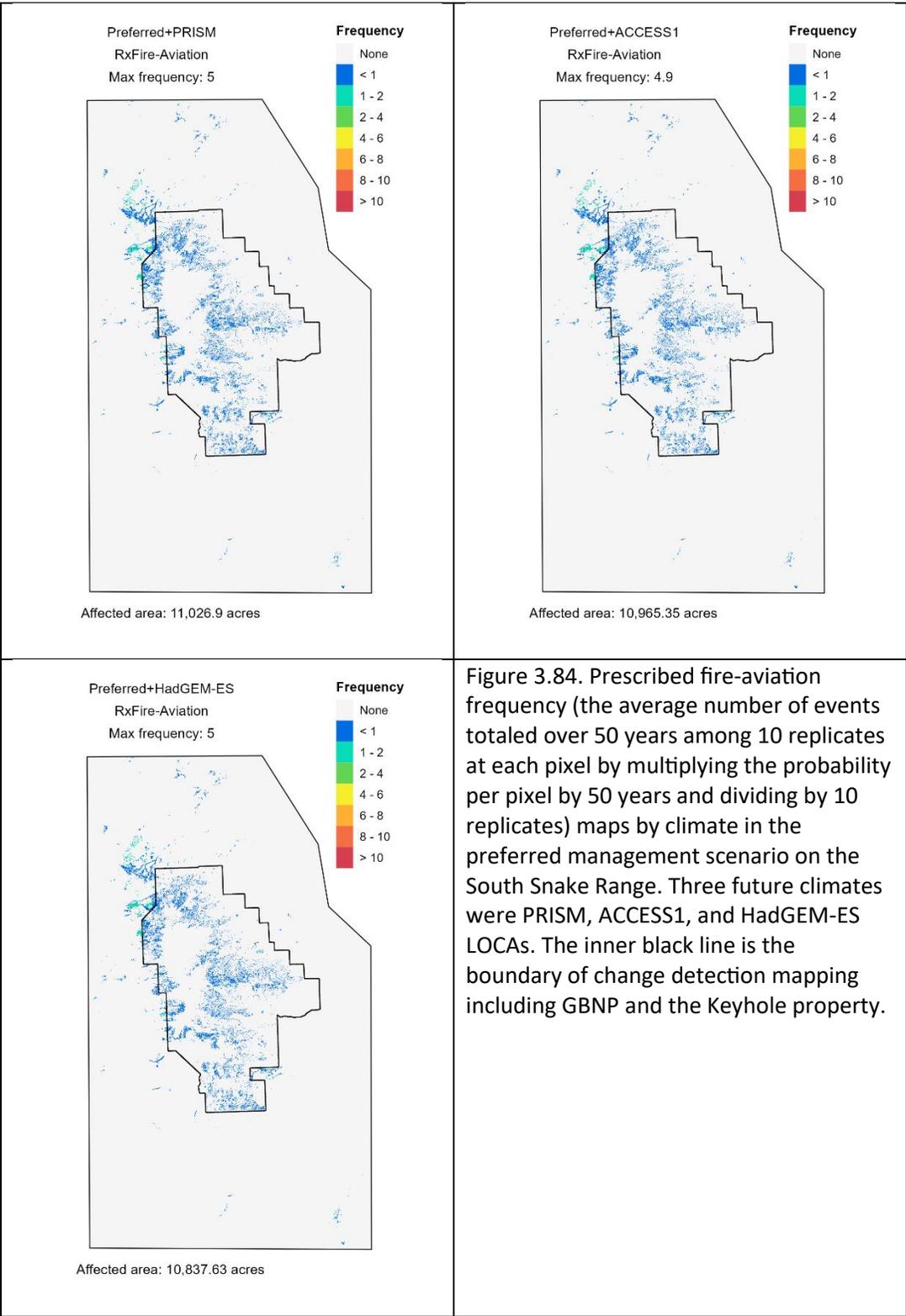


Figure 3.84. Prescribed fire-aviation frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

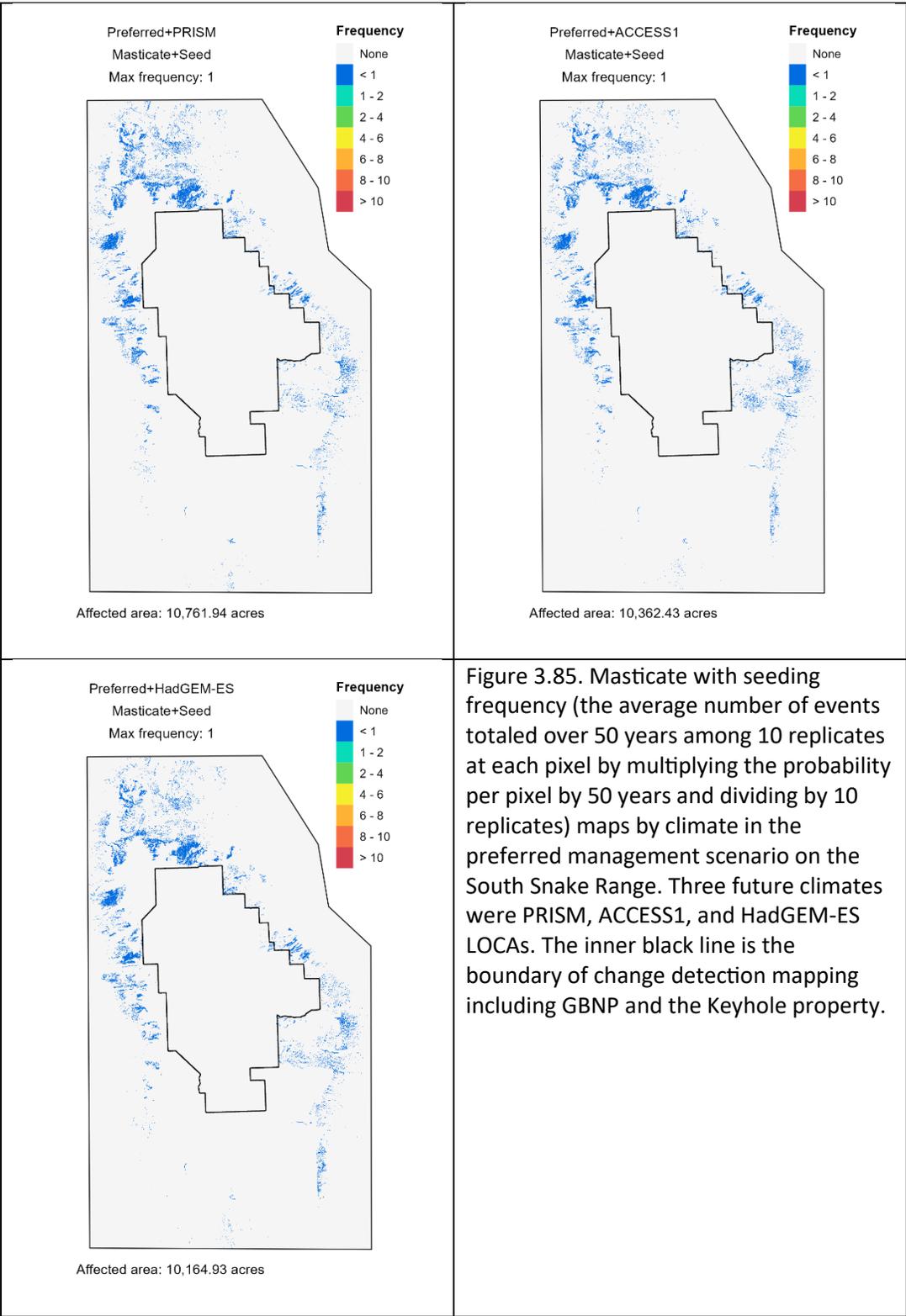


Figure 3.85. Masticate with seeding frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

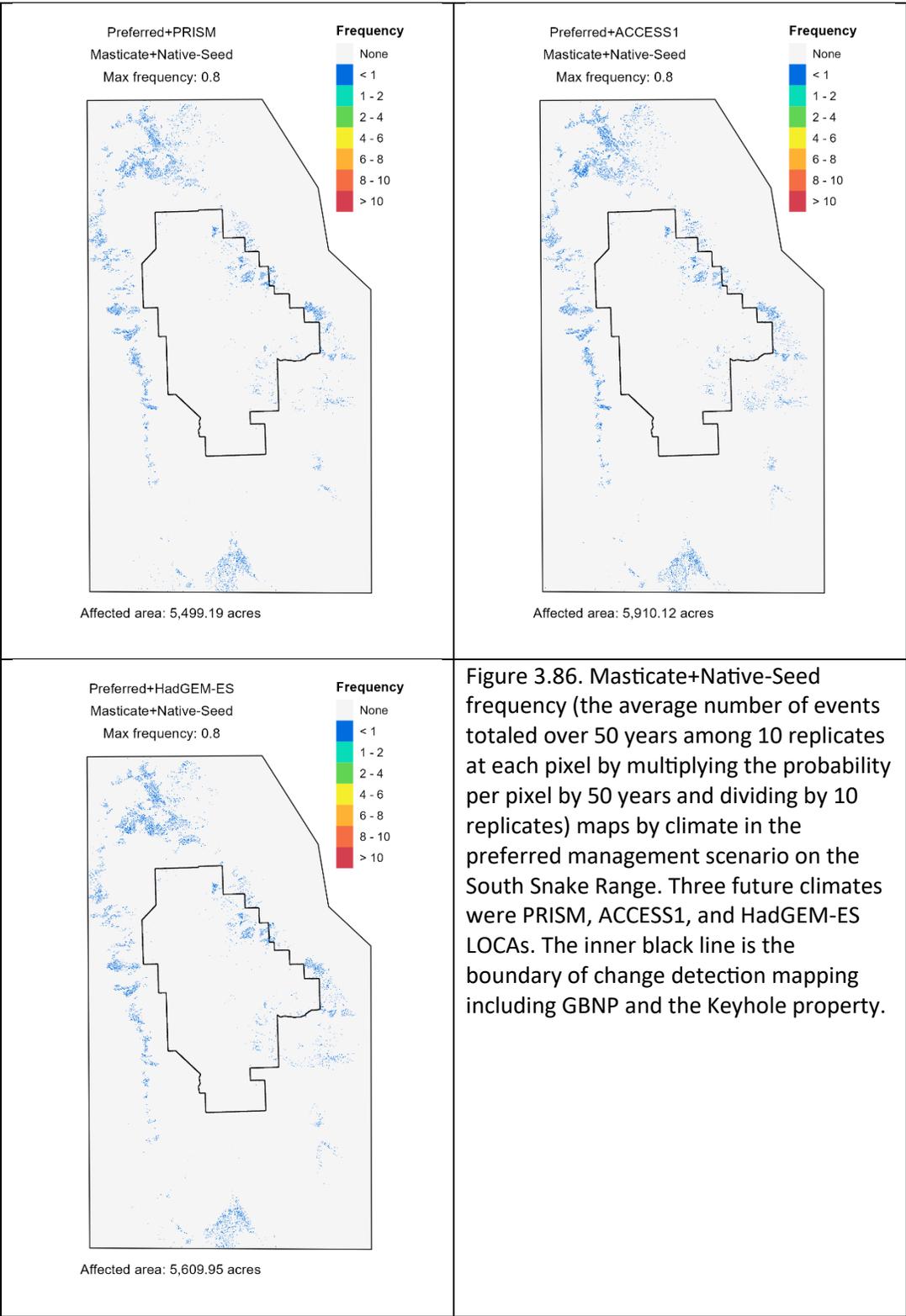


Figure 3.86. Masticate+Native-Seed frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

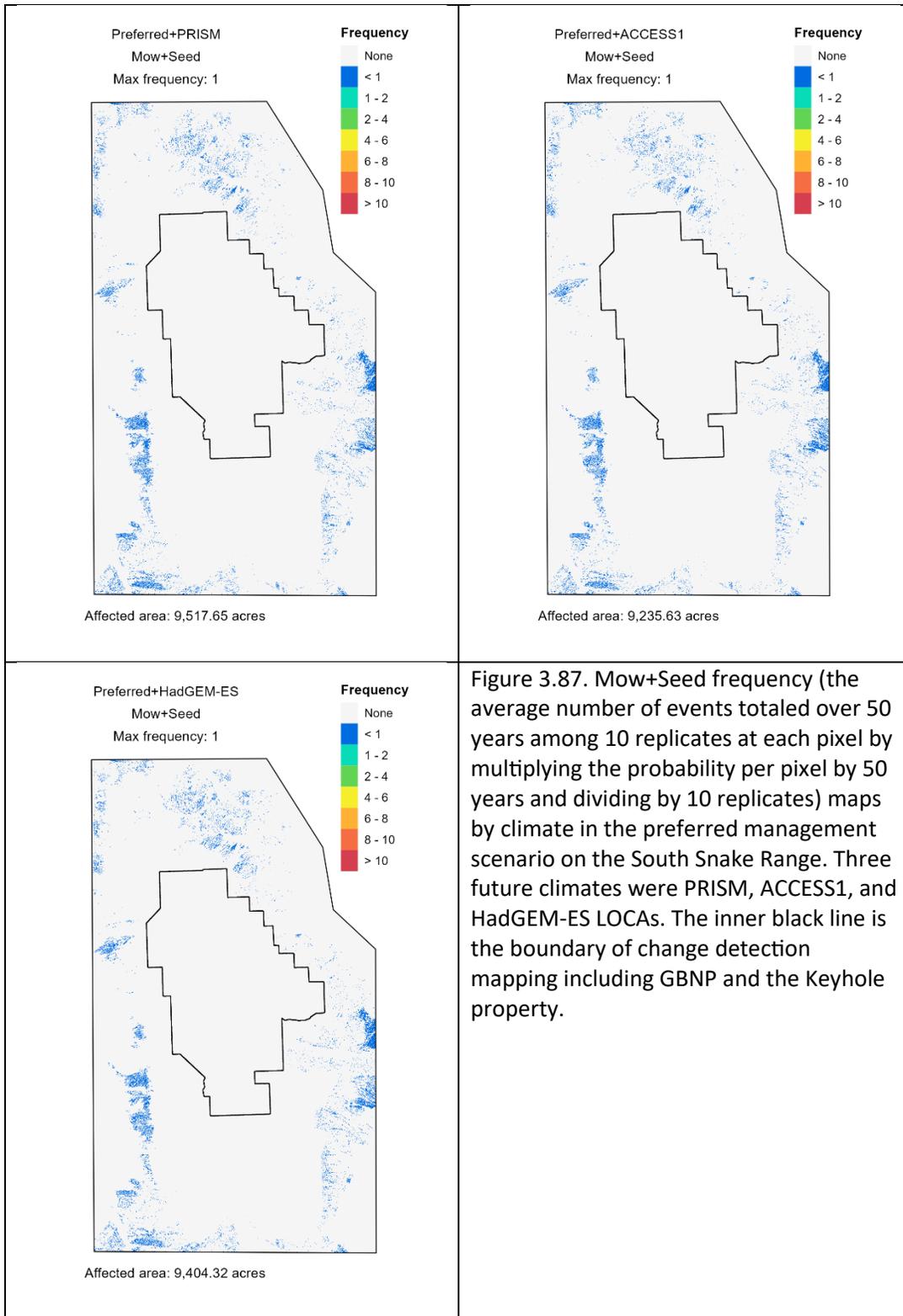


Figure 3.87. Mow+Seed frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

Lop and scatter followed by aerially ignited prescribed fire was only used in aspen-mixed conifer to provide the coniferous fuel bed to carry fire in aspen and the remaining standing

conifers (Fig. 3.88). This action and simple aerial prescribed burning were considered the two most significant actions for GBNP. About 392.2 acres (HadGEM-ES climate) to 396.0 acres (PRISM climate) were deployed in the Windy Peak area and throughout the east slope in GBNP. No climate effects were noted (Fig. 3.88).

Lop and scatter was only implemented in littleleaf mountain mahogany to cut pinyon and juniper (Fig. 3.89). Treatment locations were on scattered limestone ridges and shelves over about 228.7 acres. No climate differences were observed.

Weed inventory and spot spraying was a repetitive activity designed to visit all drainages (montane riparian, basin wildrye) and wetlands (dry wet meadow, saline meadow, and wet meadow montane) of GBNP and BLM-managed land every 5 years for detection of noxious exotic weeds and only spray small occurrences (large occurrences left for the exotic control treatment; Fig. 3.90). From 296.4 to 296.9 acres were simulated with this action with no climate differences.

Ground-ignited prescribed burning was deployed in small areas in many locations in GBNP and BLM-managed land, although most of the burning was on GBNP (Fig. 3.91). Area treated ranged from 187.8 to 190.7 acres with no observable climate differences (Fig. 3.91). The targeted systems were dry wet meadow, montane riparian, montane sagebrush steppe-upland soil, mountain shrub, and wet meadow-montane. Sagebrush and mountain shrub sites reached upper montane elevations near Snake Creek (Horse Heaven), Baker Creek, and Lehmann Creek watersheds.

Chainsaw lopping and scattering of conifers followed by native species seeding was only used in montane sagebrush steppe on upland soil in GBNP (Fig. 3.92). Area treated ranged from 568 acres (PRISM and ACCESS1 climates) to 586 acres (HadGEM-ES climate). The treatment was especially deployed in the general area around the Lehman visitor center where pile burning might be risky (Fig. 3.92). No climate effects were noted.

Fencing was used in aspen woodland and aspen-mixed conifer only on BLM-managed land (Fig. 3.93). Treated area ranged from 46.3 acres (PRISM climate) to 50.7 acres (HadGEM-ES climate), although this represented the area fenced with the understanding that BLM would build the fence on the perimeter of treated aspen. Commonly selected areas were the Windy Peak area, along the western boundary of GBNP, and along the north fork of Lexington Creek (Fig. 3.93).

Thinning shrubs followed by herbicide spraying of non-native annual species and seeding native species was only used in basin wildrye-montane (Fig. 3.94). Treated area ranged from 46.3 acres (PRISM climate) to 50.7 acres (HadGEM-ES climate). The treatment was widespread in valley bottoms in GBNP (e.g., Lehman Creek and Baker Creek) and BLM-managed land, mostly in the northern drainages (Fig. 3.94). We could not detect climate differences.

Chainsaw followed by pile burning was applied at low levels ranging from 32.6 acres (HadGEM-ES climate) to 34.1 acres (PRISM climate) on both GBNP and BLM-managed land (Fig. 3.94). Systems treated were littleleaf mountain mahogany, montane riparian, ponderosa pine, and riparian ponderosa pine at many elevations below the subalpine zone. Sites were scattered because target ecological systems were also dispersed. The largest occurrence was in littleleaf mountain mahogany on the southern border of the AOI.

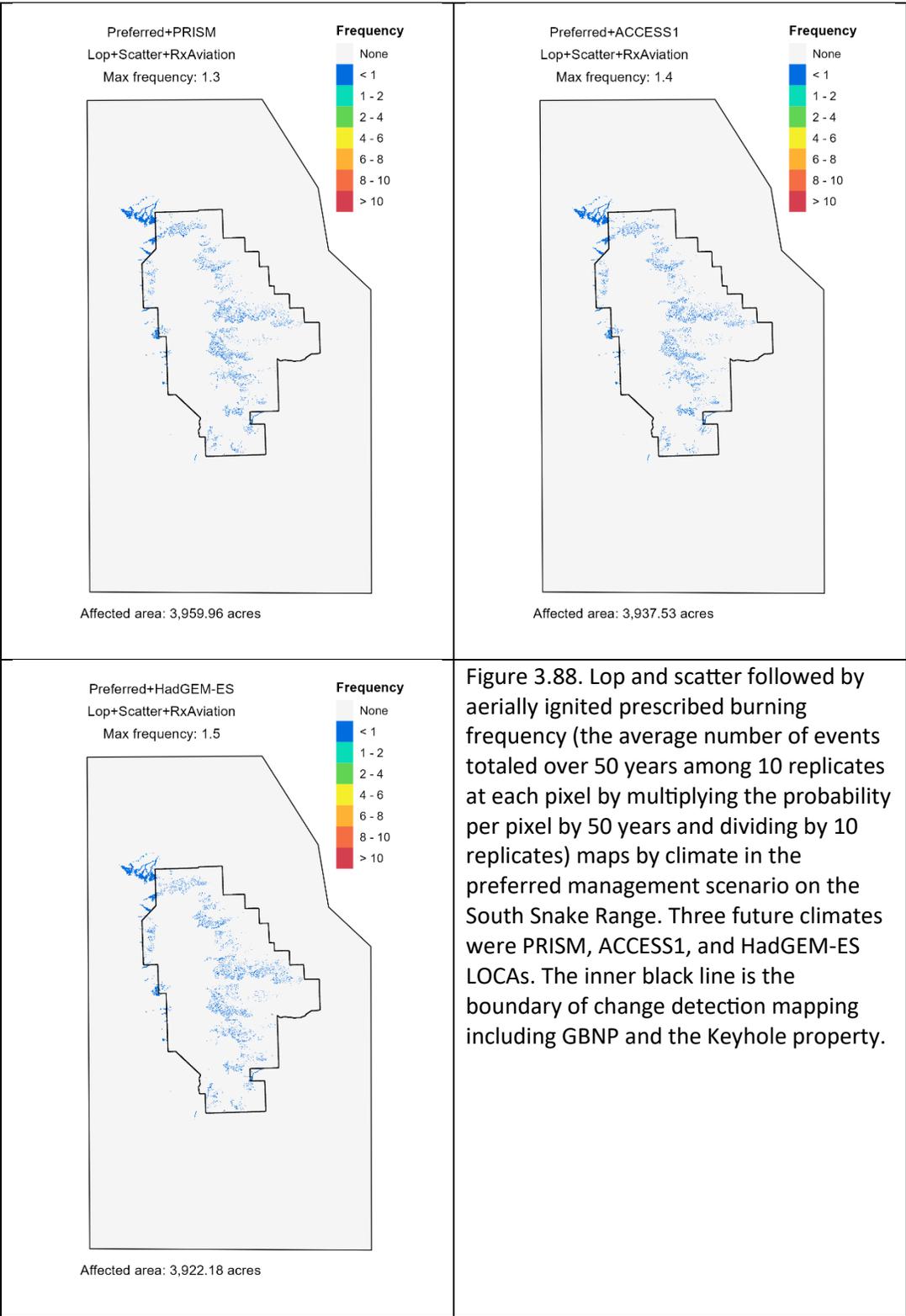


Figure 3.88. Lop and scatter followed by aerielly ignited prescribed burning frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

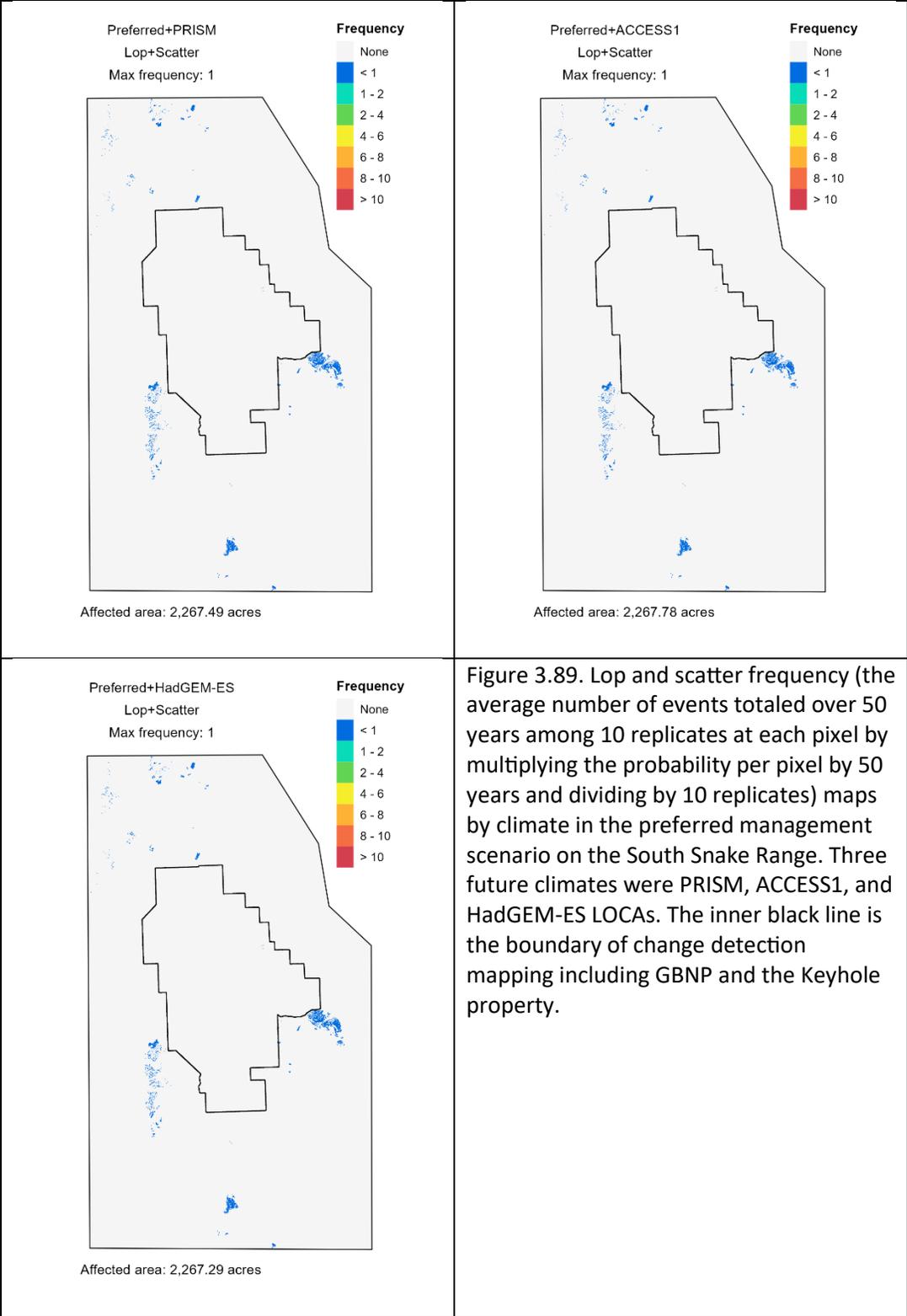


Figure 3.89. Lop and scatter frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

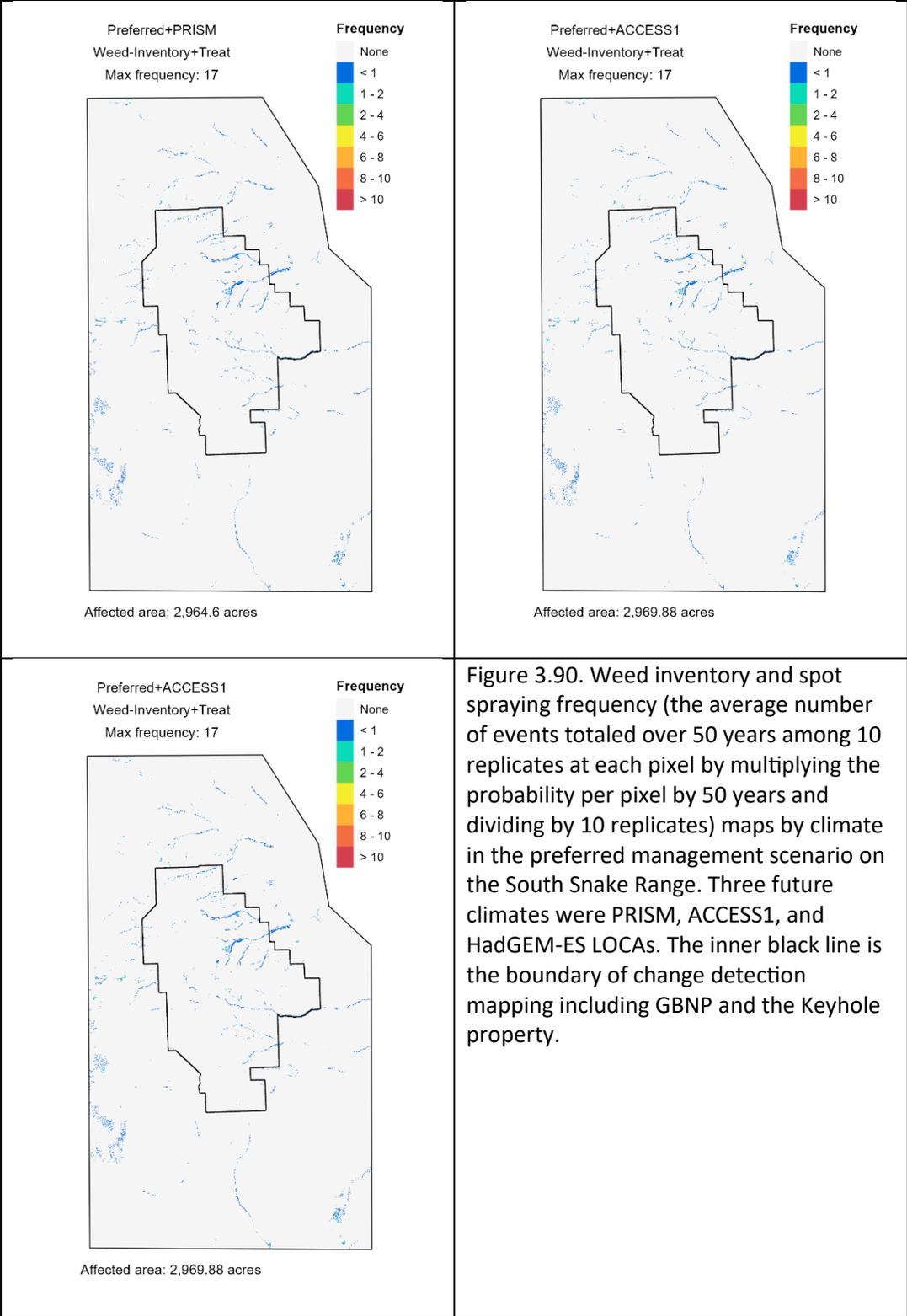


Figure 3.90. Weed inventory and spot spraying frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCA. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

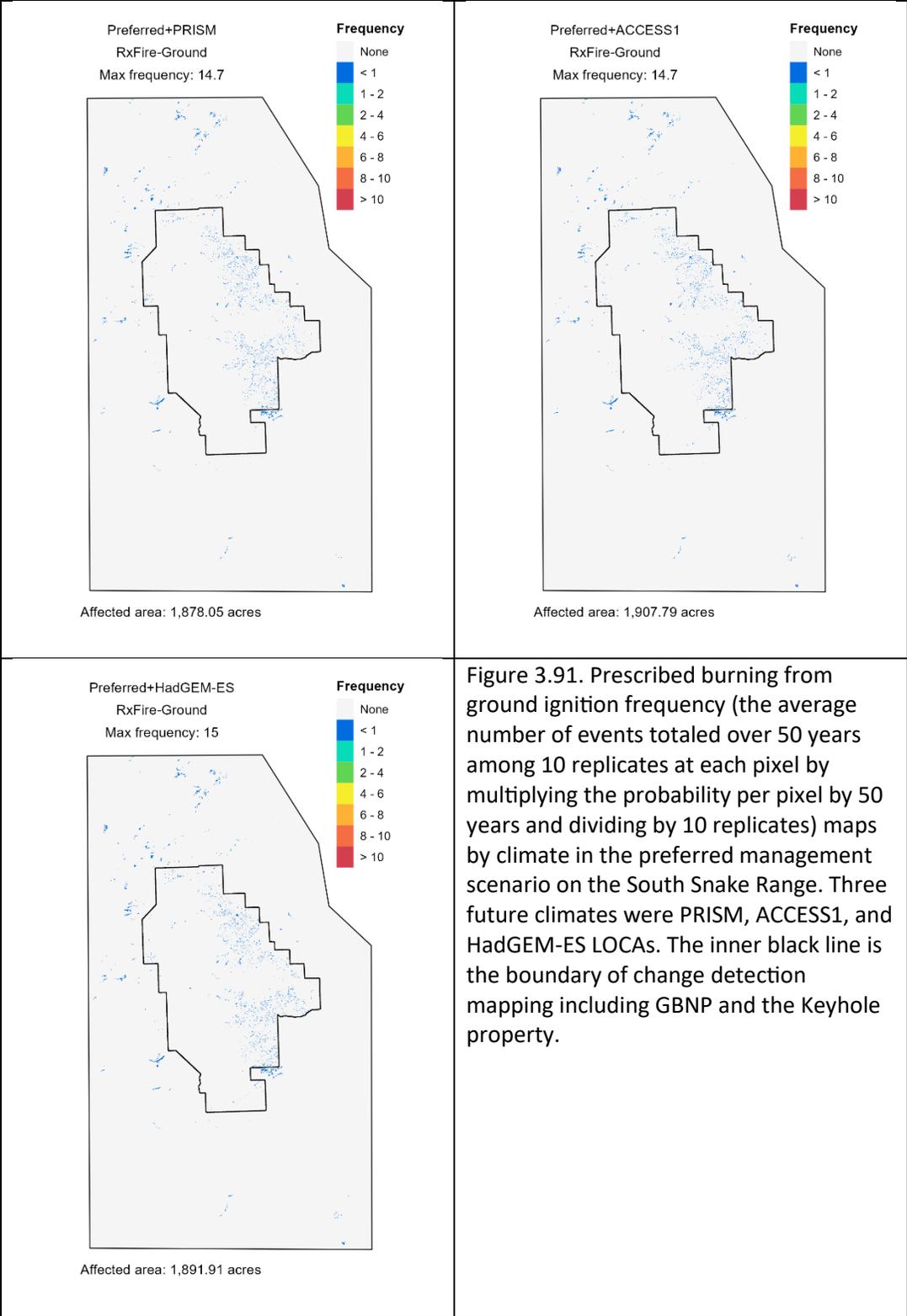


Figure 3.91. Prescribed burning from ground ignition frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

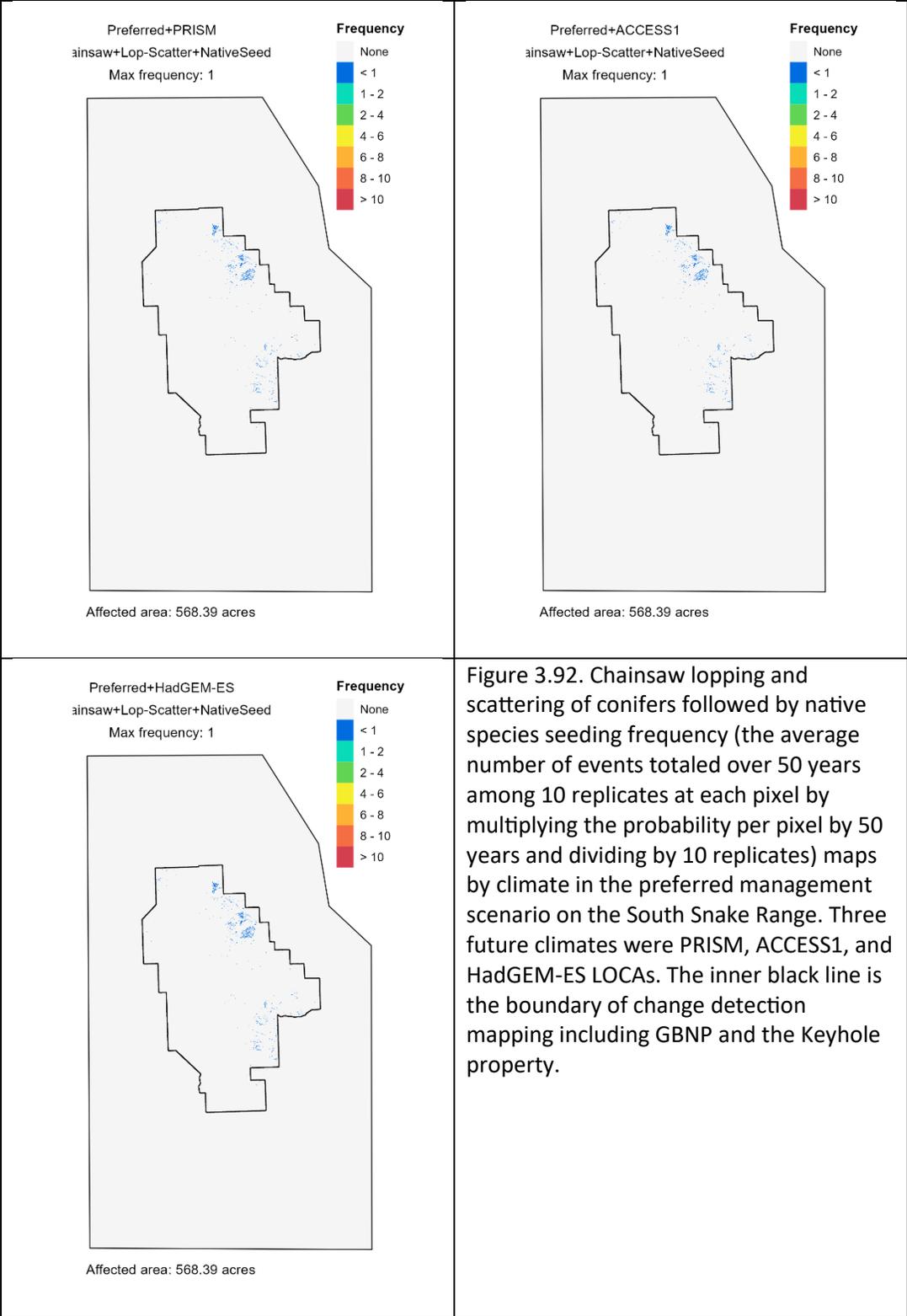


Figure 3.92. Chainsaw lopping and scattering of conifers followed by native species seeding frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

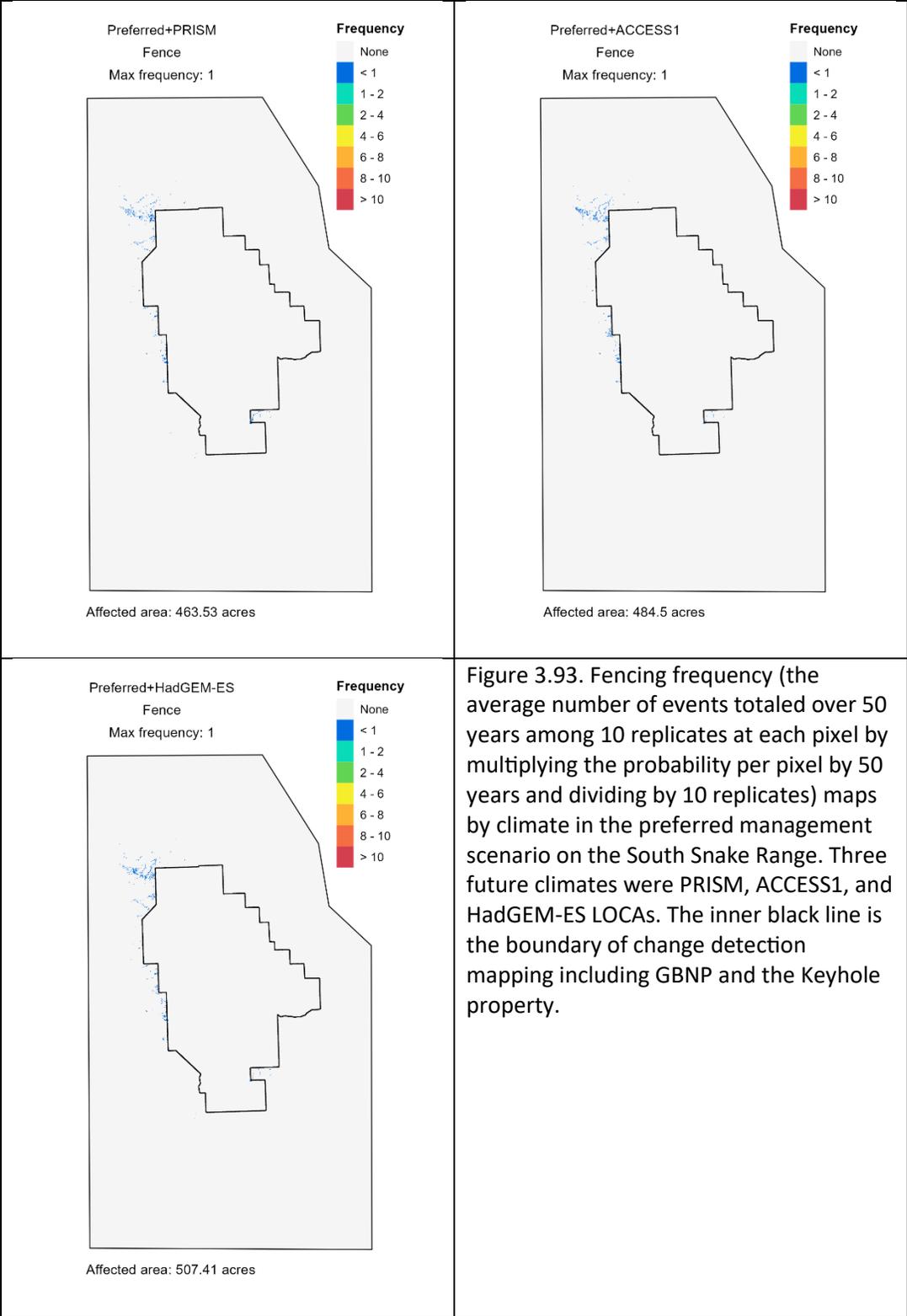


Figure 3.93. Fencing frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

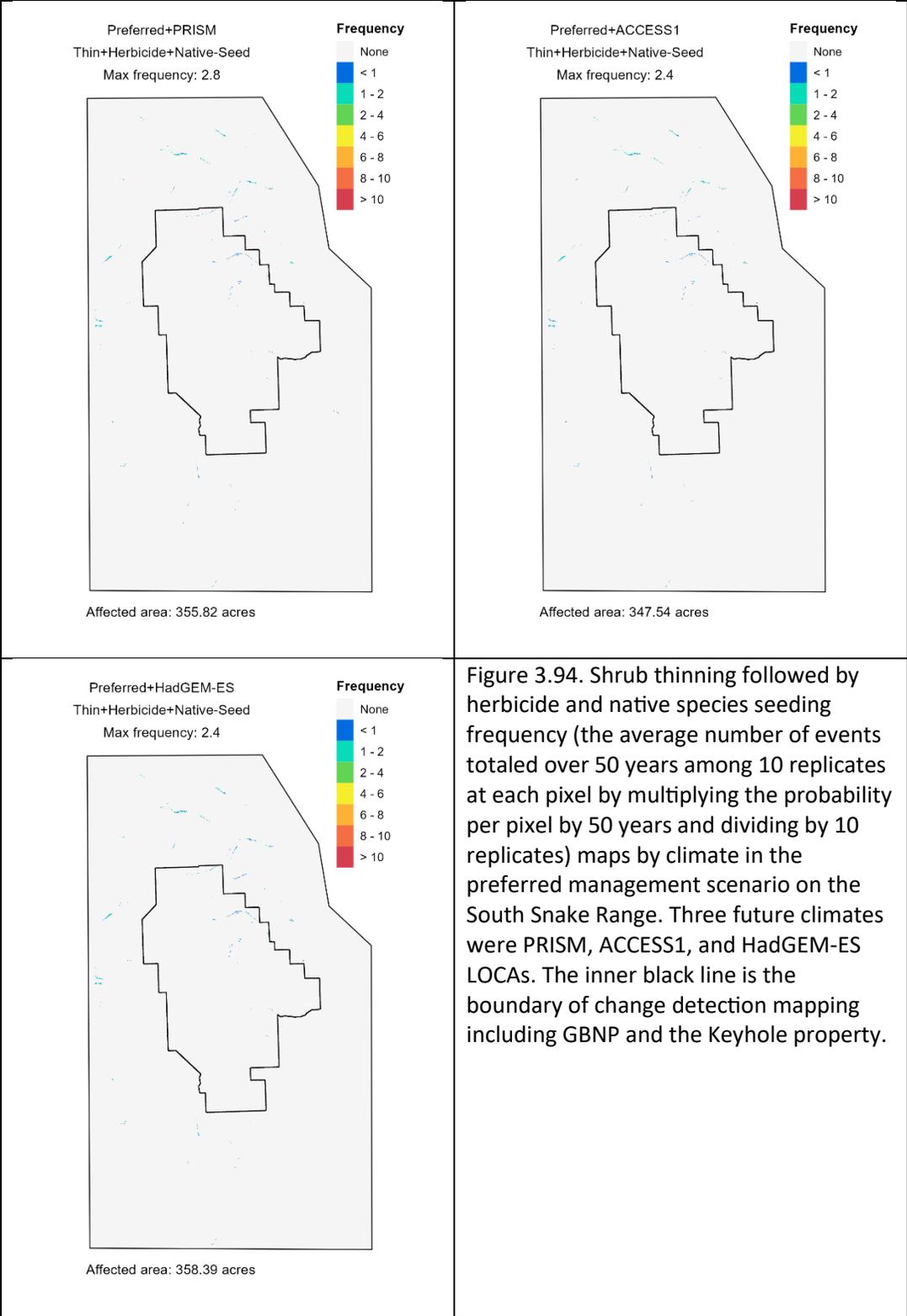


Figure 3.94. Shrub thinning followed by herbicide and native species seeding frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCA. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

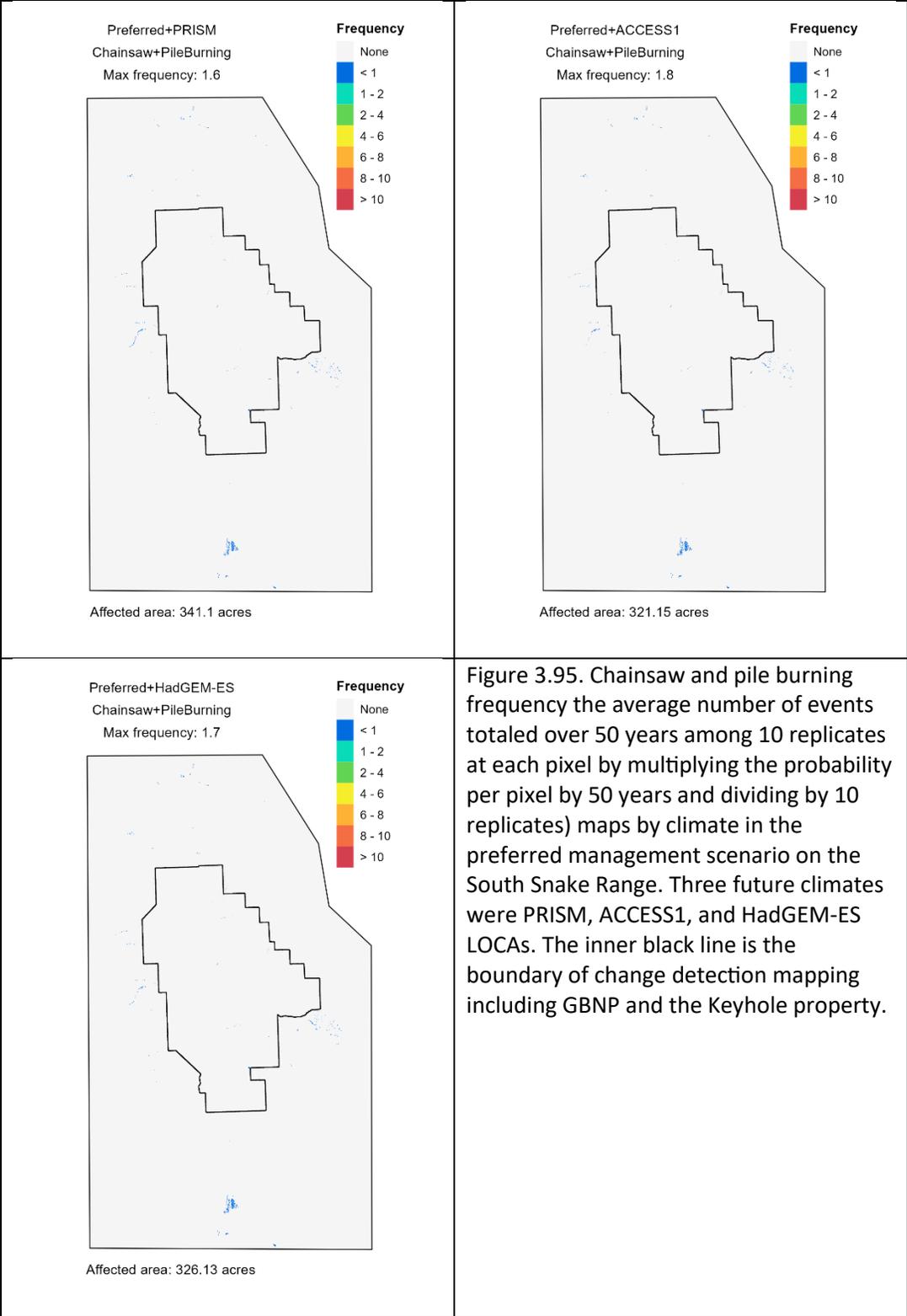


Figure 3.95. Chainsaw and pile burning frequency the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

Water table uplift was used in incised montane riparian and wet meadows in many barely visible small areas, although a wet meadow complex in the southeast portion of the AOI was a very visible implementation area (Fig. 3.96). Total area treated ranged from 14.4 acres (PRISM climate) and 15.3 acres (HadGEM-ES climate). No climate effects were visible.

Chainsaw cutting followed by pile burning and mixed introduced and native species seeding was only used for basin wildrye and only on BLM-managed land. The primary location of implementation was Mill Creek downstream from the GBNP boundary where the area treated was about 4.2 acres (Fig. 3.97). No climate effect was noted.

Chainsaw-chip followed by herbicide and native species seeding was only used in basin wildrye-montane in GBNP mostly along the Lehman Creek and Baker Creek drainages (Fig. 3.98). About 4.2 acres was deployed in linear valley bottoms. Climate had no effect on implementation (Fig. 3.98).

Three treatments were used in very small areas and not observable in figure format: exotic control (i.e., herbicide spraying), exotic control followed by native species seeding, and chainsaw cutting followed by pile burning and native species seeding using contractors. Those results were not shown but results will be part of the electronic delivery of spatial data to partners.

A spatially visible non-disturbance action was pinecone collection (Fig. 3.99). Pinecone collection was scattered in the same places where patches of older ponderosa pine, bristlecone pine, and limber pine were found (Fig. 3.99). About 20.4 acres were deployed. Climate effects were not part of this action.

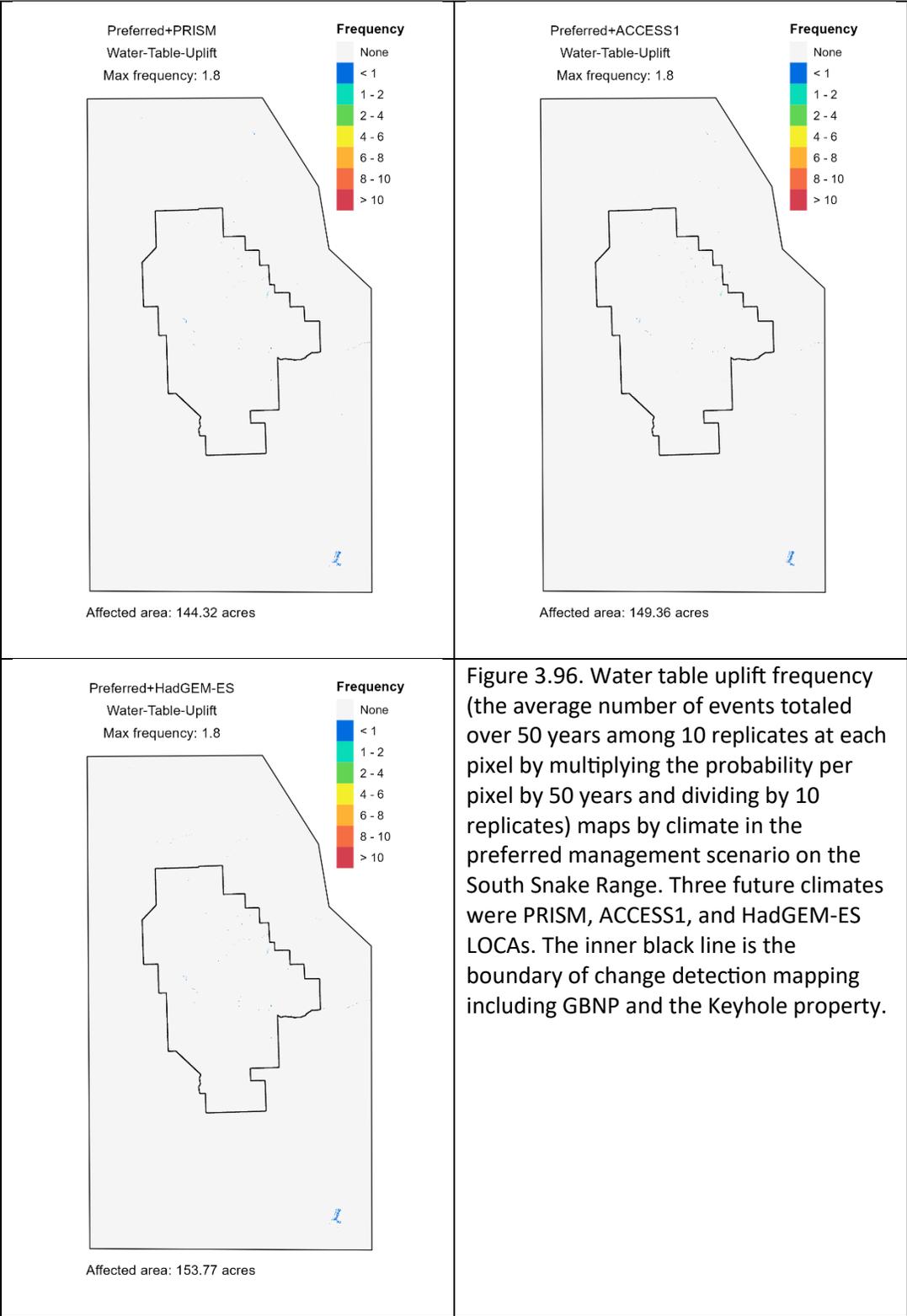


Figure 3.96. Water table uplift frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCA. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

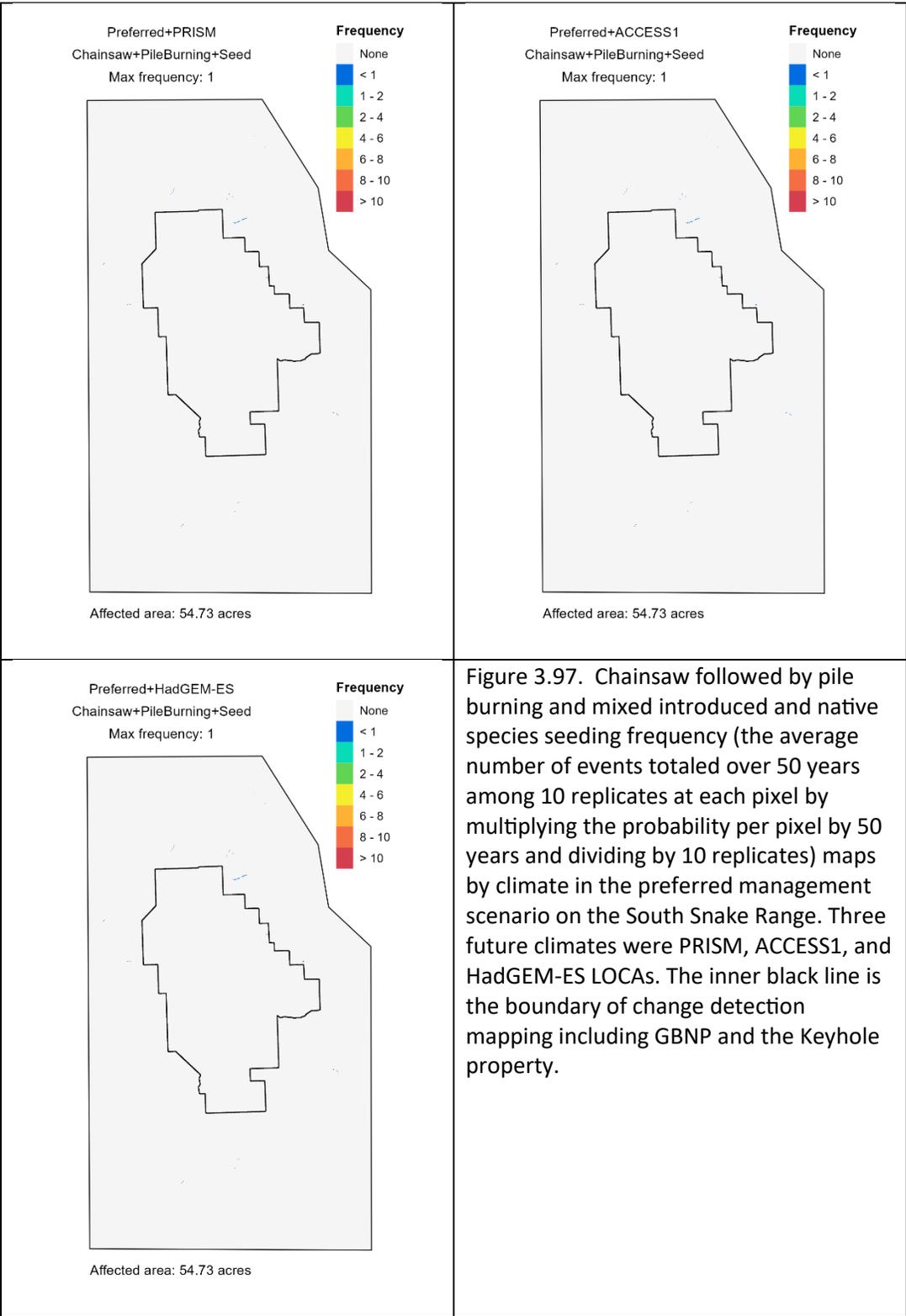


Figure 3.97. Chainsaw followed by pile burning and mixed introduced and native species seeding frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

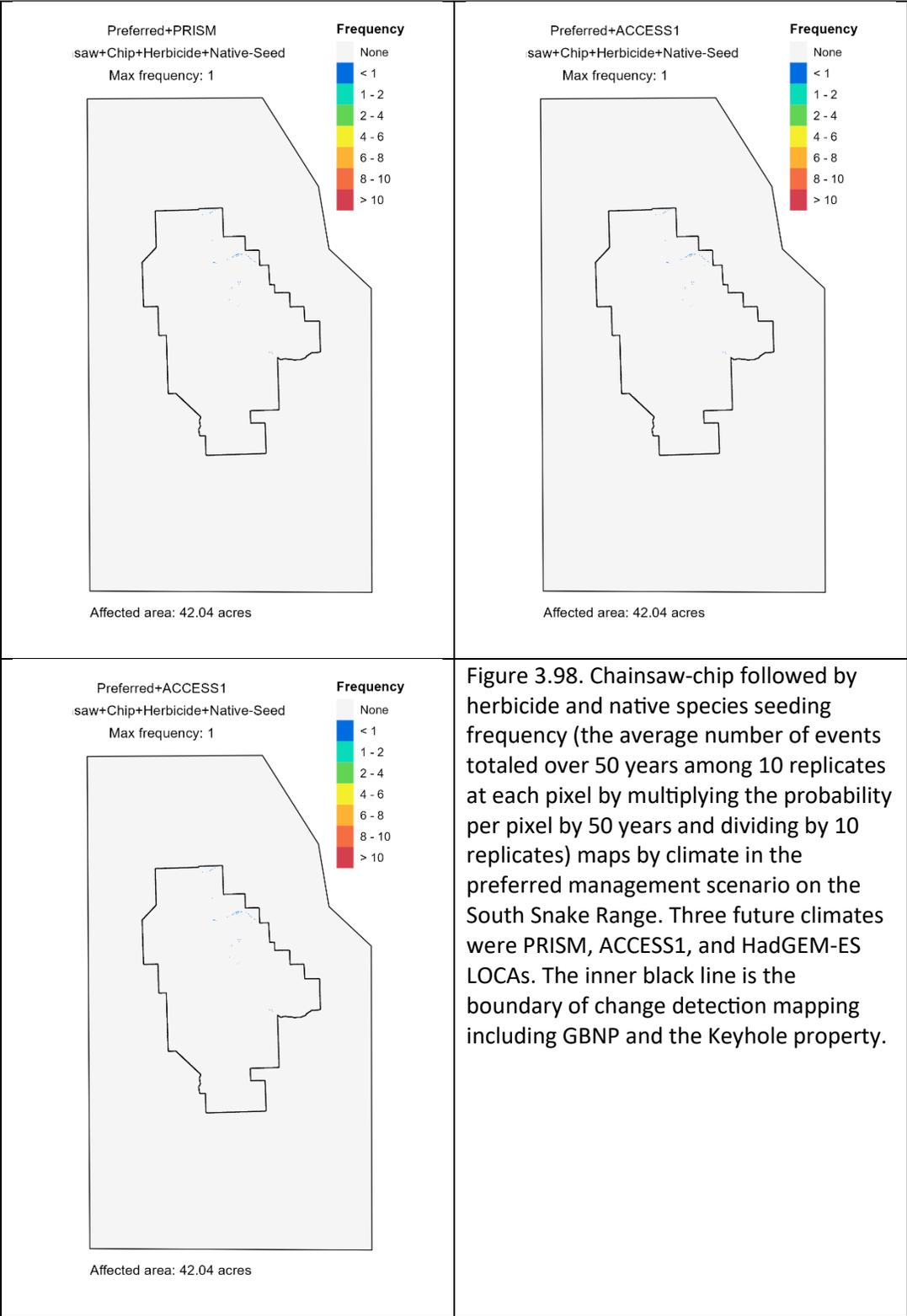


Figure 3.98. Chainsaw-chip followed by herbicide and native species seeding frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

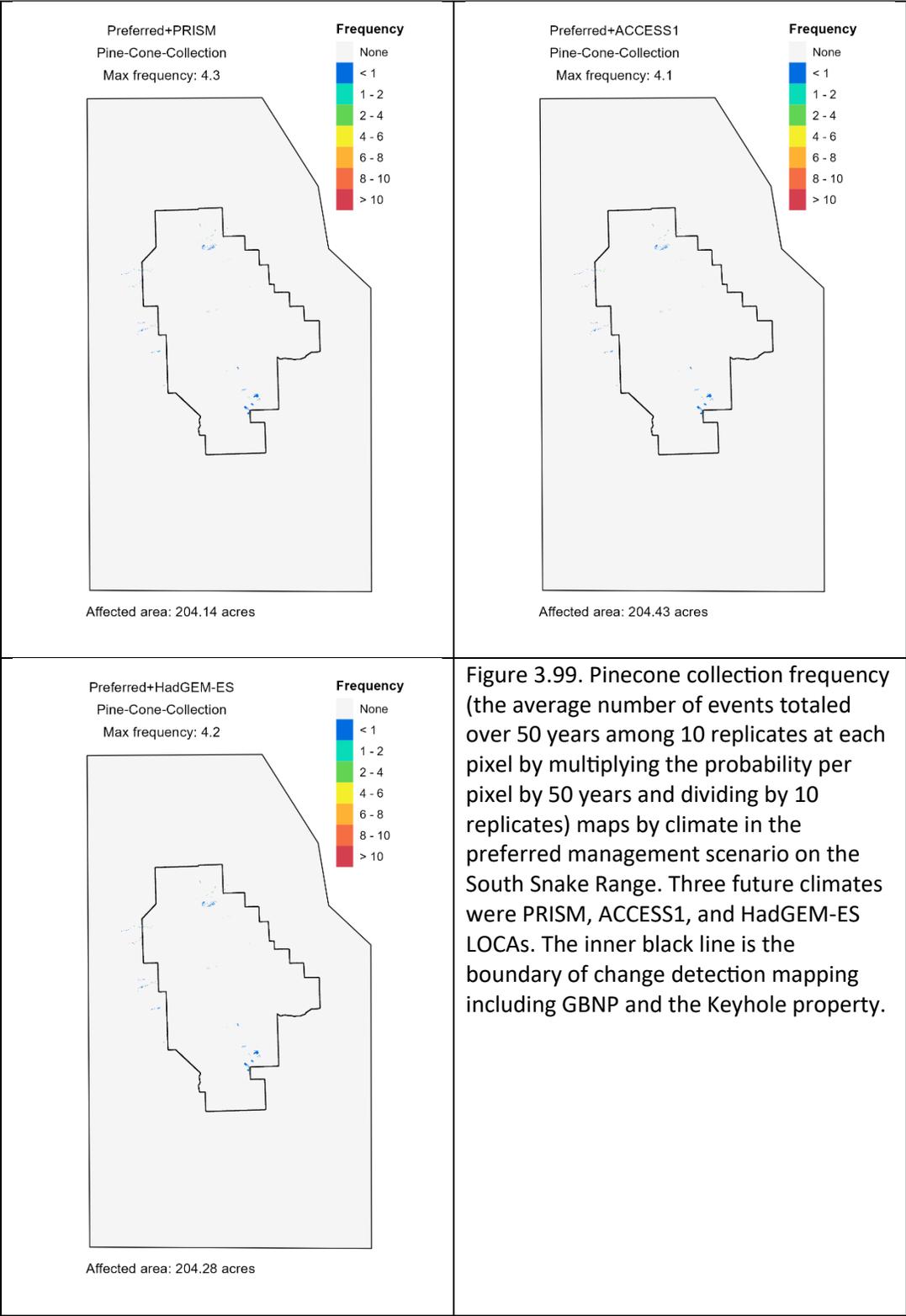


Figure 3.99. Pinecone collection frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCA. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

4. Discussion and Conclusions

Three primary questions were addressed in this study. Did vegetation management:

- Improve ED (decrease its value) of focal ecological system or get closer to a desired future condition that might result in a higher and acceptable level of ED?
- Improve the habitat of bighorn sheep, especially the forage base? And
- Improving fire management by:
 - Lowering the area burned, especially in area that might burn too much due to the fine fuels of non-native annual species? And
 - Minimizing the detrimental effects on riparian health?

ED: Answer to the first question was mixed because use of introduced species seedings or tree thinning without seeding at lower to middle elevations on BLM-managed land simply substituted one uncharacteristic class for another; therefore, non-spatial ED was generally unchanged although treatments successfully reduce fuels and increased vegetation classes targeted for management. As Provencher et al. (2021a) explained for the Black Mountains in BLM Cedar City UT Field Office, no amount of funding can change such an outcome if introduced species seedings were used. Black sagebrush restoration was a good example of this outcome. As elevation increased, native seedings were more common, required in GBNP, and restoration transitions produced reference vegetation classes that contributed to lower ED (Provencher et al. 2021a).

Non-spatial ED was estimated from the entire AOI per system; however, in 2010, the mapping was limited to GBNP and the Keyhole property. While comparing the 2022 and 2007 images (QuickBird imagery was acquired by NRCS in 2007) was not valid as >300,000 acres of additional land changed the proportions of vegetation classes per system, Provencher et al. (2010, 2013) reported ED values that were similar to the new ones for systems largely contained within GBNP. For examples, antelope bitterbrush-mountain big sagebrush, limber-bristlecone pine-dry, Engelmann spruce, low sagebrush steppe, riparian ponderosa pine, and wet meadow showed similar EDs between 2010 and 2022. Moreover, the following systems also important in GBNP showed improvement of the non-spatial ED in 12 years: aspen-subalpine conifer (from 60% to 16%), limber-bristlecone pine-mesic (from 48% to 18%), and ponderosa pine (from 54% to 51%). For systems substantially present outside GBNP, these systems' ED increased: aspen-mixed conifer (from 66% to 84%), aspen woodland (from 27% to 62%), basin wildrye (from 66% to 98%), black sagebrush (from 60% to 69%), montane sagebrush steppe on mountain soils (from 30% to 41%), montane sagebrush steppe on upland soils (from 56% to 74%), curl-leaf mountain mahogany (from 23% to 43%), pinyon-juniper woodland (from 11% to 33%), and montane riparian (from 26% to 32%).

Aspen woodland's increase in ED was a special case because of a post-fire pulse of the early-successional class exceeding the reference proportion, addition of three depleted classes in BLM-managed lands, and the increase of the lost-clone vegetation class in GBNP. The latter issue required two explanations: a) lost clones were more strongly inspected around viable clones in 2022 that revealed more loss of clones than reported in 2010 (down aspen boles) and b) we resampled all classes from the interpreted WorldView 2/3 imagery to 14 m resolution for

simulation feasibility, which caused unavoidable over-estimation of small sensitive vegetation classes that are caused for management concern, such as aspen clone loss.

Interpretation of non-spatial ED should be carefully approached for small area systems because ED becomes biased as the system's area decreases and as the dominant stand-replacement disturbance becomes less frequent (Hann and Strom 2003; Steele et al. 2006). It is a long-known theoretical problem of assessing a landscape of a sufficient area to allow enough disturbances that shape the expression of most successional classes. Small systems relative to the average interval between stand-replacing events such as antelope bitterbrush – Wyoming big sagebrush, aspen woodland, dry wet meadow, limber-bristlecone pine - dry, low sagebrush-semi-desert soil, low sagebrush steppe, montane sagebrush steppe – mountain soil, ponderosa pine, littleleaf mountain mahogany, riparian ponderosa pine, and Stansbury cliffrose could have biased non-spatial ED estimates. Focusing on desirable vegetation classes of small systems might be a better approach than strictly focusing on balancing the departed proportions of vegetation classes towards the reference conditions. Alternatively, using spatially explicit ED could focus management; however, further theoretical development will be required to make it more practical beyond the initial work by Provencher et al. (2024).

Single-system spatially explicit ED was informative in that it confirmed lower ED at subalpine elevations, moderate ED at montane to subalpine elevations, and generally higher ED at the upland and semi-desert elevations. Moreover, EDs were very mosaicked in the moderate to low range. The full-system spatial explicit ED was more interesting because it confirmed hypotheses about non-use of otherwise suitable bighorn sheep habitat (see later in Discussion) as the metric estimated departure just as an animal might perceive all systems when assessing use of different zones during travel. The full-system spatially explicit ED showed high departure west of and around Horse Heaven (north of Snake Creek on the high ridge) and on the ridge between Granite Peak and the Big Spring Ranch. These areas were in part highly departed because of conifer encroachment in shrublands and aspen-mixed conifer, which would be a deterrent to bighorn sheep avoiding timber perceived as concealing mountain lions (Comer et al. 2016).

Bighorn Sheep Habitat: Treatments in various subalpine and montane forests, woodlands, and shrublands successfully increased the early successional forage for bighorn sheep primarily by deploying prescribed burning and chainsaws. The area of early successional vegetation classes was the only variable of the habitat suitability model that could be manipulated as escape habitat, elevation, snow depth, and terrain roughness were out of the control by land managers. Prescribed burning in all three aspen types, mesic limber and bristlecone pine forest, low sagebrush steppe, and chainsaw operation in littleleaf mountain mahogany and mountain shrub caused a measurable increase of habitat suitability, especially on both sides of the ridge from Wheeler Peak into the Highland Ridge.

Climate effects on bighorn sheep habitat suitability in future years were counterintuitive because lower habitat suitability was found in the PRISM climate that showed highest fire frequencies (Fig. 3.81), which should produce more palatable forage for bighorn sheep. Wildfire, however, was least frequent, even absent, at the alpine and subalpine elevations most inhabited by bighorn sheep (Fig. 3.81). Climate effects of area burned would, therefore, be

more pronounced lower in elevation in the zone of aspen-mixed conifer where escape habitat was also sparser (i.e., less suitable habitat). We found after thorough investigation that greater area of early-successional palatable vegetation was created, but the young forage had matured to mid-successional pole-sized unpalatable aspen (i.e., lower suitability) by the 2035, 2047, and 2072 reporting years in greater amount in the PRISM climate than other climates. Additionally, the climate warming scenarios were predicted to reduce snow depth compared to historic climate (Knowles et al. 2006), which would increase habitat suitability at higher elevations (Comer et al. 2016). Finally, the strongest explanation for the highest habitat suitability in the HadGEM-ES climate, slightly less in the ACCESS1 climate, and least in the PRISM climate was the greater avalanche frequency observed in the HadGEM-ES climate, slightly less in the ACCESS1, and lowest frequency in the PRISM climate (Fig. 3.99). Avalanches frequency increased because it was modeled to increase with greater cool season precipitation extremes (i.e., greater severe drought to very wet year variability) that was higher in the HadGEM-ES and ACCESS1 climates than in the less variable PRISM climate. Increased precipitation variability associated with warmer ocean temperatures was generally predicted for Global Circulation Models for the western USA (Gershunov et al. 2019).

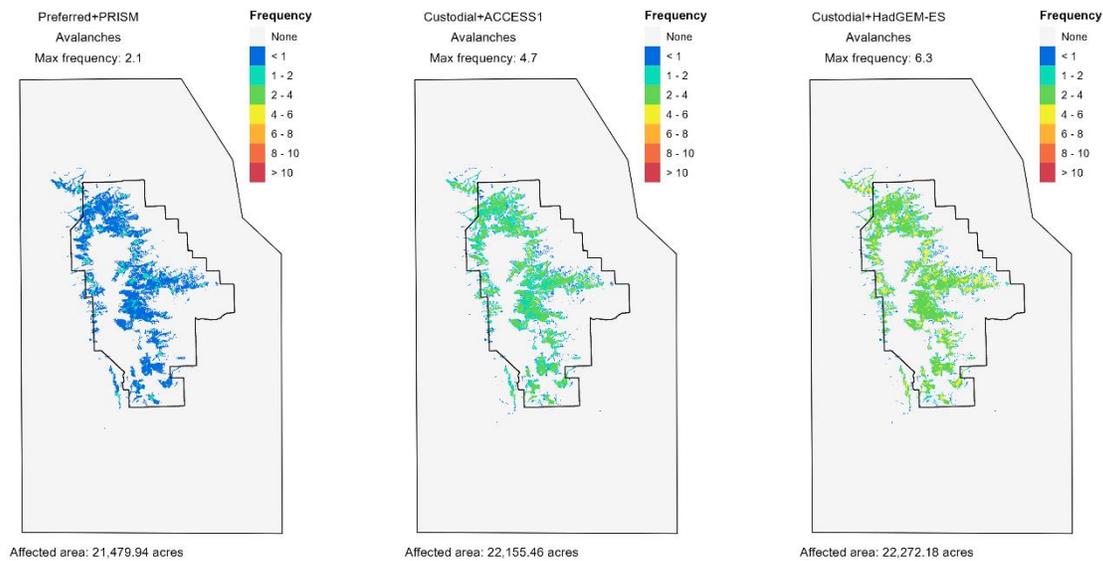


Figure 3.99. Avalanche frequency (the average number of events totaled over 50 years among 10 replicates at each pixel by multiplying the probability per pixel by 50 years and dividing by 10 replicates) maps by climate in the preferred management scenario on the South Snake Range. Three future climates were PRISM, ACCESS1, and HadGEM-ES LOCAs. The inner black line is the boundary of change detection mapping including GBNP and the Keyhole property.

Bighorn sheep habitat suitability was predictability high in areas where animals have been found for decades (i.e., Mt Washington greater area from south of Wheeler Peak to south of Lincoln Peak, called the Highland Ridge; Comer et al. 2016); however, the suitability model

detected many areas of high suitability but where bighorn sheep have not been found, although occasional young males might explore these parts. These unoccupied areas were:

1. The southeast high elevation ridge of the Snake Range extending from the Granite Peak area and ending near Big Spring Ranch headquarters. We do not have a good understanding for the lack of use of this area, although GBNP staff suggested that timbered bottlenecks might provide concealment for mountain lions that bighorn sheep should avoid; however, agency partners were “content” that bighorn sheep did not use the southern part of the ridge because of possible contact risk with domestic sheep in their winter sheep allotment. The full-system spatially explicit ED confirmed areas of high departure, with some of the unburned areas that the Black Fire did not burn covered with well-timbered aspen and shrublands that bighorn sheep might perceive as concealing mountain lions.
2. The Windy Peak area and limestone ridges and cliffs connecting it to GBNP and southwestern slopes of Mt Moriah (i.e., above the Mexican freetail bat cave and some USFS-managed land). This area was thought to be avoided by bighorn sheep because of possible human interactions; however, young males were known to explore the area very occasionally. Distance to roads was a covariate of the habitat suitability model. Several dirt roads were found there, OHV use was present (TNC staff observed several off-road vehicles during field work), and hiking (not in the model of suitability) occurs in GBNP far from paved and major dirt roads; and
3. The Horse Heaven ridge that extends from Pyramid Peak towards the east and paralleling north of Snake Creek. Again, GBNP staff suggested a known timbered bottleneck towards the west that sheep might associate with high mountain lion predation. The timbered area appeared to match the zone of high full-system spatially explicit ED separating the eastern and western portions of the ridge.

Fire Management: By far climate scenarios had the greatest effect of the total area burned (Fig. 3.81). The effect of preferred management on fire writ large was viewed from different metrics:

1. The preferred management scenario noticeably decreased the area and frequency of wildfires in all climates compared to the custodial management scenario. The zones of highest fire frequency were less extensive and lower with treatments. Moreover, effects were stronger at the lower elevations of the AOI where non-native annual fuels and past fires dominated by these fuels played a key role. As such, BLM’s contribution to management of high intensity and large fires, fueled by non-native annual species, was disproportionately important as these fires can easily spread to GBNP, private lands, and USFS and further spread the dominance of non-native annual species.
2. The primary reason to model runoff and recharge was as an input (covariate) to the Index of Proper Functioning Condition. However, the Basin Characterization Model yielded interesting results as is and a lesson learned. Positive and negative differences per basin (preferred – custodial) for runoff and recharge were found in all years until 2072, although greater positive than negative amplitudes were found in the PRISM and ACCESS1 climates, whereas the opposite was found in the HadGEM-ES climate. We did not have any expectation of change in runoff or recharge as a function of the area treated per basin because restoration included treatments that would, respectively, increase sublimation

(loss of moisture to the atmosphere) or decrease evapotranspiration depending on canopy cutting versus thinning, and elevation affecting snow accumulation and timing of snowmelt. While relationships were not strong, basins at lower elevations dominated by shrubland treatment exhibited negative differences of runoff and recharge between scenarios, whereas small to moderate-sized basins that generally experienced small to moderate-sized treatments (however, disproportionately large in a small basin) at high elevations and high snowfall generally showed stronger or weak positive differences in runoff and recharge.

3. At a more granular scale, vegetation treatments reduced the area on montane riparian burned in the HadGEM-ES and ACCESS1 climate, respectively by 2.1% and 1.0% of the total riparian area. These estimates amount to miles of streams. Vegetation treatments had no cumulative effect on the riparian area burned in the PRISM climate although treatments at least reduced burned area in the Pole Creek and Can Young Canyon and in the entire AOI. This would imply that the riparian area burned increased elsewhere as the PRISM climate experienced the largest area burned. While fire can often be beneficial to wet systems, partners were hoping to avoid uncharacteristically large and high severity fires in heavy woody fuels that repeat the Strawberry Fire and detrimental effects to Bonneville cutthroat trout.
4. Fire management through the cumulative area burned between the custodial and preferred management scenarios did not appear to change the index of riparian health. Distance from roads was the strongest determinant of the index in 2022 and 2047. In 2047, however, climate had multiple effects on area burned, cumulative runoff, and the area invaded by exotic species. The strongest differences in 2047 were among the driest (ACCESS1) and wettest (PRISM) climates because less annual precipitation was modeled to cause fewer exotic species invasions, which reduced the index of riparian health in the ACCESS1 climate compared to the PRISM climate. This effect was stronger than that of reduced runoff.

Prioritization and Funding. Agency partners chose to manage 22 ecological systems, albeit at very different levels of funding. The 22 systems covered the management objectives of GBNP and BLM spanning different elevations, whereas a single ownership might have contended with fewer systems. Regardless, annually spreading <\$200,000 for Great Basin National Park and <\$600,000 for BLM among so many systems diluted the investment in any single system and likely rendered change in ED small at best. For example, restoration of black sagebrush alone consumed \$180,000 (one third) of BLM's annual budget. TNC had never simulated more than 13 systems, often in larger landscapes. Provencher et al. (2010) simulated 10 ecological systems in a 311,483-acre southwest Utah landscape with a budget >\$1 million. Therefore, we do not recommend the management of more than 12-15 systems if simulations attempt to imitate single system management.

Alternatively, TNC could innovatively retool simulations to manage treatments across systems and let the software place each treatment in the landscape in all eligible systems according to simple rules specified by partners (e.g., no introduced species seed in GBNP). There would be no guarantee that the software will meet implementation level expectations for each focal system, although ST-Sim menus allow fine-tuning of realized implementation rates per system. We are not aware of this approach in rangelands with a tradition of single-system management, although Daniel et al. (2017) simulated with STSMs boreal forest timber harvest planning based

on landscape-wide harvest targets not specific to forest types. This different approach pays off if the cost per unit area of the treatment is lowered compared to single system mobilization because it would be assumed that the simulation really imitates practice. Because this is a different approach to workshops and planning, all partners would need to agree to the approach in advance as simulation databases are built months before the first management workshop.

5. Acknowledgments

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