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Natural Resource Stewardship and Science

Great Basin National Park Aspen Stand Condition and Health Assessment

Natural Resource Report NPS/GRBA/NRR—2014/782

ON THE COVER
Fall colors from Mather Overlook, Great Basin National Park
Photograph by: Margaret Horner

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This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

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Executive Summary

- Aspen systems represent the largest vegetation type in Great Basin National Park (19, 997 acres or 27.3 % of park lands).
- Aspen ecosystems are represented by three biophysical settings: stable aspen woodland, seral aspen, and seral subalpine aspen. Seral subalpine aspen is the largest aspen system (11,320 acres), followed by seral aspen (8,110 acre) and stable aspen (570 acres).
- The ecological condition of park aspen varies: stable aspen stands are 27% departed from natural range of variation, seral aspen are 66% departed, and seral subalpine aspen stands are 60% departed.
- The current condition of aspen in the park (i.e. percent departure from natural range of variation) is due to an over representation of late successional classes; under representation of early classes; poor aspen regeneration and recruitment; and a loss of aspen clones on 1,229 acres.
- The current condition of aspen stands is a direct result of fire exclusion.
- Under current management practices, aspen stands will continue to decline. The conversion of aspen to conifer is predicted to result in permanent loss of aspen from over 10,000 acres within 50 years. This would likely constitute impairment under NPS policy.
- Aspen stand condition and health was relatively homogenous across the park. This homogeneity is consistent with the effects of broad scale fire exclusion.
- Decathon Canyon had the best aspen condition assessment score and the Burnt Mill watershed the worst.
- Prescribed fire is recommended for mid to late-succession classes for all aspen systems to correct ecological departure and prevent conversion of aspen to conifer.
- Ecological restoration using prescribed fire is recommended in Baker, Lehman, Strawberry, Snake and five west-side watersheds (14,174 acres). These treatments should be phased to allow the development of mid-successional classes.
- Almost all aspen stands in the park are recommended for wildland fire use (19,608 acres).

Acknowledgments

We would like to acknowledge The Nature Conservancy (TNC) for performing landscape conservation forecasting™, modeling and mapping for the park, and especially thank Greg Low and Tanya Anderson for their work under Cooperative Agreement #H8420090605. We would also like to thank our peer reviewers for their constructive comments. Funding was made possible through the Southern Nevada Public Land Management Act (SNPLMA).

List of Terms

Adaptive management is a systematic approach for improving resource management by learning from management outcomes. It uses ongoing monitoring to evaluate and adjust management actions to meet desired objectives or avoid undesired outcomes. Adaptive management helps managers maintain flexibility in their decisions, knowing uncertainties exist and provides them with the ability to change strategies for continued progress toward desired outcomes (Williams et al. 2009).

Apical dominance is the suppression of suckering of new aspen shoots by auxins, a chemical compound produced in the aerial parts of mature aspen trees. The chemical is transported from the canopy to the stems and roots to limit or prevent the orientation and outgrowth of lateral buds, branches, roots, tubers, etc. (Cline 1991).

Aspen condition score is equivalent to the biophysical setting's ecological departure score, a broad-scale measure of biophysical setting condition.

Biophysical setting represent the dominant ecological systems (vegetation) on the landscape prior to Euro-American settlement (Forbis et al. 2007, Provencher et al. 2008, Rollins 2009). They are formed by both the biophysical environment (i.e. slope, elevation, soils, and climate) and an approximation of the historical disturbance regime (i.e., frequency and severity of fire, drought, flooding, or insect outbreaks), including the influence of Native American fire use prior to Euro-American settlement (Barrett and Arno 1982, Gruell 1985, Barrett 1994, Boyd 1999, Griffin 2002, Mann 2005, Rollins 2009). Biophysical settings divide the landscape into areas with similar biological and physical characteristics.

Ecological departure is a broad-scale measure of biophysical setting condition – an integrated, landscape-level estimate of the ecological condition of terrestrial and wet biophysical settings. Ecological departure incorporates species composition, vegetation structure, and disturbance regimes to estimate a biophysical setting's *departure* from its natural range of variation. Ecological departure is equivalent to the continuous metric of Fire Regime Condition.

Fire Regime Condition Class (FRCC) is used by federal agencies to group ecological departure scores into three classes: FRCC 1 represents biophysical settings with low (<34%) departure; FRCC 2 indicates biophysical setting with moderate (34 to 66%) departure; and FRCC 3 indicates biophysical settings with high (>66%) departure. Although FRCC is an important index for wildland fire managers, FRCC classes are arbitrarily grouped along a continuum of ecological departure.

High risk vegetation classes are the uncharacteristic classes that meet at least two of the three following criteria: (1) ≥5% cover of invasive non-native species; (2) cost prohibitive restoration; (3) a direct pathway to either one of the above.

Historical vegetation, for the purposes of this report, is equivalent to biophysical setting and represents the flora that existed during the reference period prior to Euro-American settlement. These ecosystems were sometimes influenced by Native American fire use.

Impairment, as defined by National Park Service Management Policies (2006), is an impact that, in the professional judgment of the responsible NPS manager, would harm the integrity of park resource or values, including the opportunities that otherwise would be present for the enjoyment of those resources or values. Under the Organic Act (1916), the Park Service must leave park resources and values 'unimpaired for the enjoyment of future generations.' Whether an impact is deemed impairment depends on four parameters: the particular resource or values affected; the severity, duration and timing of the impact; the direct and indirect effects of the impact; and the cumulative effects of the impact in question in relation to other known impacts.

LANDFIRE (Landscape Fire and Resource Management Planning Tools) is an interagency vegetation, fire, and fuel characteristics mapping program, sponsored by the United States Department of the Interior and the United States Department of Agriculture, Forest Service. LANDFIRE produces a comprehensive, consistent, scientifically credible suite of spatial data layers for the entire United States. LANDFIRE data products consist of over 50 spatial data layers in the form of maps and other data that support a range of land management analysis and modeling. Specific data layer products include: Existing Vegetation Type, Canopy, and Height; Biophysical Settings; Environmental Site Potential; Fire Behavior Fuel Models; Fire Regime Condition Classes; and Fire Effects layers. LANDFIRE is a standardized tool for determining the degree of departure from reference conditions of vegetation, fuels and disturbance regimes.

Landscape conservation forecasting™ was developed by The Nature Conservancy to assist land agencies with planning, management and restoration of large landscapes using satellite imagery, remote sensing, predictive ecological models and cost benefit analyses. The process integrates maps created from interpreted satellite imagery, metrics to track the ecological health of each ecosystem, and ecological computer models to assess ecosystem health, explore alternative restoration strategies to improve the landscape, and identify strategies with the best return on investment.

Management scenarios are comparable to alternatives used in agency management plans or National Environmental Policy Act (NEPA) documents. The Nature Conservancy model's included three management scenarios: minimum management, maximum management and preferred management. *Minimum management* was the control scenario that only included natural disturbances (fire, avalanches, drought, insects/disease, and grazing by native ungulates), unmanaged non-native species invasion and fire suppression. Fire suppression was simulated by reducing natural, reference fire return intervals based on current fire events/histories from adjacent areas. Fire event data were obtained by TNC from the Federal Fire Occurrence Website. This scenario was considered a no-treatment control representing a custodial level of NPS management, but depending on the biophysical setting was not necessarily equivalent to current management. *Maximum management* scenarios assumed no financial or other resource constraints with the goal of reducing ecological departure and high-risk vegetation classes to the greatest extent possible. All applicable management strategies were considered and applied to significantly reduce ecological departure and/or limit the area of high-risk classes to less than 10%. These scenarios were often unrealistic, exceeding annual agency budgets. *Preferred management* scenarios were developed by Park staff using cost-effective management strategies to reduce ecological departure and high-risk vegetation classes while incorporating agency budgets, fund availability and regulatory constraints.

Natural range of variation is the expected "natural" distribution of vegetation classes based on biophysical settings and historic disturbance regimes, such as the frequency and intensity of fire, disease, insect outbreaks, and flooding.

Potential vegetation is equivalent to biophysical setting - the vegetation that may have been dominant on the landscape prior to Euro-American settlement based on both the current biophysical environment and an approximation of the historical disturbance regime.

Unacceptable impacts are impacts that fall short of impairment, but are still not acceptable within a particular park's environment. Unacceptable impacts are impacts that, individually or cumulatively, would be inconsistent with a park's purpose or values; impede the attainment of a park's desired future conditions for natural or cultural resources as identified through park planning processes; or create an unsafe or unhealthful environment for visitors or employees.

Wildland fire use refers to natural ignitions that are intentionally allowed to burn to improve resource condition.

Acronyms

BPS	Biophysical setting
BLM	Bureau of Land Management
ENLRP	Eastern Nevada Landscape Restoration Project
FRCC	Fire Regime Condition Class
GRBA	Great Basin National Park
NEPA	National Environmental Policy Act
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NRV	Natural Range of Variation
SNPLMA	Southern Nevada Public Land Management Act
TNC	The Nature Conservancy
USDA	United States Department of Agriculture
USFS	United States Forest Service

Background and Need

Quaking aspen (*Populus tremuloides*) is the most widely distributed tree species in North America (Little 1971, Jones et al. 2005a, b). Aspen is regarded as a keystone species because it supports a high diversity of flora and fauna (Kay 1997, Bartos 2001, Hamilton et al. 2009, Kuhn et al. 2011); and after riparian communities, provide the second highest level of biodiversity in arid environments (Kay 1997, Kuhn et al. 2011). Aspen communities are highly distinct plant assemblages with minimal species overlap with other vegetation types and exhibit greater heterogeneity in plant composition at the site-scale (Kuhn et al. 2011). The significance of this species is highly disproportionate to their typically limited distribution in the Great Basin.

Aspen provide many beneficial ecosystem services and support a higher level of biodiversity than other forested landscapes (Kuhn et al. 2011). Not only do aspen support higher vascular plant diversity, they provide essential habitat for wildlife, maintain soil moisture, serve as natural fire breaks, and augment water yields. Aspen and other forested uplands are critical to watershed health because they regulate run-off and groundwater recharge (Rogers et al. 2001). Watersheds dominated by aspen release more water into stream channels and water tables than watersheds dominated by conifers and allow greater downstream water availability (Bartos and Campbell 1998, Hamilton et al. 2009). In the West, aspen are often associated with riparian habitat and enhanced stream bank stability, increased resistance to catastrophic flooding events, increased stream nutrient inputs and provide shade and cover for aquatic species (Swanson et al. 2010).

Aspen dominated ecosystems provide important refugia to plant and animal species in semi-arid regions dominated by desert shrublands and conifer forests (Appendix 3). Elk and deer depend on aspen stands and productive understories for cover and forage. Aspen communities contain a high abundance and diversity of invertebrates because they contain a higher diversity of understory plants than other forest types. Mature aspen stands provide habitat for breeding birds; and due to their susceptibility to certain diseases (e.g. heart rot), aspen stands provide nesting habitat for primary and secondary avian cavity nesters (Swanson et al. 2010). Aspen stands are also highly valued for their esthetic and recreational value in the semiarid West.

Aspen is an early seral species and responds well to disturbance (Rogers 2002, Swanson et al. 2010). Aspen is often one of the first species to reoccupy a recently disturbed site, but over time conifer encroachment can reduce or eliminate aspen regeneration. Aspen are a relatively short-lived species, with individual trees reaching senescence after approximately 100 years (Shepperd et al. 2006, Swanson et al. 2010, Provencher et al. 2010). Although aspen can reproduce via seed, sexual reproduction is rare in the western USA, but enabled aspen to reach its extensive geographic range during past climate regimes. Vegetative reproduction (i.e. cloning) allows this species to persist during periods unfavorable to seedling establishment (Otting and Lytjen 2003). Aspen benefit from cloning versus seed propagation because new stems have access to stored carbohydrate reserves and an established root system. Disturbance to roots or mature trees stimulates the production of new stems from underground root buds; but without fire or other disturbance, more shade-tolerant conifer species encroach, overtop and replace aspen. Without disturbance, apical dominance (Schier et al. 1985) can also limit regeneration in older, mature aspen stands.

Aspen are declining throughout the West. Substantial aspen dieback has been observed over the last fifteen years with recent, large aspen mortality events in southwestern Colorado and Arizona (Worall et al. 2008, Fairweather et al. 2008). Bartos (2001) reported declines in historic aspen ranges between 49% (Colorado) and 96 % (Arizona) and estimated a 60% decline in aspen acreage across all eight western states. These recent and wide-ranging declines in aspen suggest that current management strategies and climate conditions are affecting aspen vigor in many portions of its western range (Guyon and Hoffman 2011).

Major factors contributing to aspen decline in western forests include: fire exclusion; competition with and shading by encroaching conifers; excessive browsing of aspen suckers by wild and domestic ungulates; and environmental stressors – climate change, drought, insects and disease. The greatest anthropogenic impact on aspen health over the last century has been the exclusion of fire and chronic browsing (Bartos and Campbell 1998, Rogers et al. 2001, Kay 1997, Kitchen 2012, Heyerdahl et al. 2011). Historically, conifer encroachment and overtopping of aspen (i.e. successional decline) were balanced by disturbance, primarily fire, but also by insect outbreaks, disease and avalanches (Swanson et al. 2010). Successional decline has resulted in the deterioration and loss of aspen in many areas (Bartos 2008) including Great Basin National Park (GRBA) where over a century of fire suppression and wild and domestic ungulate grazing has greatly decreased early seral stages of aspen and left park aspen systems vulnerable to conifer encroachment and loss of aspen clones.

Fire regimes changed in the Great Basin with Euro-American settlement when intense grazing and active fire suppression began and Native American burning practices ended (Kay 1995, Griffin 2002, Kitchen 2012). By 1900, the beneficial effects of fire were virtually absent from what is now Great Basin National Park. Fire histories for one GRBA watershed reveal the last large fire occurring in 1865 (Heyerdahl et al. 2011, Kitchen 2012). Before this time small, frequent fires in mid-elevation plant communities were common (Kitchen 2012) and maintained early seral state plant communities and habitat heterogeneity. Fire suppression, along with favorable climate conditions, has shifted vegetation away from a range of seral states and community types and towards a preponderance of late-successional woody plant communities. As a result, conifer species have expanded and crowded out fire dependent species like aspen.

Declines in aspen forests have the potential to reduce local and landscape level plant species diversity and negatively impact other beneficial ecosystem functions aspen provide (Kuhn et al. 2011). Negative impacts include: 1) changes in fire frequency and intensity; 2) net loss in biodiversity; 3) loss of soil stability, increased erosion and reduced nutrient cycling; 4) loss of productivity and forage and associated wildlife implications; 5) loss in resistance of aspen communities to non-native weeds, insects, and pathogens; and 6) loss of resiliency of communities to recover from disturbance and perturbations. Efforts by land managers to restore and conserve aspen communities will benefit species diversity at local and landscape scales providing ecosystem resilience, productivity, nutrient retention and resistance to invasive plants (Kuhn et al. 2011).

Aspen occur across the Great Basin and throughout GRBA; but large, contiguous forests dominated by aspen or pure aspen stands are not common. Aspen cover in Nevada is estimated at only one percent (GBBO 2010).

Although aspen are an important park ecosystem, the dynamics, distribution, condition and health of park aspen stands was not known. To better understand the condition and composition of aspen, GRBA entered into an agreement with The Nature Conservancy (TNC) in 2009 to use landscape conservation forecasting™ to map vegetation using remote sensing technologies, determine existing vegetation condition, estimate ecological departure from the natural range of variation, and simulate the effects of alternative management scenarios on vegetation condition. This was a cost-effective way to obtain spatial and quantitative information about aspen condition and develop restoration strategies focused on maintaining and restoring park aspen communities and the beneficial ecosystem services they provide.

Purpose

This report partially fulfills the requirements of Southern Nevada Public Land Management Act, Eastern Nevada Landscape Restoration (ENLRP) Initiative Funding for Project # N001 "Landscape Level Vegetation Management Plan." It is intended to inform managers about aspen stand health and condition and make recommendations for restoration of park aspen stands. This report will serve as fulfillment of the ENLRP proposal requirement:

"Task 4 –Aspen Stand Condition and Health Assessments **-** Aspen stands on the eastside of the park will be inventoried and a stand condition database will be developed. Based upon this information, restoration projects will be developed and incorporated into the final plan and emphasize stand regeneration and improving stand vigor by removal of encroaching conifers. Types of actions will be based upon current existing conditions."

Project Area

Great Basin National Park (N 38.98°, W -114.30°; 77,180 acres) is located in the South Snake Range of east central Nevada in the Great Basin desert (Figure 1). Elevations in the South Snake Range vary from 5,318 feet in the town of Baker to 13,063 feet at the summit of Wheeler Peak. The climate is cool, semi-arid and varies dramatically with elevation. At the Lehman Caves Visitor Center (elevation – 6,875 feet) annual precipitation is 13 inches and the mean annual temperature is 48°F (Western Regional Climate Center, unpubl. data). At the highest elevations, mean annual precipitation is estimated to be between 30 and 35 inches (Western Regional Climate Center, unpubl. data). The northern portion of the park situated north of Mount Washington is generally composed of quartzite, whereas the southern portion is dominated by carbonate rocks (limestone and dolomite). As a consequence of this geology, creeks are generally perennial in the north but dry in the south. Springs are also more common in the north.

Great Basin National Park is a mostly unfragmented landscape that includes a wide diversity of Great Basin ecosystems, ranging from desert upland shrublands, piñon-juniper woodlands, conifer forests, subalpine bristlecone pines, and alpine. The area contains multiple terrestrial and aquatic ecological systems, many uncommon to rare in the Great Basin. Three aspen systems are found within the park and occur between 7,000 and 10,000 feet elevation. Aspen are associated with riparian corridors and higher elevation springs and occur in mixed stands of mid-elevation and subalpine conifers, in avalanche scars and on talus slopes. Pure stands of aspen are rare and typically occur in small patches that often contain a conifer and/or sagebrush steppe component.

Figure 1. Location of Great Basin National Park.

Methods

The park entered into a cooperative agreement with The Nature Conservancy to collaborate on fire and vegetation management at GRBA. The Nature Conservancy applied landscape conservation forecasting™ to map potential vegetation and current vegetation, determine ecological departure, define fire regime condition classes, forecast future ecological conditions and develop cost-effective management strategies to maintain or restore park lands. Landscape conservation forecasting™ was built upon LANDFIRE's vegetation mapping and fire regime condition metric, to which TNC added uncharacteristic vegetation classes, state-and-transition simulation of management models, strategy development, management scenario comparisons, and calculation of return-on-investment for different management scenarios.

The Nature Conservancy followed its landscape conservation forecasting™ protocol to map vegetation to biophysical setting, determine ecological departure, natural range of variation, and fire regime condition class (Low et al. 2010). The protocol included:

1. Obtain high-resolution satellite imagery, ground-truth the imagery via field surveys and conduct remote sensing to interpret and map current vegetation and succession classes

2. Map biophysical settings (the dominant vegetation types expected to occur under a natural disturbance regime or the potential ecological system)

3. Determine the natural range of variation through modeling of pre-European settlement vegetation dynamics and successional states of each biophysical setting

4. Determine ecological departure from the natural range of variation and percentage of high risk classes of each system

5. Classify the ecological departure of each biophysical setting into fire regime condition classes (FRCC 1 = low departure at <34%; FRCC 2 = moderate departure from 34-66%; and FRCC 3 = high departure at >66%).

6. Classify the percentage of high risk vegetation as low (0%); medium (1-10%); high (11-30%); and very high (>30%).

7. Assess future conditions under three management scenarios – minimum management, maximum management and preferred management – using percentage of high risk classes and ecological departure scores.

8. Recommend management strategies to restore park ecosystems to their natural range of variation.

Detailed methodologies for each of these steps are found in Appendix 1.

Aspen Stand Condition and Health Assessment

Aspen stands were defined as contiguous areas of *potential* aspen with compositional and structural integrity. Stands are characterized by similar plant species composition differentiated from adjacent stands by a discernible boundary that may be abrupt or distinct. Stands are also characterized by structural integrity, with similar horizontal and vertical spacing of plant species. Aspen stands were identified using the remote sensing component of landscape conservation forecasting™ applied to all biophysical settings in the park and then separated by watershed. Ground-truthing was required to distinguish between mixed conifer and some classes of aspen-mixed conifer. Nineteen park watersheds were defined and used to further delineate aspen stands. A condition and health assessment was conducted on aspen in each park watershed based on each aspen stand's departure score from natural range of variation. Watersheds were ranked by size, percent aspen and aspen condition/health score. All aspen biophysical settings (seral subalpine, seral, and stable aspen) were combined for this analysis.

Aspen stand condition and health were projected out 50 years based on two final scenarios: preferred management and minimum management. Preferred management scenarios were developed by GRBA staff using cost-effective management strategies to reduce ecological departure and high-risk vegetation classes while keeping within agency budgets and regulatory constraints. Strategies for treating aspen biophysical settings included prescribed fire, wildlife fire use, hand felling, and pile burning. Minimum management scenarios were considered the no-treatment control scenario and included natural disturbance, unmanaged non-native species invasion and fire suppression. Minimum management represented a custodial level of NPS management with no proactive management actions other than the continuation of fire suppression. Fire suppression was simulated by reducing natural, reference fire return intervals based on current fire histories from adjacent areas. Fire event data were obtained by TNC from the Federal Fire Occurrence Website. The project also included a third, maximum management scenario which was characterized by aggressive restoration with an unlimited budget and a goal of reducing ecological departure and high-risk vegetation classes to the greatest extent possible.

Results

Three aspen systems were classified: stable aspen (aspen woodland), seral aspen (aspen-mixed conifer), and seral subalpine aspen (aspen-subalpine conifer). Acreages for the three aspen systems were: stable aspen 567 acres; seral aspen 8,114 acres; seral subalpine aspen 11,316 acres (Figure 2, Table 1). The total acreage of all aspen systems in the park was 19,997 acres, making aspen the largest vegetation type in the park.

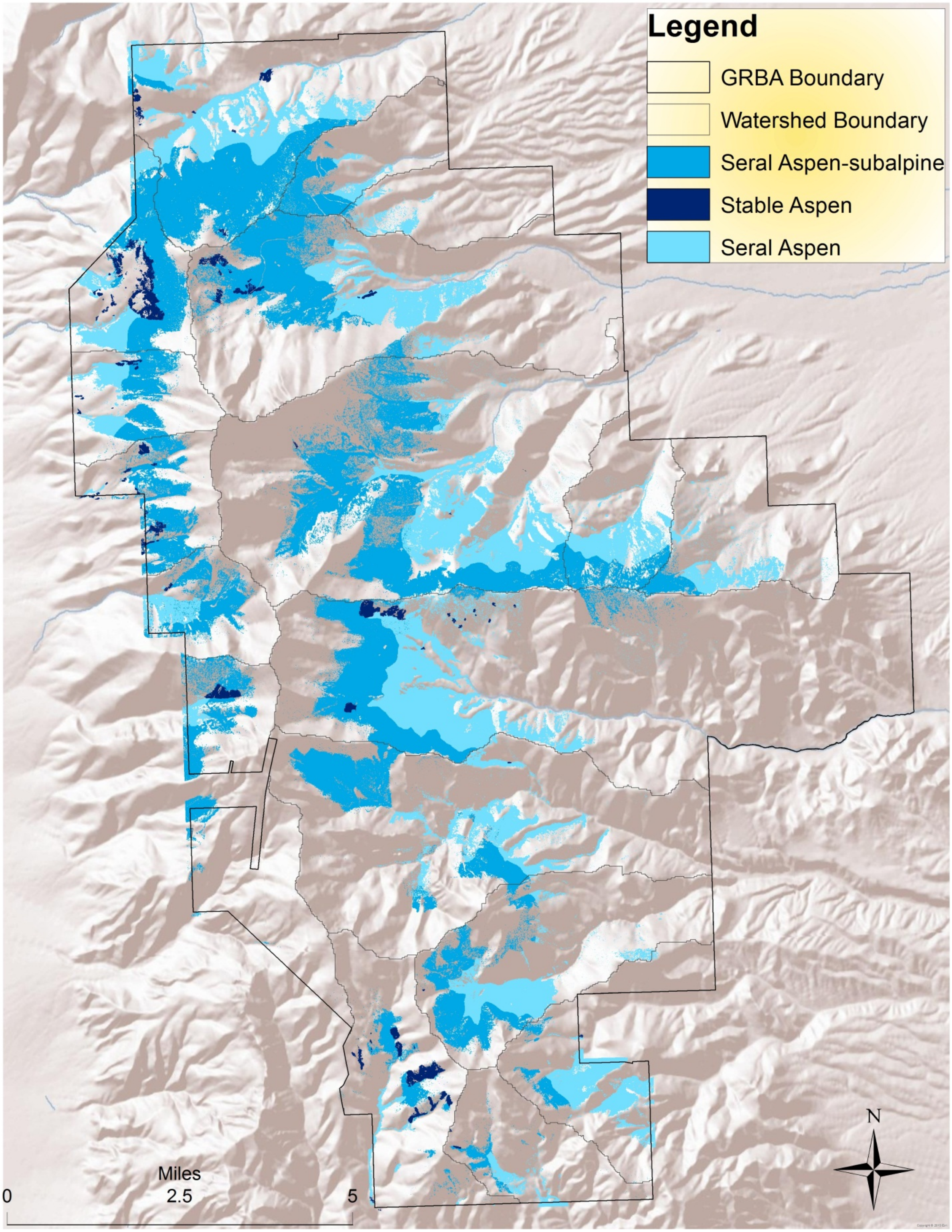

Figure 2. Aspen biophysical settings within Great Basin National Park: stable aspen, seral aspen and seral subalpine aspen.

All three aspen systems showed departure from their natural range of variation due to fire exclusion, historic grazing, and other land use practices (Provencher et al. 2010). Ecological departure was lowest for stable aspen (27%). Seral and seral subalpine aspen showed higher levels of departure: seral aspen was 66% departed, and seral subalpine aspen was 60% departed. The primary cause of ecological departure was the lack or near absence of early-succession classes and an over-representation of late-succession classes. Uncharacteristic classes negatively influenced ecological departure scores and increased the percentage of high-risk classes. Seral and seral subalpine aspen stands have already experienced a six and seven percent loss of aspen clones, respectively, a total of 1,229 acres permanently converted to conifer systems (Table 1). The seral aspen acres already converted to mixed conifer or spruce systems fall within the uncharacteristic, high-risk NAS (no aspen) class which is equivalent to late-succession mixed conifer class E or late-succession spruce class D.

Table 1. Current conditions in Great Basin National Park for each aspen system including: current acres in each vegetation class, current percent acres in each vegetation class, natural range of variation (NRV) which represents the desired condition for each biophysical setting, and ecological departure. Vegetation class and NRV descriptions can be found in Appendix B.

Aspen Woodland (Stable Aspen)								
Class[1]	**A**	**B**	**C**	**D**	**E**	**DP**[3]	**NAS**[3]	**Total**
Current Acres in Class	39	263	82	91	-	92	0	567
NRV (%)[2]	16	41	33	10	0	0	0	100
Current % in Class	7	46	15	16	0	16	0	100
Ecological Departure (%)						0	0	**27**
Aspen-Mixed Conifer (Seral Aspen)								
Class[1]	**A**	**B**	**C**	**D**	**E**	**DP**[3]	**NAS**[3]	**Total**
Current Acres in Class	133	321	1,149	2,439	3,580	-	492	8,114
NRV (%)[2]	19	43	24	9	5	0	0	100
Current % in Class	2	4	14	30	44	0	6	100
Ecological Departure (%)						0	0	**66**
Aspen-Subalpine Conifer (Seral Aspen-subalpine)								
Class[1]	**A**	**B**	**C**	**D**	**E**	**DP**[3]	**NAS**[3]	**Total**
Current Acres in Class	1,161	1,207	1,294	6,917	-	-	737	11,316
NRV (%)[2]	12	33	47	8	0	0	0	100
Current % in Class	10	11	11	61	0	0	7	100
Ecological Departure (%)								**60**

[1]Standard LANDFIRE coding for the 5-box vegetation model: A = early-development; B = mid-development, closed; C = mid-development, open; D = late-development, open; E = late-development, closed. Uncharacteristic classes defined by TNC, but not defined by LANDFIRE: DP = Depleted; NAS = No aspen (conversion to mixed-conifer, MC-D or subalpine conifer, SP-D). [2]Natural Range of Variation (%). [3]For aspen biophysical settings, high risk classes are represented by uncharacteristic classes DP and NAS. Vegetation class descriptions can be found in Appendix B.

Aspen systems were classified as FRCC 1 or 2. Seral aspen and subalpine seral aspen systems were classified as high FRCC 2 because of high departure scores (Table 2).

Aspen stand condition was rated using two metrics: ecological departure score and percentage of high-risk vegetation classes. After running management scenario models, aspen systems responded differently for these two metrics. Ecological departure scores improved after 50 years under the minimum management scenario while the percentage of high-risk classes increased (Table 2). The improvement in departure score is somewhat counterintuitive, but was the result of a modest failure rate of fire suppression activities built into the models. Escaped fire increased early succession classes, which are currently underrepresented in park aspen stands, and decreased the amount of late succession classes, improving ecological departure by bringing aspen stands closer to the natural range of variation. The improvement in ecological condition created by escaped fire may not reflect what happens *in situ* as the escape rate for wildfire is variable (Provencher et al. 2010) and due to site conditions, may not develop as models predict.

Just as important for determining the health of aspen systems is the percentage of high-risk vegetation classes. The percentage of high-risk classes for both seral aspen systems increased (got worse) under a minimum management strategy (Table 2). The increase in high-risk vegetation classes (depleted and no aspen classes) indicates continued conifer encroachment and conversion of late succession aspen classes to conifer. Any increase in the percentage of high-risk aspen classes is problematic because of the conversion of aspen to conifer and the potential for an irreversible loss of aspen clones.

Table 2. Current and predicted ecological departure, fire regime condition class (FRCC) and percentage of high risk vegetation classes for aspen systems at GRBA. Predicted future conditions represent minimum management (only sporadic natural ignition fires) over 50 years (Provencher 2010). Ecological departure scores were classified as good (0-33%, FRCC 1); fair (34%-66%, FRCC 2); and poor (>67%, FRCC 3). Percentage of high risk classes was ranked as low (0%); medium (1-10%); high (11-30%); and very high (>30%).

	Ecological Departure (%) and FRCC			**Percent (%) High Risk Classes[1]**	
Biophysical Setting	**Current Condition (FRCC)**	**Minimum Mgmt. – 50 yrs. (FRCC)**		**Current Condition**	**Minimum Mgmt. – 50 yrs.**
Stable aspen	27 (1)	10 (1)		16	11
Seral aspen	66 (2)	33 (1)		6	12
Seral aspen-subalpine	60 (2)	27 (1)		7	20

[1]For aspen biophysical settings, high risk classes are represented by uncharacteristic classes DP (depleted) and NAS (no aspen).

Based on TNC's mapping of biophysical settings, the potential area for aspen was approximately 20,000 acres or twenty-five percent of park lands (Figure 2). However, current aspen cover is not this extensive, indicating a conversion from aspen to conifer on the landscape. The estimated area of aspen loss for seral aspen and seral subalpine aspen is currently 1, 229 acres (Figure 3). Stable aspen stands, on the other hand, appeared to be within their natural range of variation, with no apparent conversion or loss of stable aspen in the park based on TNC mapping. Without a change in current management practices, 10, 590 acres of aspen are predicted to convert to conifer within 50 years. The predicted conversion from aspen to conifer is reflected as an increase in the percentage of high-risk vegetation classes (Figure 4). Aspen would no longer be present in these classes, and the conversion would be irreversible due to a loss of aspen clones.

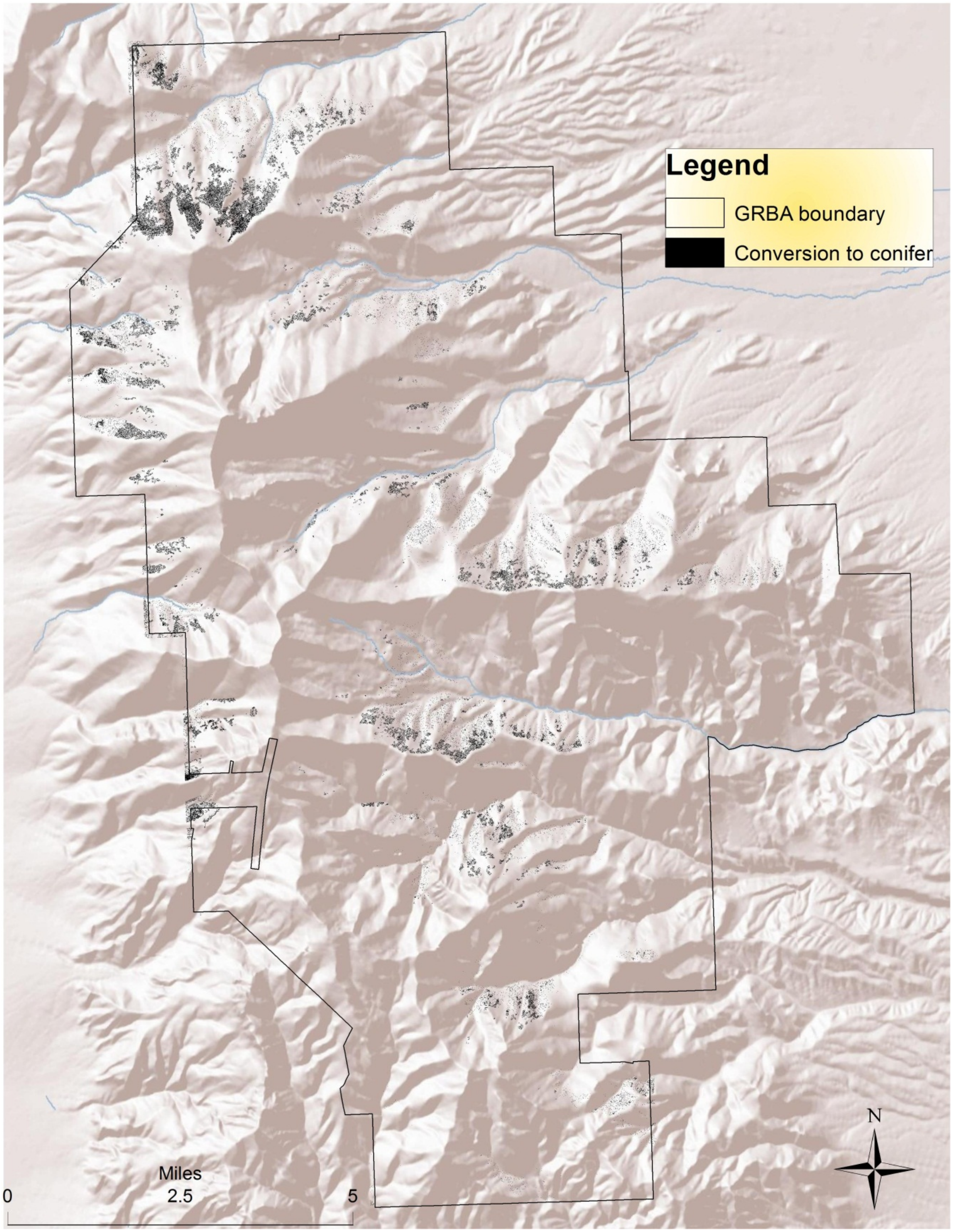

Figure 3. Current area of conversion from seral aspen to mixed-conifer forest (492 acres, 6%) and seral subalpine aspen to spruce forest (737, 7%). Data shown include the uncharacteristic class NAS (No Aspen) for seral and seral subalpine aspen systems.

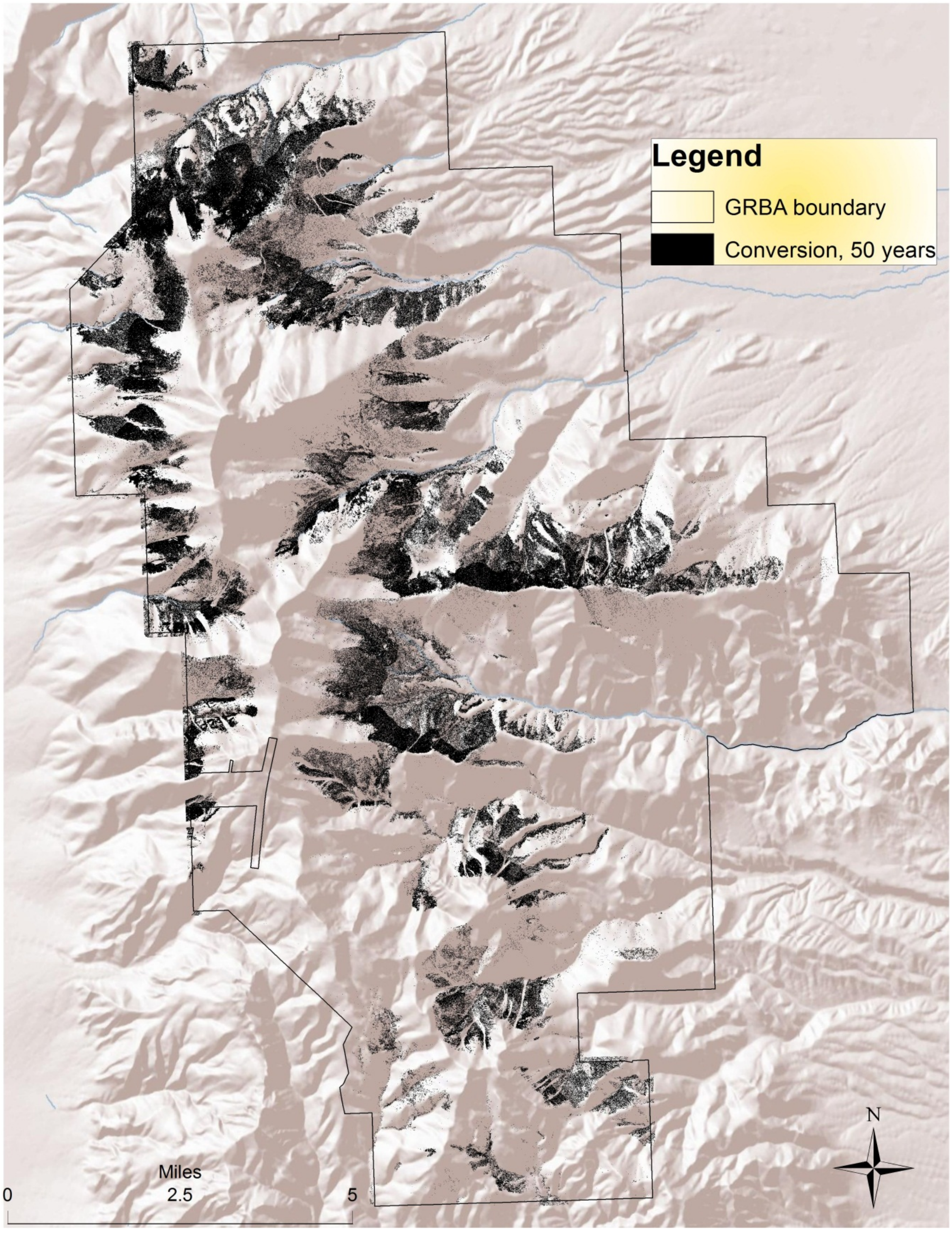

Figure 4. Potential conversion of seral aspen systems to mixed-conifer or spruce (10,590 acres) in 50 years without a change in management strategies. Data include late-succession classes D (seral subalpine); E (seral aspen); and DP (depleted, stable aspen).

Aspen Biophysical Settings

Stable Aspen

Stable aspen woodlands (Figure 5 and 6) occur at middle and upper elevations in the park between 8, 000 and 11, 200 feet. Stable aspen in the park is often associated with springs, seeps or other riparian features. Soils are usually deep, well-developed and loamy. Stable aspen occurs on gentle to moderate slopes on all aspects, although some patches do occur on steeper slopes. Stable aspen stands typically contain older, more mature aspen stems with diverse understories. Understories include a variety of herbaceous and shrub species. Early-succession stands contain *Ribes* sp. and mountain snowberry with very little sagebrush. Conifers are usually present in this system after 40 years, but successional pathways do not lead to conifer dominance or conversion. Rather, succession leads to conversion from stable aspen to montane sagebrush steppe once mature aspen have reached senescence (~ 125 years). Without disturbance or some level of regeneration, sagebrush and bitterbrush dominate after 100 years as mature trees die-off.

Stable aspen woodlands cover less than one percent of the park (567 acres, Figure 2), but had the highest percentage of high risk classes (16%). Ecological condition was rated as good (27% departure) and fell into FRCC 1 (Table 2 and 3), but the high percentage of high risk classes indicates a potential need for management action. Departure in this system was attributed to a low percentage of early and mid-succession classes and a component of a depleted uncharacteristic class. Aspen woodland's natural range of variation requires 70% of this system to fall within mid-succession classes B and C, 16% within class A and no acres in uncharacteristic classes (Table 2, Appendix 2). With minimum management over the next 50 years, this system was predicted to improve for both metrics although the decrease in high risk classes is only five percent (Table 3).

This system was not chosen for active management analyses by TNC. However, because fire has been precluded from this system and the percentage of high risk classes is so high, a brief discussion of management strategies applicable to this system is included below.

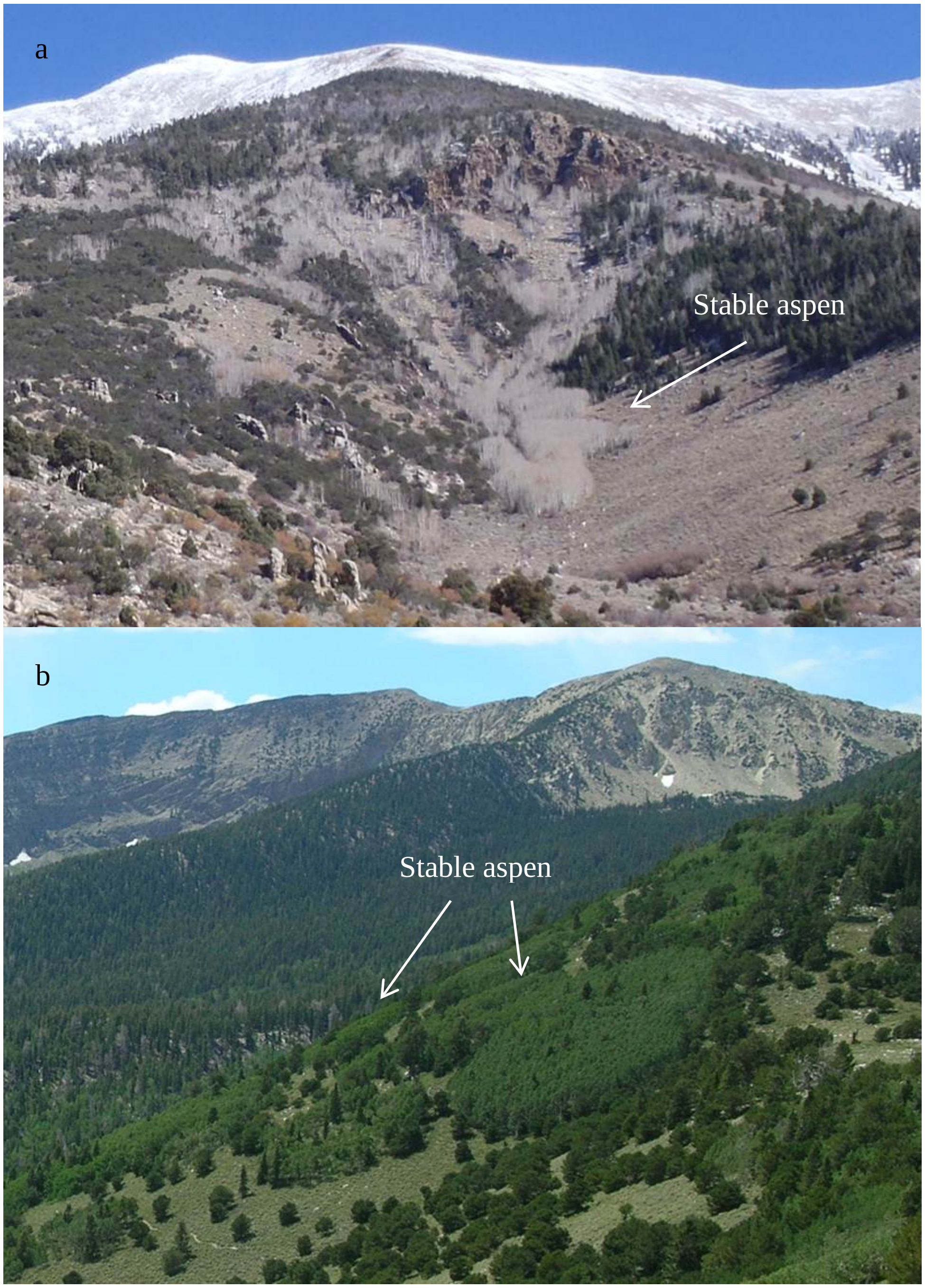

Figure 5. Stable aspen stands in Hub Mine Basin (a) and Snake Creek (b).

Figure 6. Stable aspen stand in Snake Creek.

Seral Aspen

Aspen-mixed conifer forests (Figure 7) occur at middle and upper elevations, typically between 7, 500 and 9, 500 feet, and cover 11% of the park (8,114 acres, Figure 2). It is the second largest park aspen system. Understories are diverse and include a range of shrubs, forbs and grasses (Appendix 2). Common shrubs include sagebrush, *Ribes* sp., and mountain snowberry. Herbaceous cover is diverse and species composition is dependent on soil moisture and canopy cover. Conifers in this system are white fir and Douglas-fir. After 40 years, conifers are present in seral aspen stands. Without disturbance (e.g. fire), conifers are dominant in this system after 100 years, but reach co-dominance after 80 years. Soils are usually deep, well-developed and loamy with seral aspen stands occurring on gentle to steep slopes on all aspects. In the park, seral aspen stands are often associated with riparian corridors. Fifty percent of seral aspen stands in the park are currently dominated by conifer (Provencher et al. 2010).

Early and mid-successional seral aspen classes A and B are virtually nonexistent and late-succession classes dominated by conifers (class D and E) are over-abundant. This system had an ecological departure of 66%, one percent away from a 'high' departure ranking and fell into FRCC 2. Six percent (492 acres) of the potential area has already converted to mixed-conifer, the high risk class for this system (Table 2). High departure was caused by a lack of natural disturbance which resulted in a large over-abundance of late-succession classes and a subsequent lack of early and mid-succession classes.

Ecological departure improved after 50 years of minimum management (66% to 33%) because of sporadic wildfires, but the percent of high risk classes (conversion of aspen to mixed conifer) increased under the same parameters from 6% to 12%, an increase of nearly 500 acres. Permanent clone loss was predicted because of the high percentage of conifer dominated, late-succession classes eventually converting to pure mixed-conifer.

Figure 7. Seral aspen stands in Snake Creek.

Seral Subalpine Aspen

Aspen-subalpine conifer forests (Figure 8) occur at upper elevations in the park, typically above 9, 000 feet. Understories of higher elevation stands are typically less productive and less diverse than seral aspen stands, but do include low shrubs, forbs and grasses. Shrub species include common juniper, *Ribes* sp., *Ericameria* sp., and mountain snowberry. The herbaceous understory is sparse, but does contain both grasses and forbs. The dominant conifers in this system are Engelmann spruce or limber pine, and less frequently bristlecone pine. After forty years, conifers are present in this system and without adequate disturbance may become co-dominant after 170 years. Conversion to subalpine conifer (spruce forest) can occur within 130 years (Provencher et al. 2010). Subalpine aspen stands are sometimes associated with upper reaches of riparian systems and occur on moderate to steep slopes on all aspects. Sixty-eight percent of seral subalpine aspen are currently dominated by spruce (Appendix 2).

Aspen-subalpine conifer is the largest of park aspen systems (11,316 acres, Figure 2). Approximately 7,000 acres of aspen-subalpine conifer (61%) are in the late-closed succession class D. The target for this class under natural range of variation is only eight percent. Mid-closed and mid-open succession classes B and C are highly underrepresented. Seven percent of the potential area has already converted to subalpine conifer, the uncharacteristic, high risk class for this system. Ecological departure ranked at the high end of fair (60%) missing a FRCC 3 classification by six percent (Table 2 and 3). High ecological departure stemmed from a large over-abundance of the late-succession class which is dominated by subalpine conifers, and an underrepresentation of the two mid-succession classes.

Ecological departure was predicted to drastically improve (60% to 27%) over 50 years with only minimum management due to sporadic fire. However, a large increase in conversion of aspen to subalpine conifer was also predicted. Permanent clone loss was predicted to increase by 13% (a loss of over 1,400 acres) without active management because of the large proportion of the late-succession, conifer dominated class.

Figure 8. Seral subalpine aspen stands in Snake Creek.

Aspen Stand Condition and Health Assessment

Aspen stand condition was relatively homogenous across park watersheds (Table 3, Figure 9). The mean condition and health score was 63.2 % departure from NRV with a standard deviation of 11.7%. The relatively homogenous, high ecological departure scores are consistent with the effects of fire exclusion on a landscape scale. Decathon Canyon had the lowest departure score and contains a high percentage of stable aspen (30 %), a system defined by an absence of conifer encroachment.

Table 3. Aspen condition and health scores for all watersheds.

Watershed	Acres	% park	Acres aspen	% aspen	Aspen condition score	FRCC score	Proportion park aspen
Baker	10781	14%	3568.2	33%	62.3	2	18%
Snake	13605	18%	2728.8	20%	57.8	2	14%
Strawberry	5373	7%	2455.3	46%	73.1	3	13%
Lehman	8233	11%	2059.4	25%	60.4	2	10%
NF Big Wash	8306	11%	1480.2	18%	60.3	2	8%
SF Big Wash	4451	6%	1154.5	26%	50.8	2	6%
Shingle	1992	3%	1146.6	58%	72	3	6%
Can Young	1999	3%	708.9	35%	74.4	3	4%
Pine Ridge	1722	2%	610.5	35%	79	3	3%
Hub	1582	2%	569.6	36%	61.1	2	3%
Lexington	2508	3%	559.5	22%	59.3	2	3%
Williams	1485	2%	539.5	36%	66.5	3	3%
Dry	1289	2%	442.1	34%	59.9	2	2%
Young	2807	4%	436	16%	64.1	2	2%
Mill	1652	2%	404.1	24%	59	2	2%
Decathon	3239	4%	390.2	12%	27.6	1	2%
Big Springs	1988	3%	184.3	9%	59.1	2	1%
Burnt Mill	1764	2%	134.6	8%	79.1	3	1%
Lincoln	2251	3%	48.3	2%	74.1	3	0%

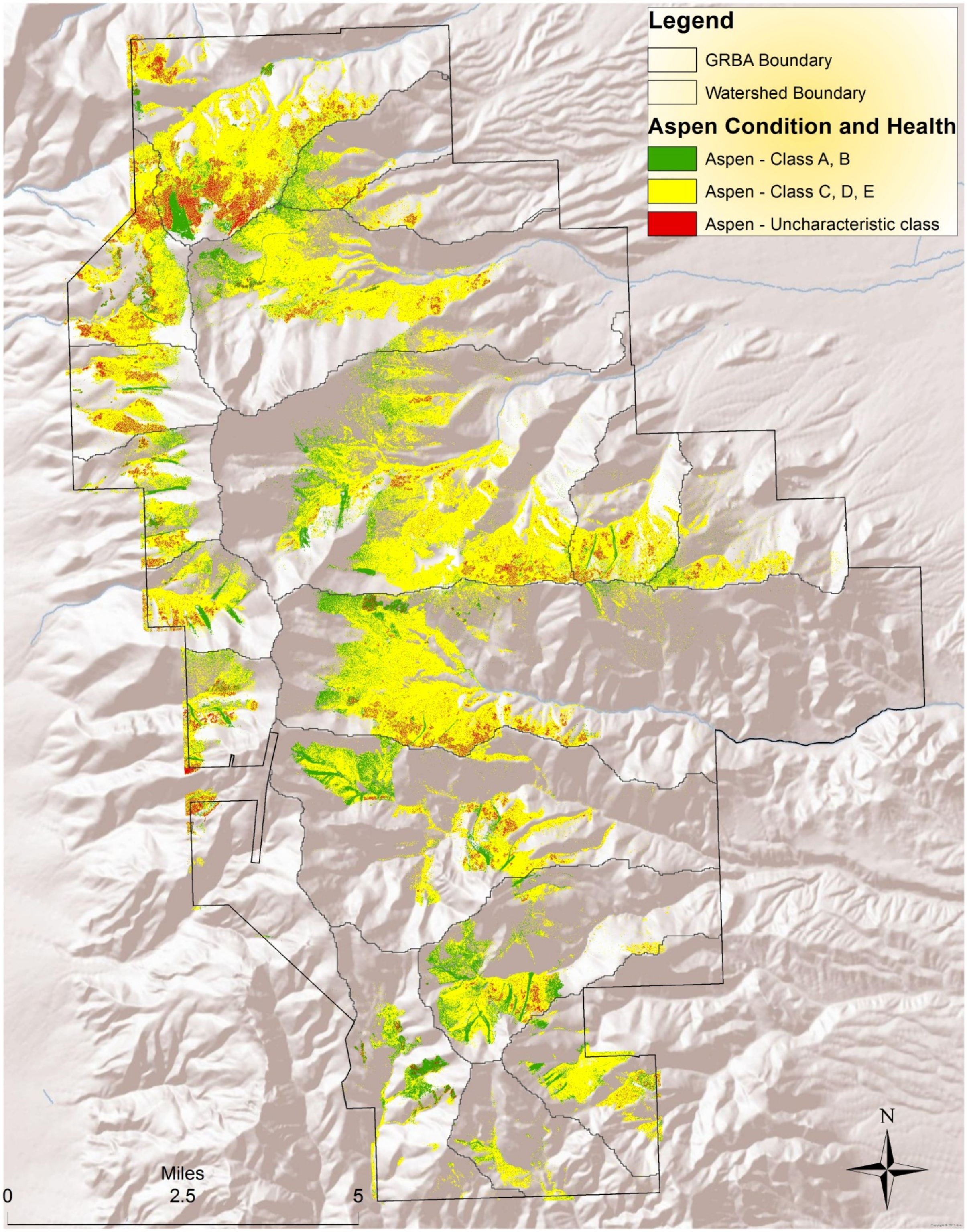

Figure 9. Current condition and health of aspen stands (all three aspen types). Green represents early successional classes, yellow mid and late successional classes, and red uncharacteristic classes where aspen clones have been lost.

Watershed Assessments

Baker Creek

The Baker Creek watershed comprises 14% of the park (10,781 acres). 3,568 acres (33% of the watershed) are seral or stable aspen. The Baker creek aspen stand is 62.3 % departed from natural range of variation.

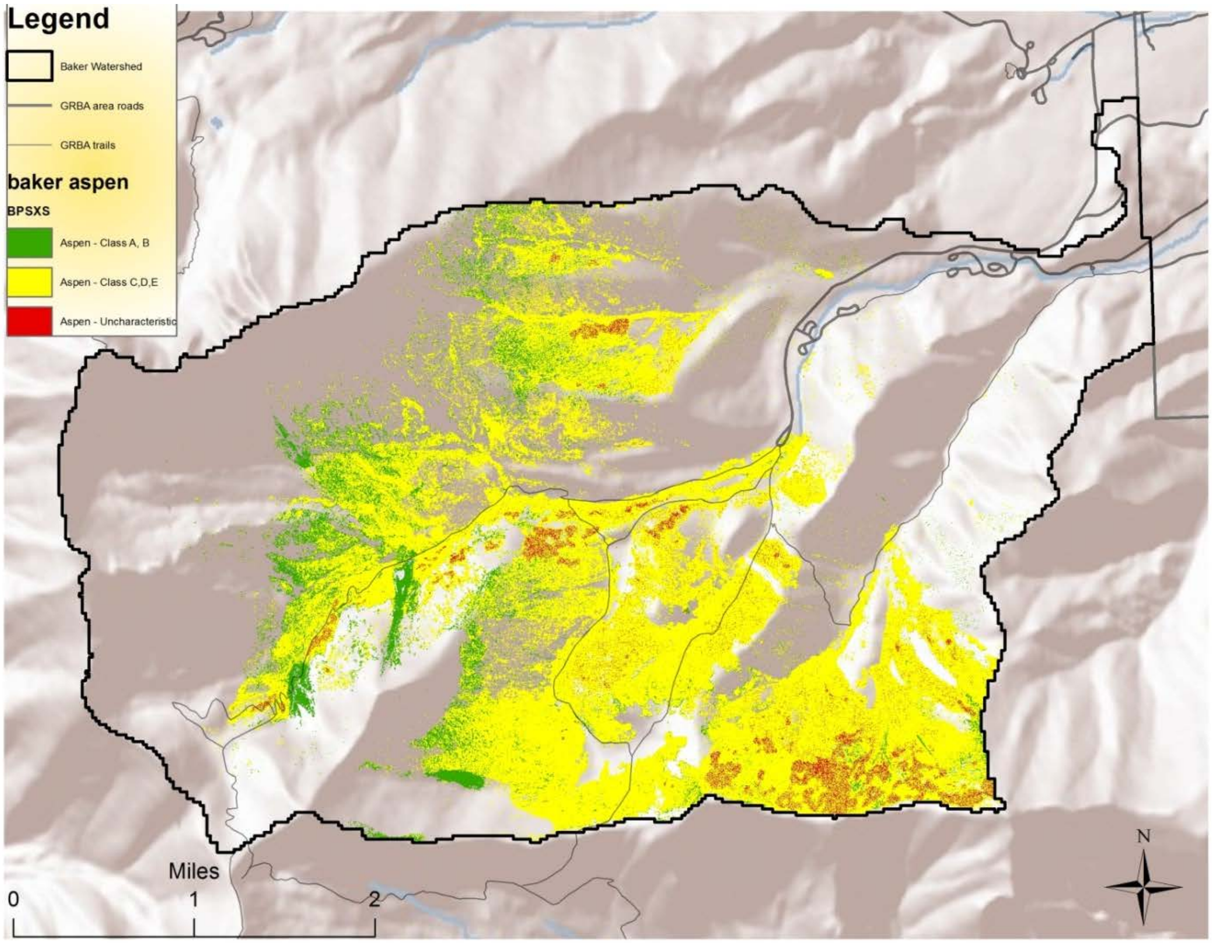

Figure 10. Baker Creek aspen stand condition and health assessment.

Snake Creek

The Snake Creek watershed is the largest park watershed and comprises 17.7% of the park (16,605 acres). 2,729 acres (20% of the watershed) are seral or stable aspen. Snake Creek aspen is 57.8% departed from natural range of variation.

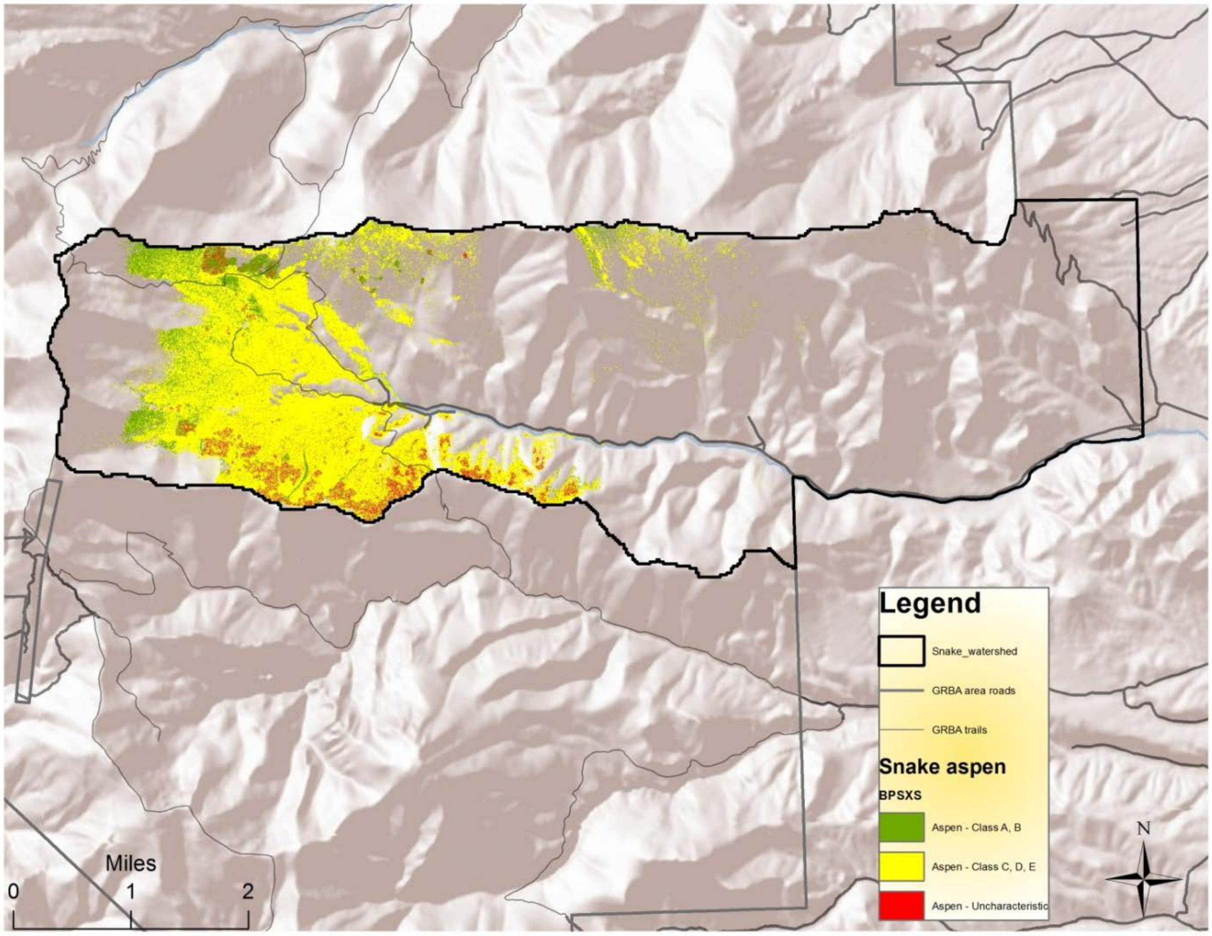

Figure 11. Snake Creek aspen stand condition and health assessment.

Strawberry Creek

The Strawberry Creek watershed comprises 7% of the park (5,373 acres). 2,455 acres (46% of the watershed) are seral or stable aspen. The Strawberry creek aspen stand is 73.1 % departed from natural range of variation.

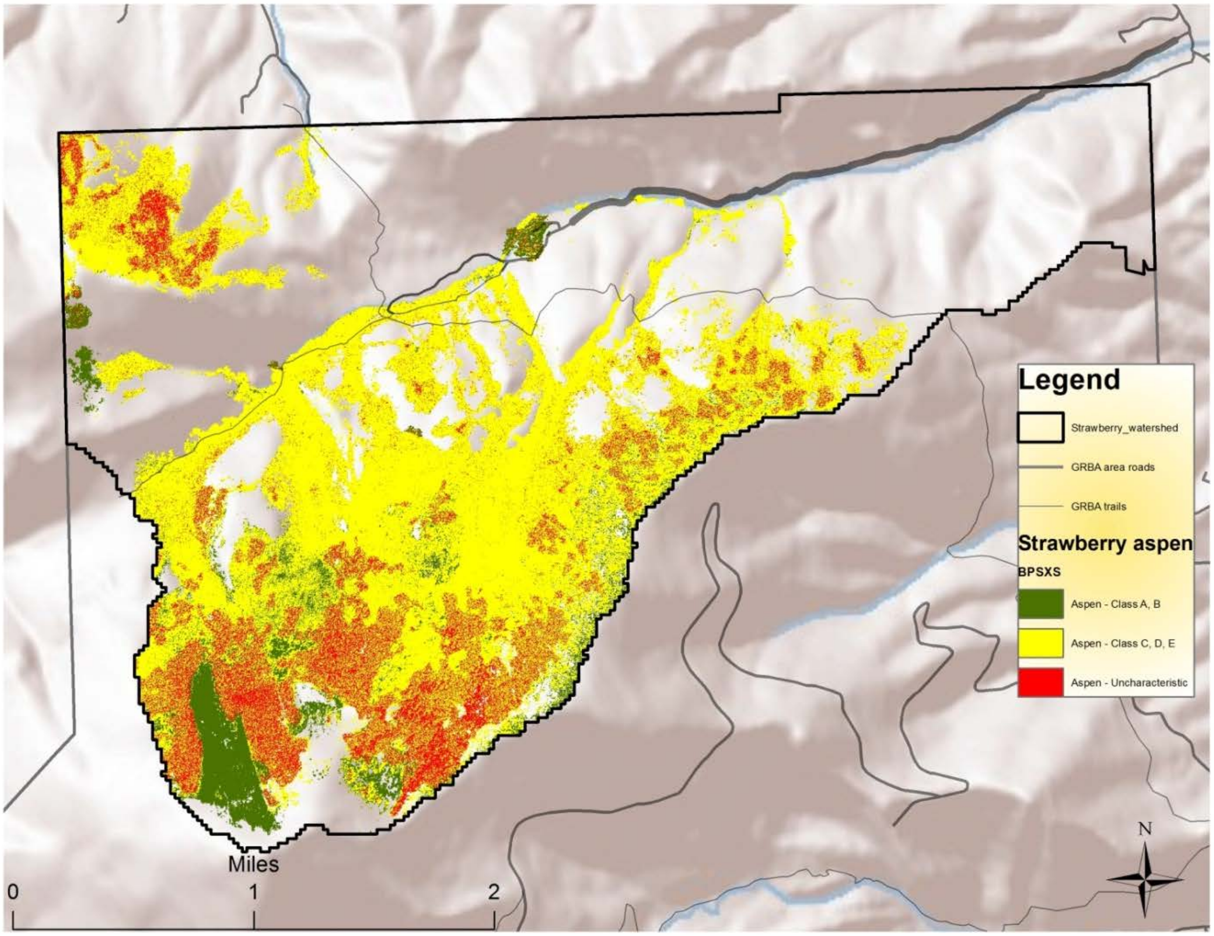

Figure 12. Strawberry Creek aspen stand condition and health assessment.

Lehman Creek

The Lehman Creek watershed comprises 10.6% of the park (8,233 acres). 2,059 acres (25% of the watershed) are seral or stable aspen. The Lehman Creek aspen stand is 60.4 % departed from natural range of variation.

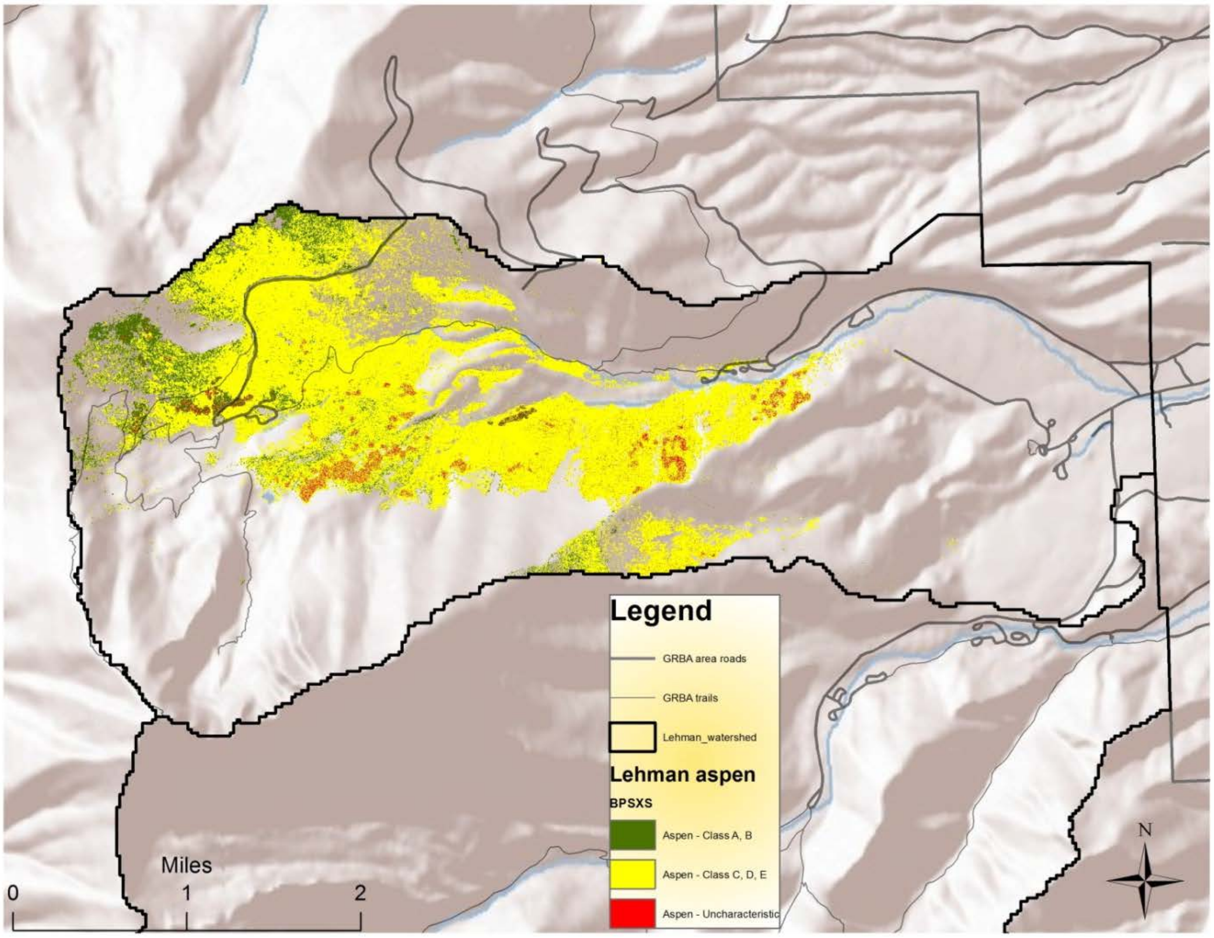

Figure 13. Lehman Creek aspen stand condition and health assessment.

North Fork of Big Wash

The North Fork of Big Wash comprises 10.8% of the park (8,306 acres). 1,480 acres (18% of the watershed) are seral or stable aspen. The NF Big Wash aspen stand is 60.3% departed from natural range of variation.

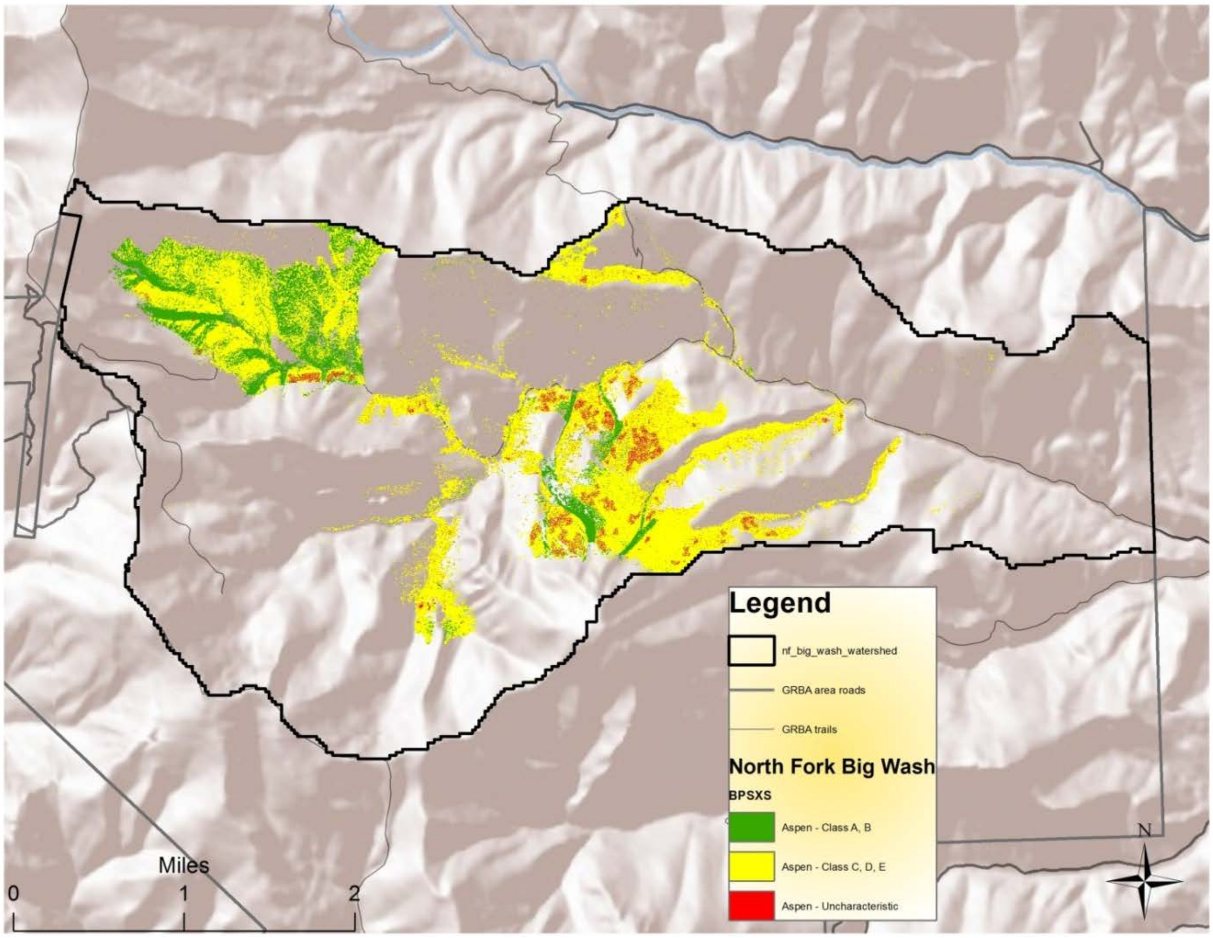

Figure 14. North Fork of Big Wash aspen stand condition and health assessment.

South Fork Big Wash

The South Fork of Big Wash comprises 5.8% of the park (4,451 acres). 1,154 acres (26% of the watershed) are seral or stable aspen. The SF Big Wash aspen stand is 50.8% departed from natural range of variation.

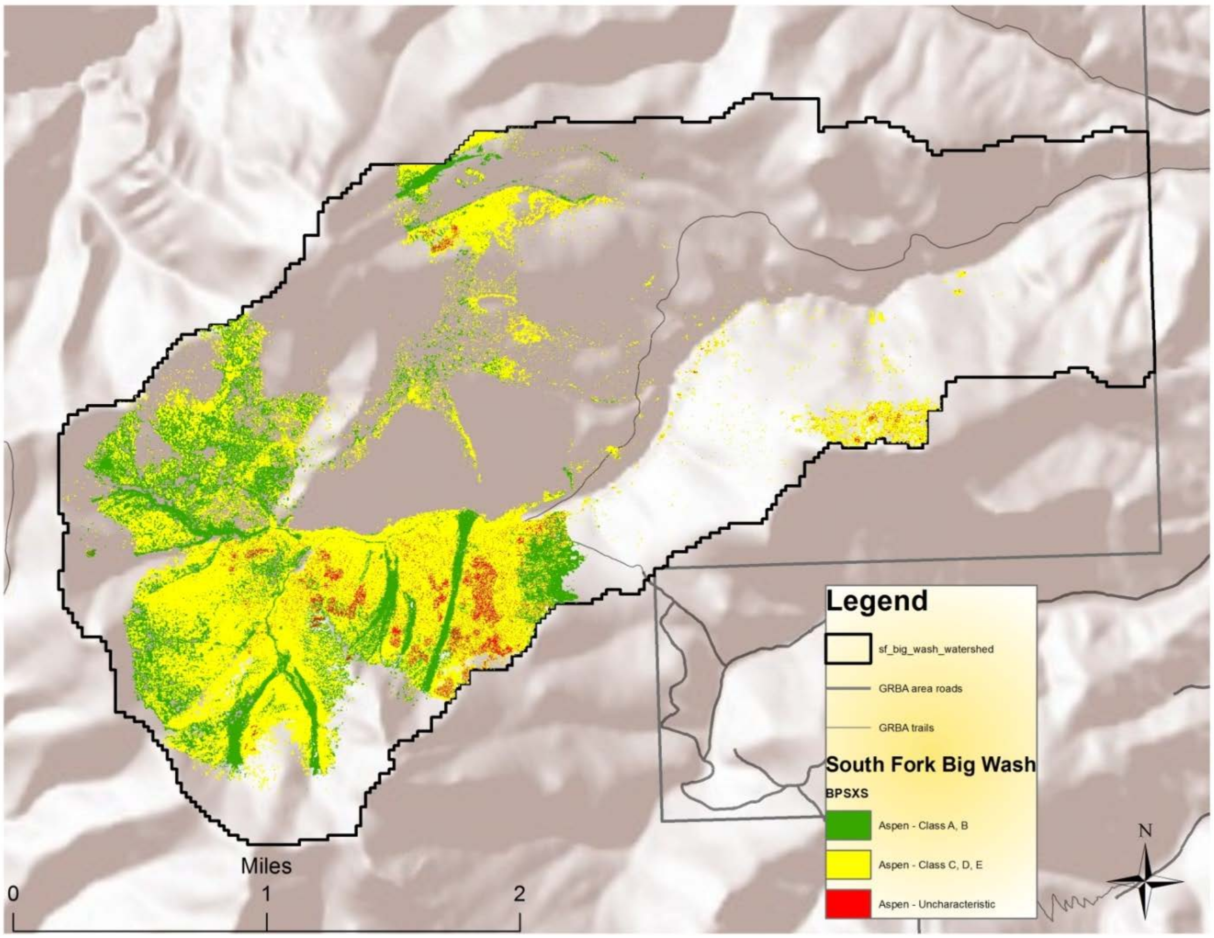

Figure 15. South Fork of Big Wash aspen stand condition and health assessment.

Shingle Creek

Shingle Creek comprises 2.6% of the park (1,992 acres). 1,146 acres (58% of the watershed) are seral or stable aspen. The Shingle Creek aspen stand is 72.0% departed from natural range of variation.

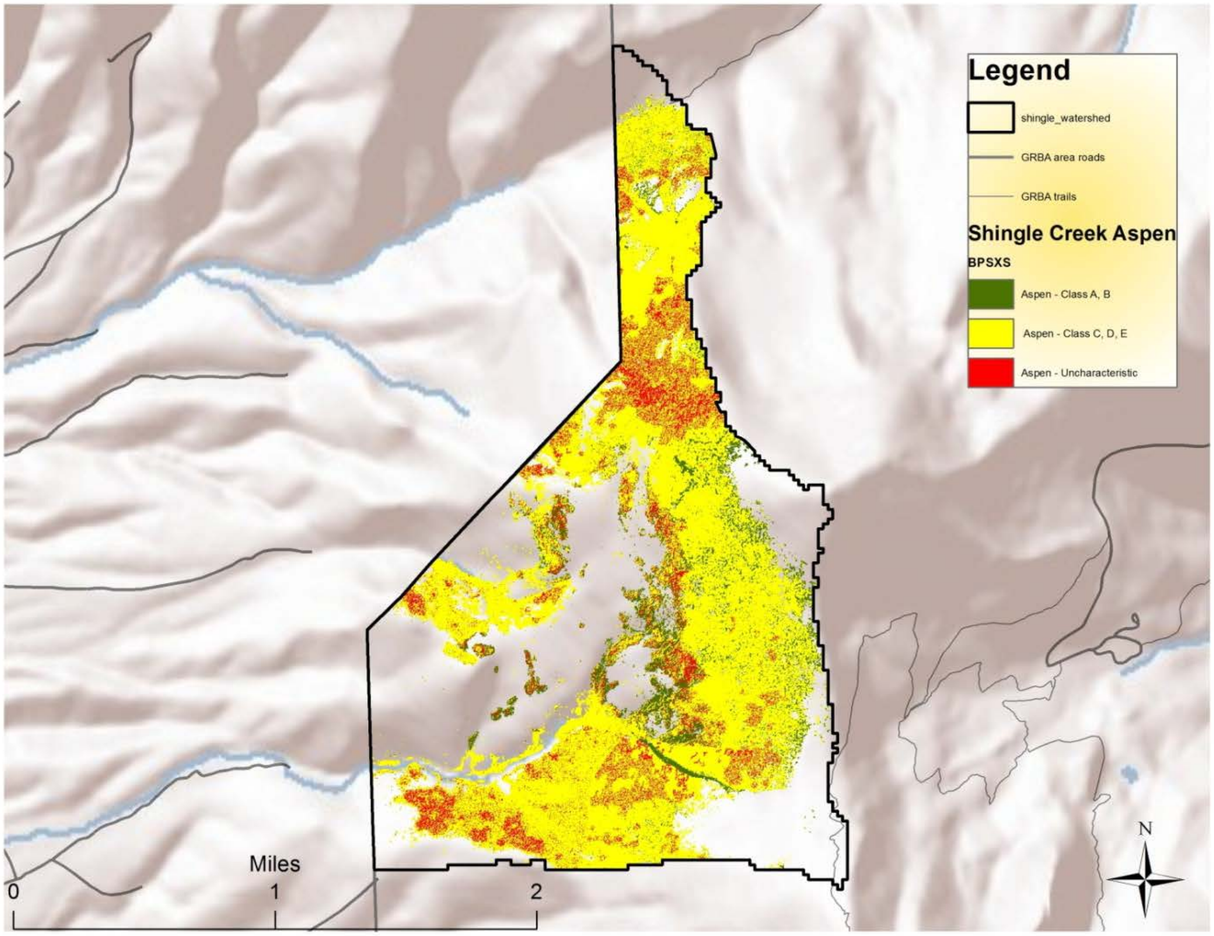

Figure 16. Shingle Creek aspen stand condition and health assessment.

Can Young Canyon

Can Young Canyon is 2.6% of the park (1,999 acres). 709 acres (35% of the watershed) are seral or stable aspen. The Can Young Canyon aspen stand is 74.4% departed from natural range of variation.

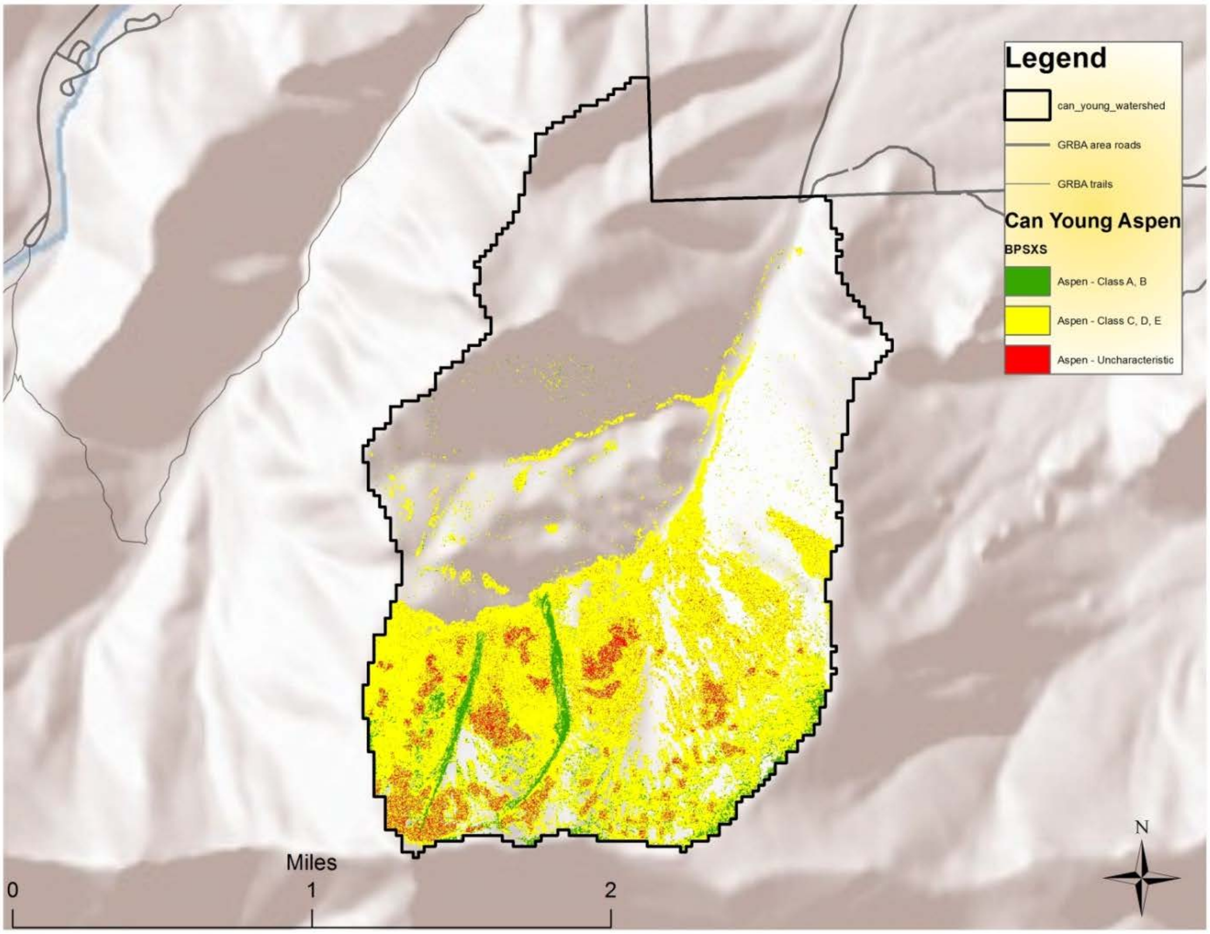

Figure 17. Can Young Canyon aspen stand condition and health assessment.

Pine and Ridge Creek

Pine and Ridge Creeks comprise 2.2% of the park (1,722 acres). 610 acres (35% of the watershed) are seral or stable aspen. The Pine and Ridge Creek aspen stands are 79.0% departed from natural range of variation.

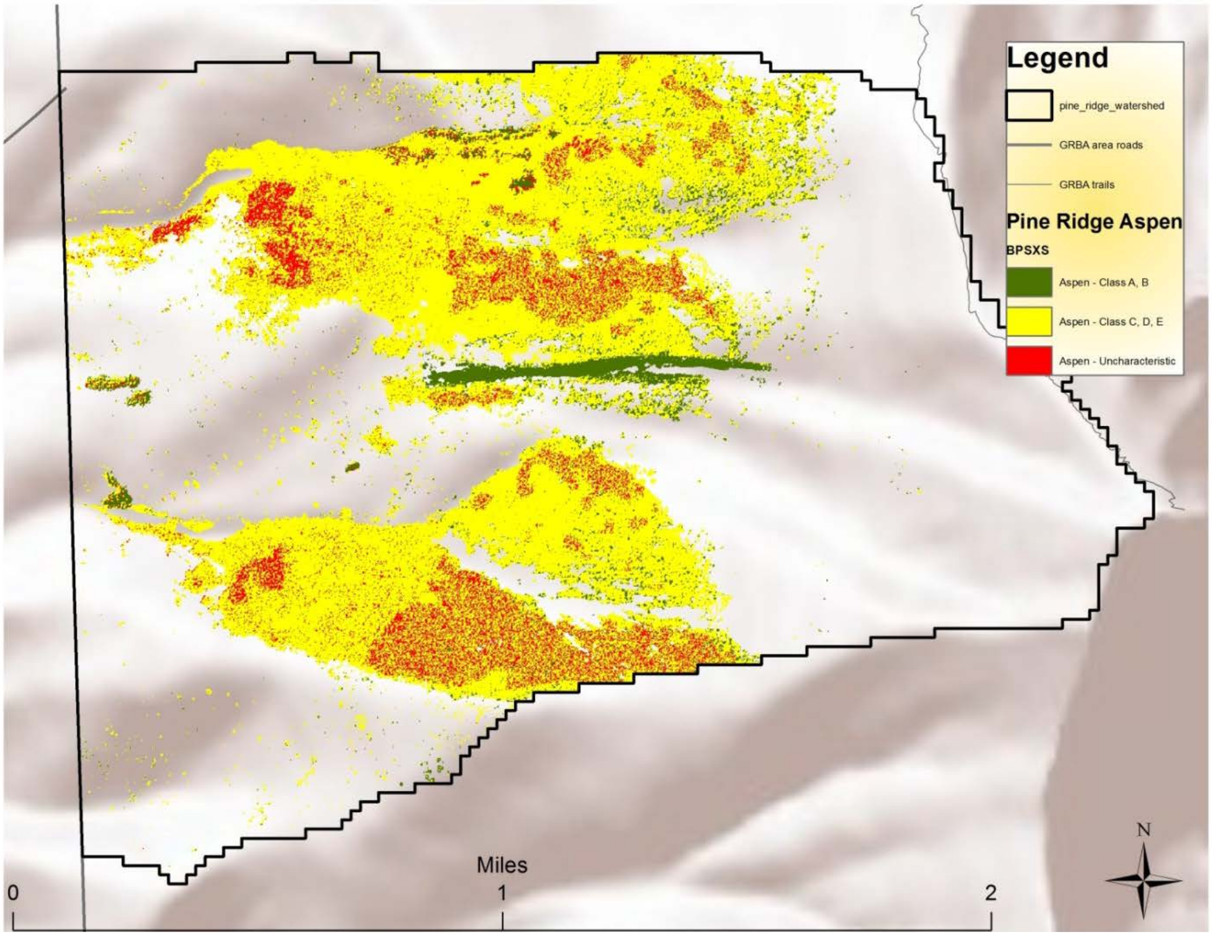

Figure 18. Pine and Ridge Creek aspen stand condition and health assessment.

Hub Basin

Hub Basin comprises 2.1% of the park (1,582 acres). 570 acres (36% of the watershed) are seral or stable aspen. The Hub Basin aspen stand is 61.1% departed from natural range of variation.

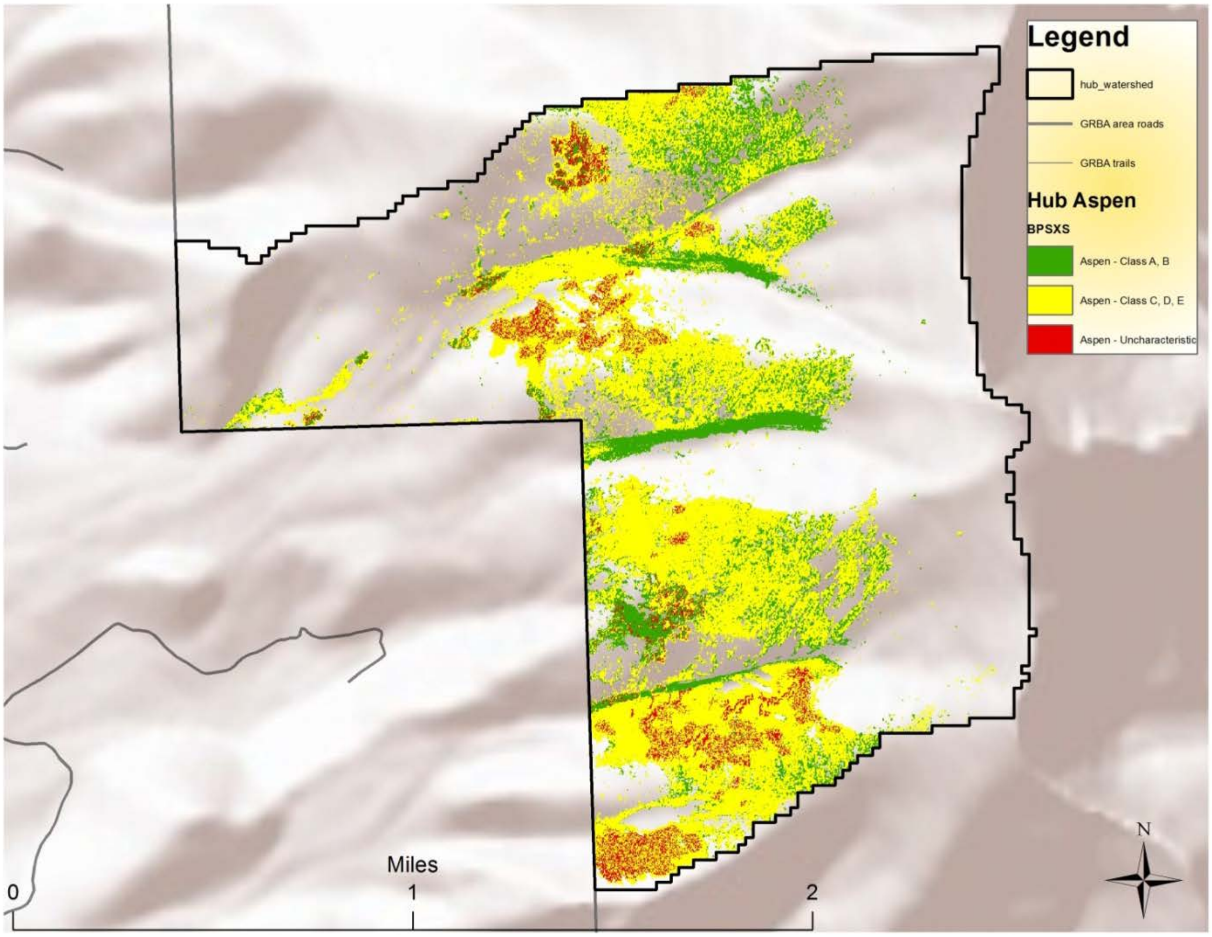

Figure 19. Hub Basin aspen stand condition and health assessment.

Lexington Canyon

Lexington Canyon comprises 3.3% of the park (2,508 acres). 560 acres (22% of the watershed) are seral or stable aspen. Lexington Canyon's aspen stand is 59.3% departed from natural range of variation.

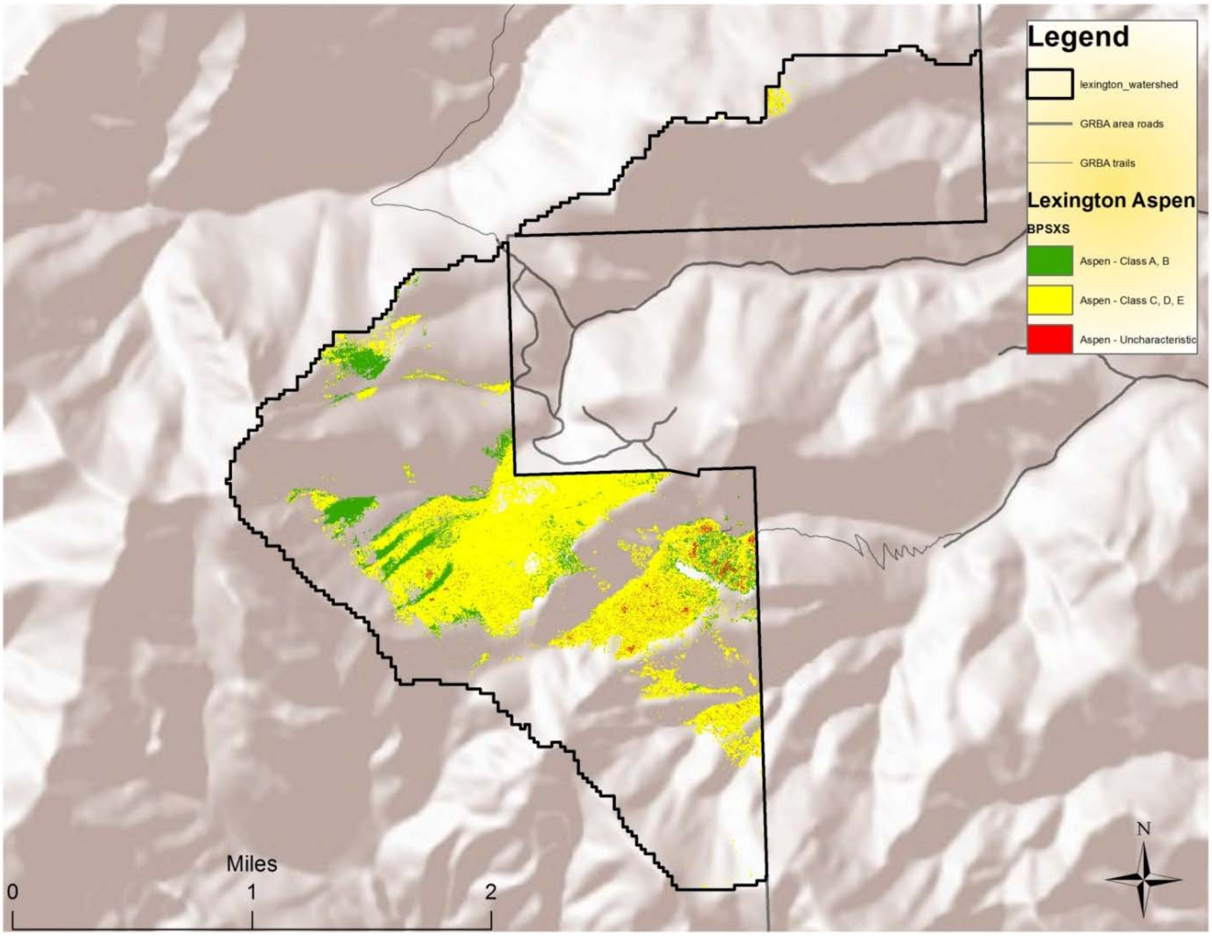

Figure 20. Lexington Canyon aspen stand condition and health assessment.

Williams Creek

Williams Creek comprises 1.9% of the park (1,485 acres). 540 acres (36% of the watershed) are seral or stable aspen. The Williams Creek aspen stand is 66.5% departed from natural range of variation.

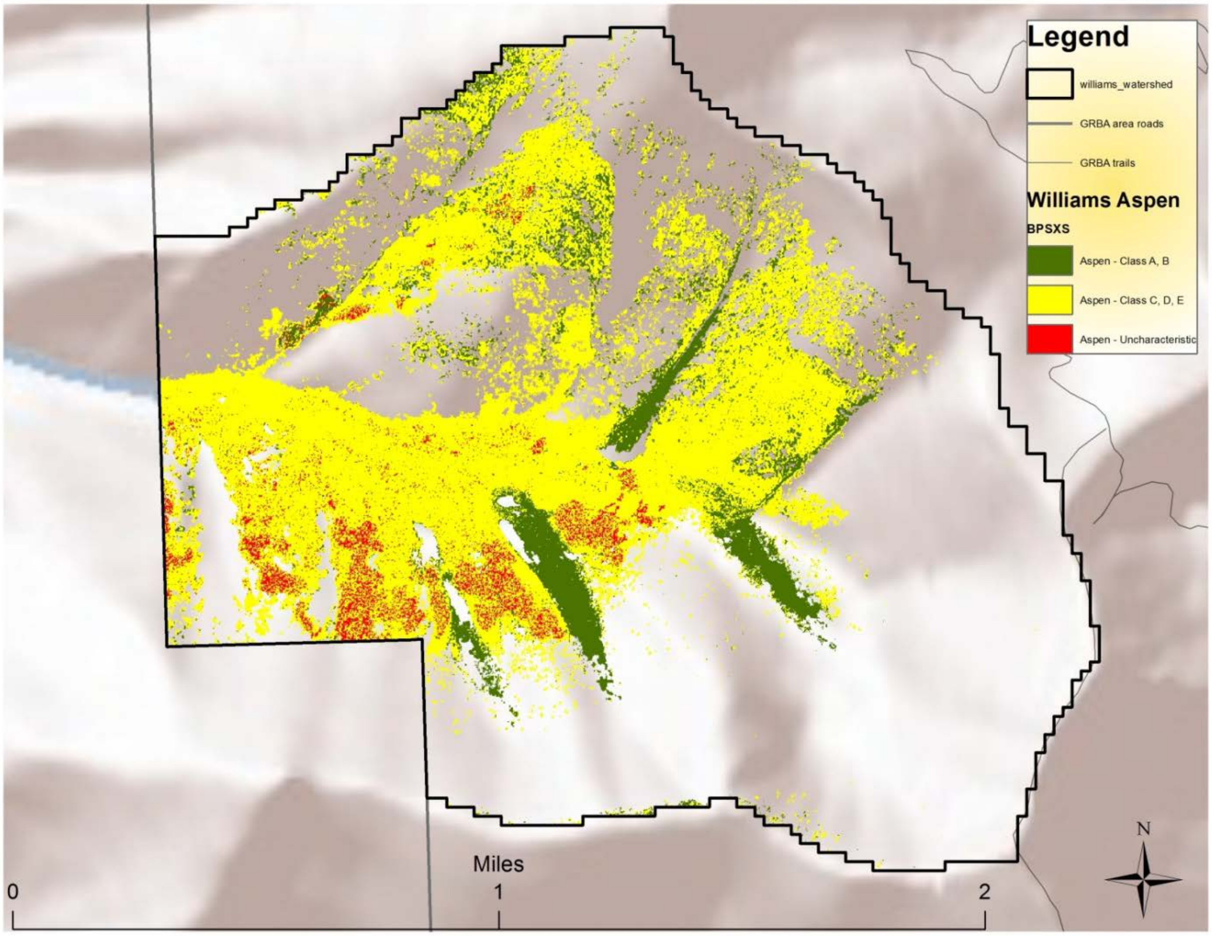

Figure 21. Williams Creek aspen stand condition and health assessment.

Dry Canyon

Dry Canyon comprises 1.7% of the park (1,289 acres). 442 acres (34% of the watershed) are seral or stable aspen. The Dry Canyon aspen stand is 59.9% departed from natural range of variation.

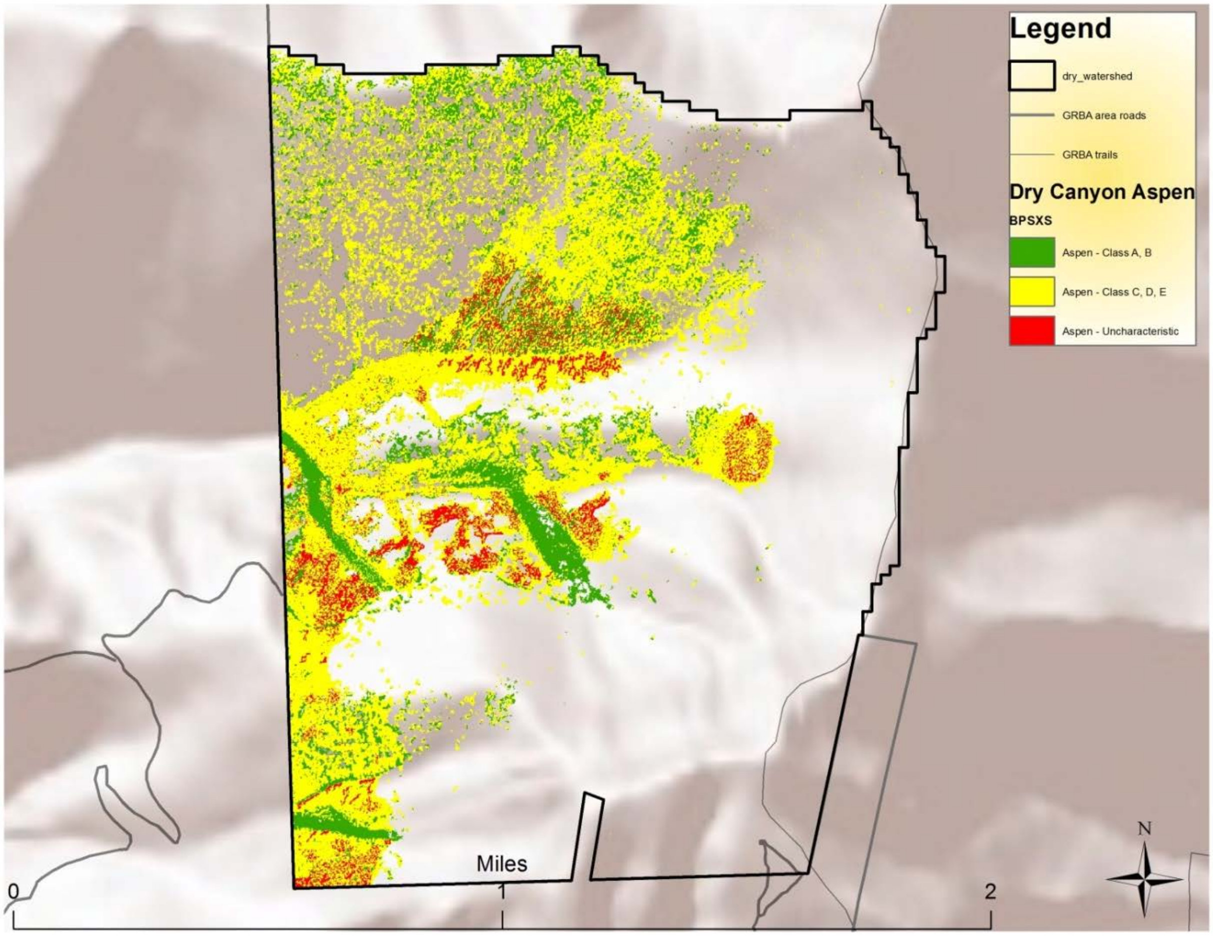

Figure 22. Dry Canyon aspen stand condition and health assessment.

Young Canyon

Young Canyon comprises 3.6% of the park (2,807 acres). 436 acres (15.5% of the watershed) are seral or stable aspen. The Young Canyon aspen stand is 64.1% departed from natural range of variation.

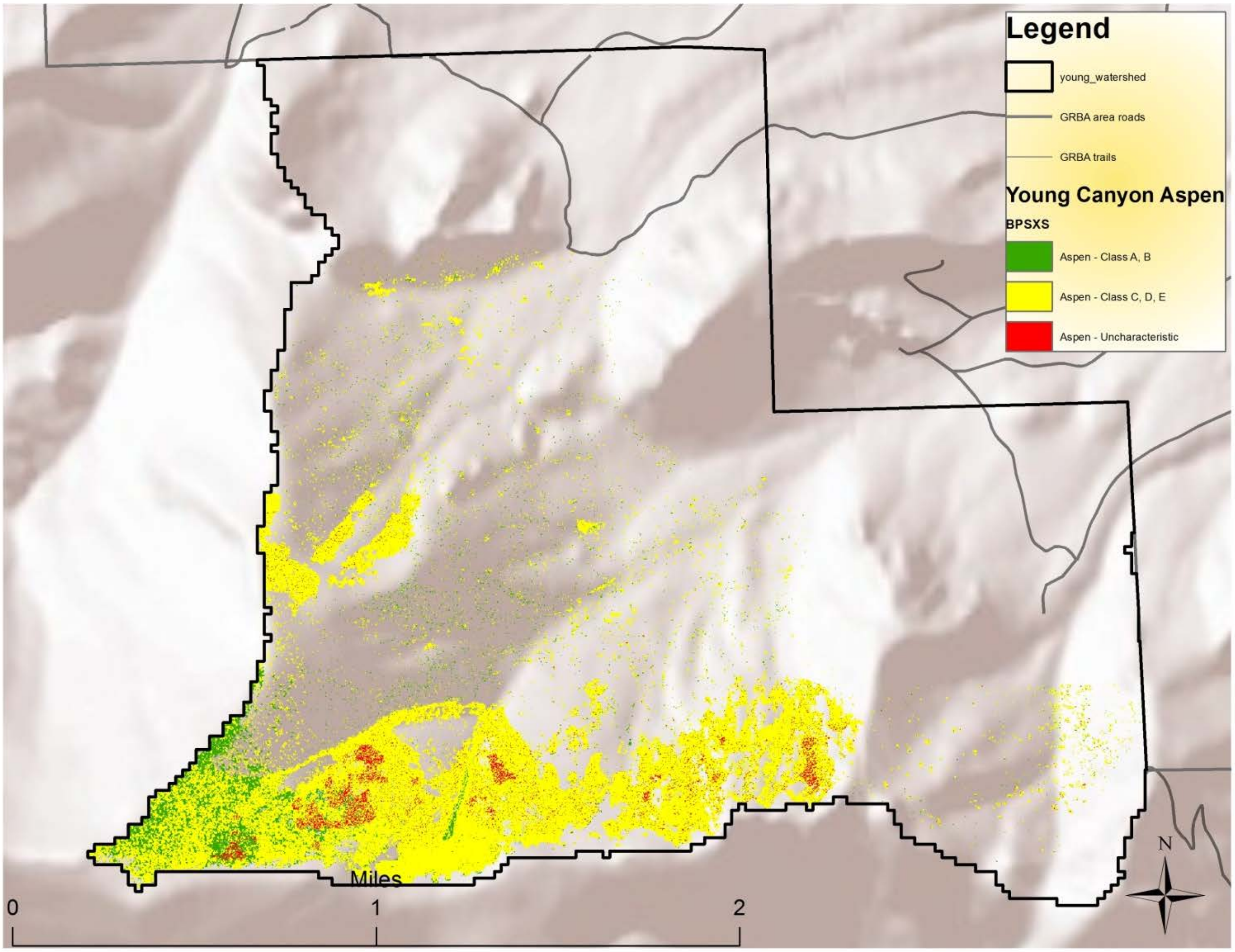

Figure 23. Young Canyon aspen stand condition and health assessment.

Mill Creek

Mill Creek comprises 2.1% of the park (1,652 acres). 404 acres (24% of the watershed) are seral or stable aspen. Mill Creek's aspen stand is 59.0% departed from natural range of variation.

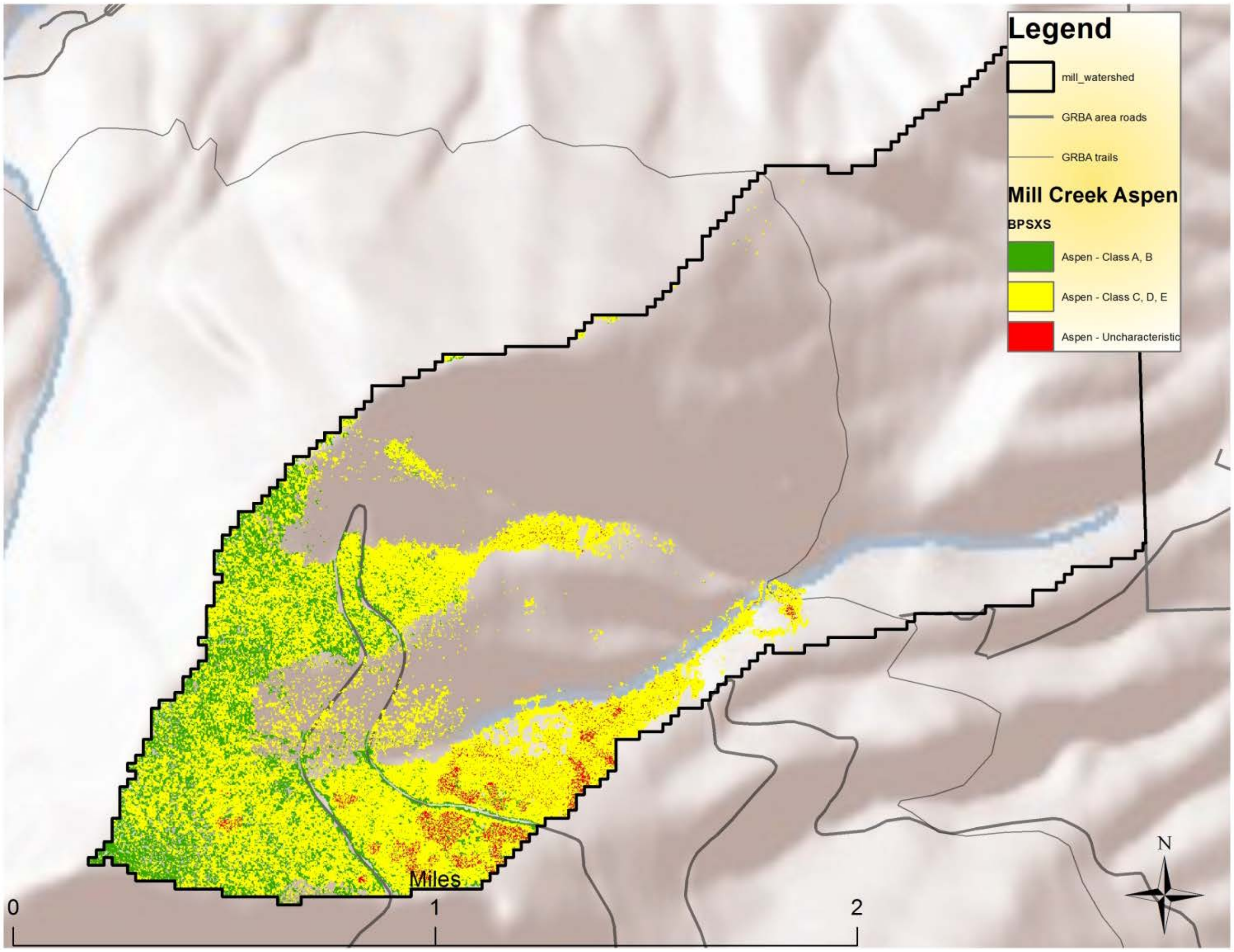

Figure 24. Mill Creek aspen stand condition and health assessment.

Decathon Canyon

Decathon Canyon comprises 4.2% of the park (3,239 acres). 390 acres (12% of the watershed) are seral or stable aspen. Decathon Canyon's aspen stand is 27.6% departed from natural range of variation.

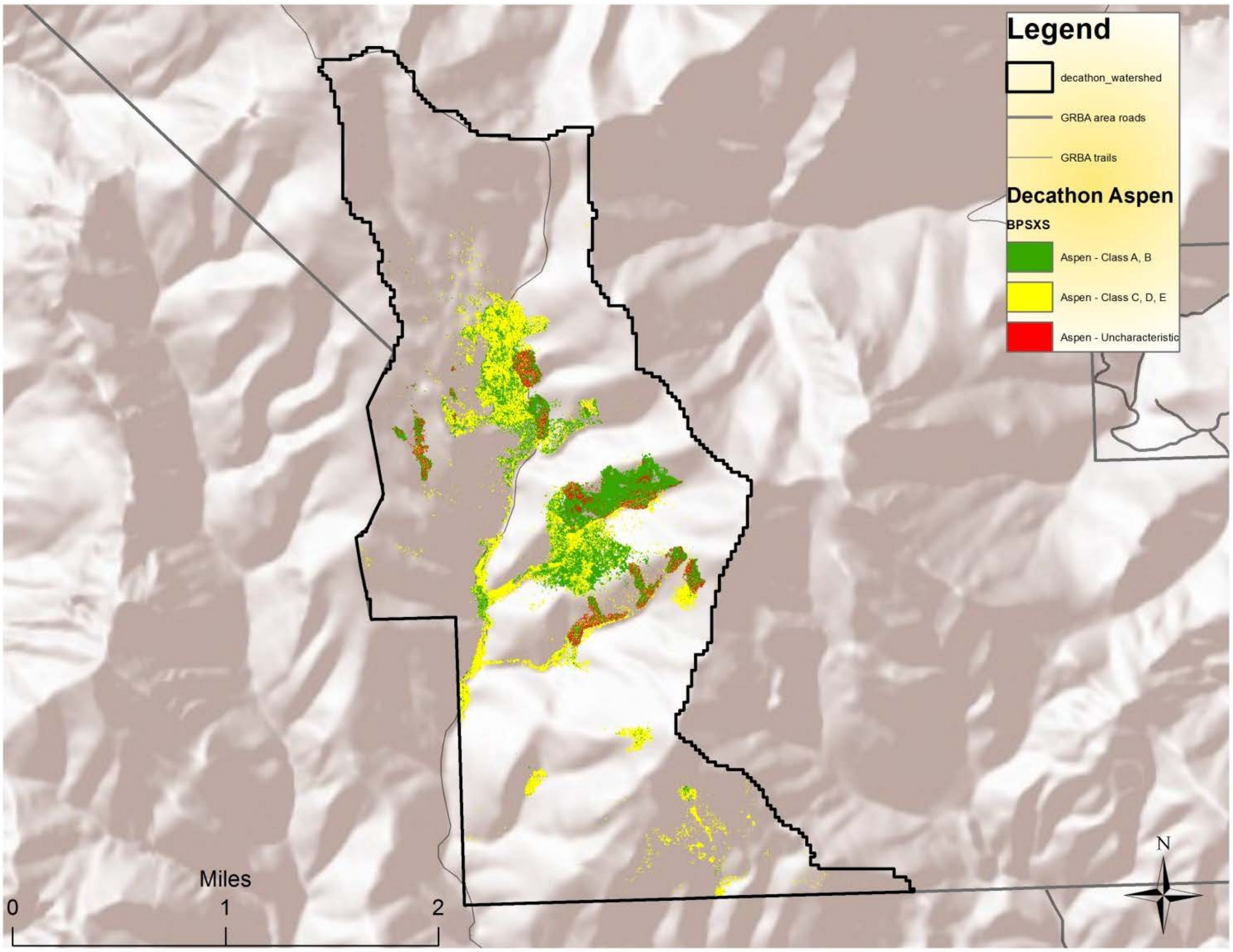

Figure 25. Decathon Canyon aspen stand condition and health assessment.

Big Springs Wash

Big Springs Wash comprises 2.6% of the park (1,988 acres). 184 acres (9% of the watershed) are seral or stable aspen. The Big Springs aspen stand is 59.1% departed from natural range of variation.

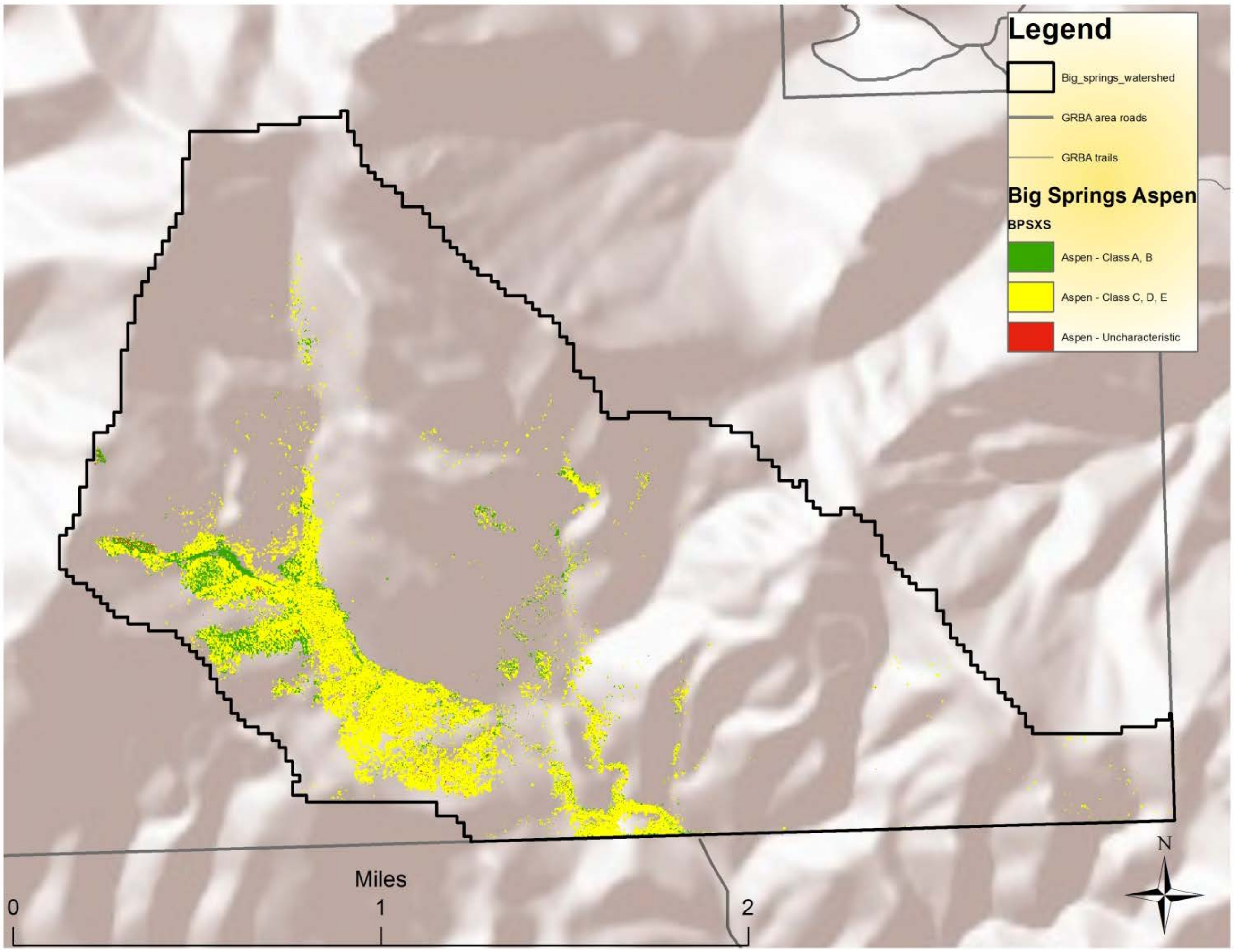

Figure 26. Big Springs Wash aspen stand condition and health assessment.

Burnt Mill Creek

Burnt Mill Creek comprises 2.3% of the park (1,764 acres). 135 acres (8% of the watershed) are seral or stable aspen. The Burnt Mill aspen stand is 79.1% departed from natural range of variation.

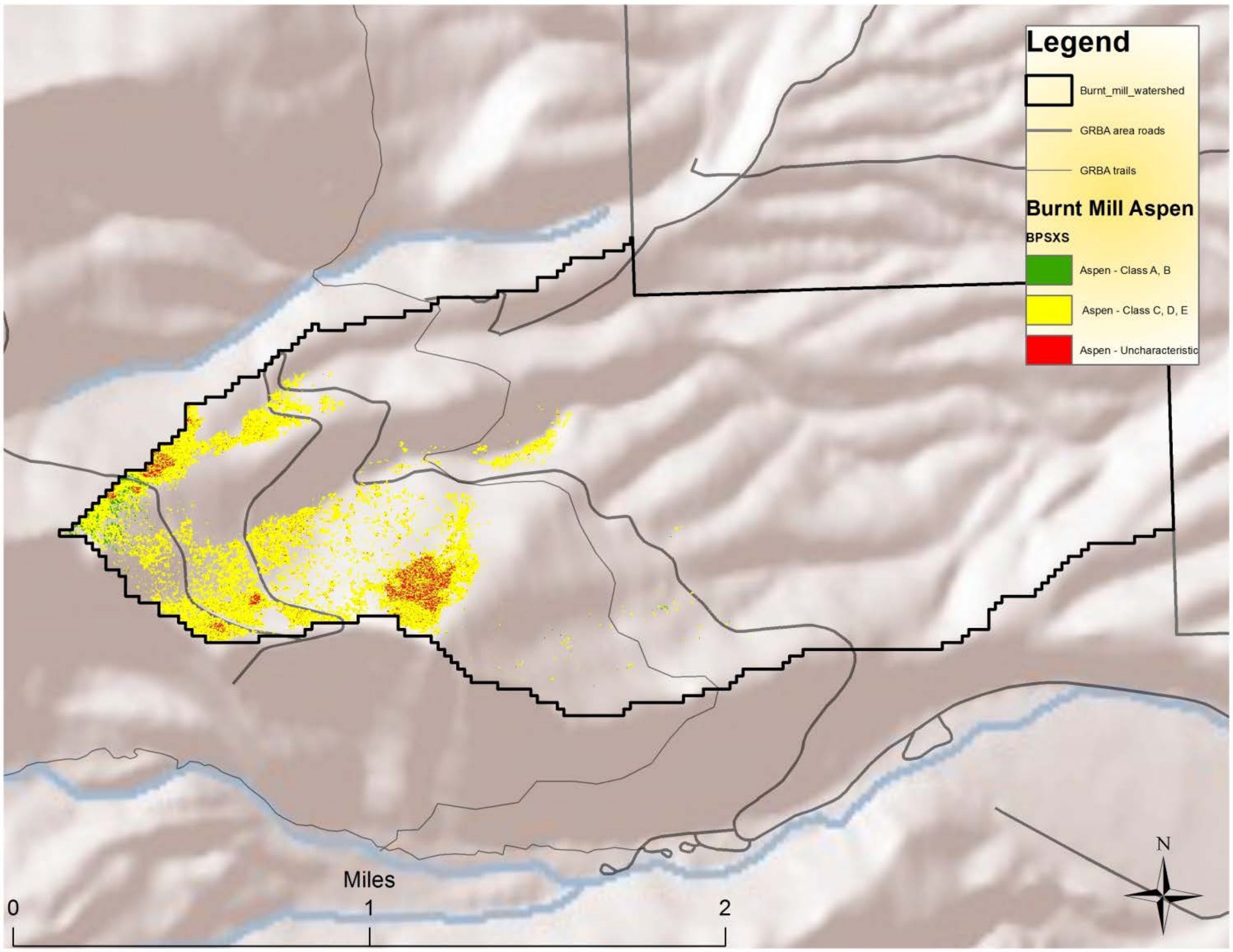

Figure 27. Burnt Mill aspen stand condition and health assessment.

Lincoln Canyon

Lincoln Canyon comprises 2.9% of the park (2,251 acres). 48 acres (2% of the watershed) are seral or stable aspen. Lincoln Canyon's aspen stand is 74.1% departed from natural range of variation.

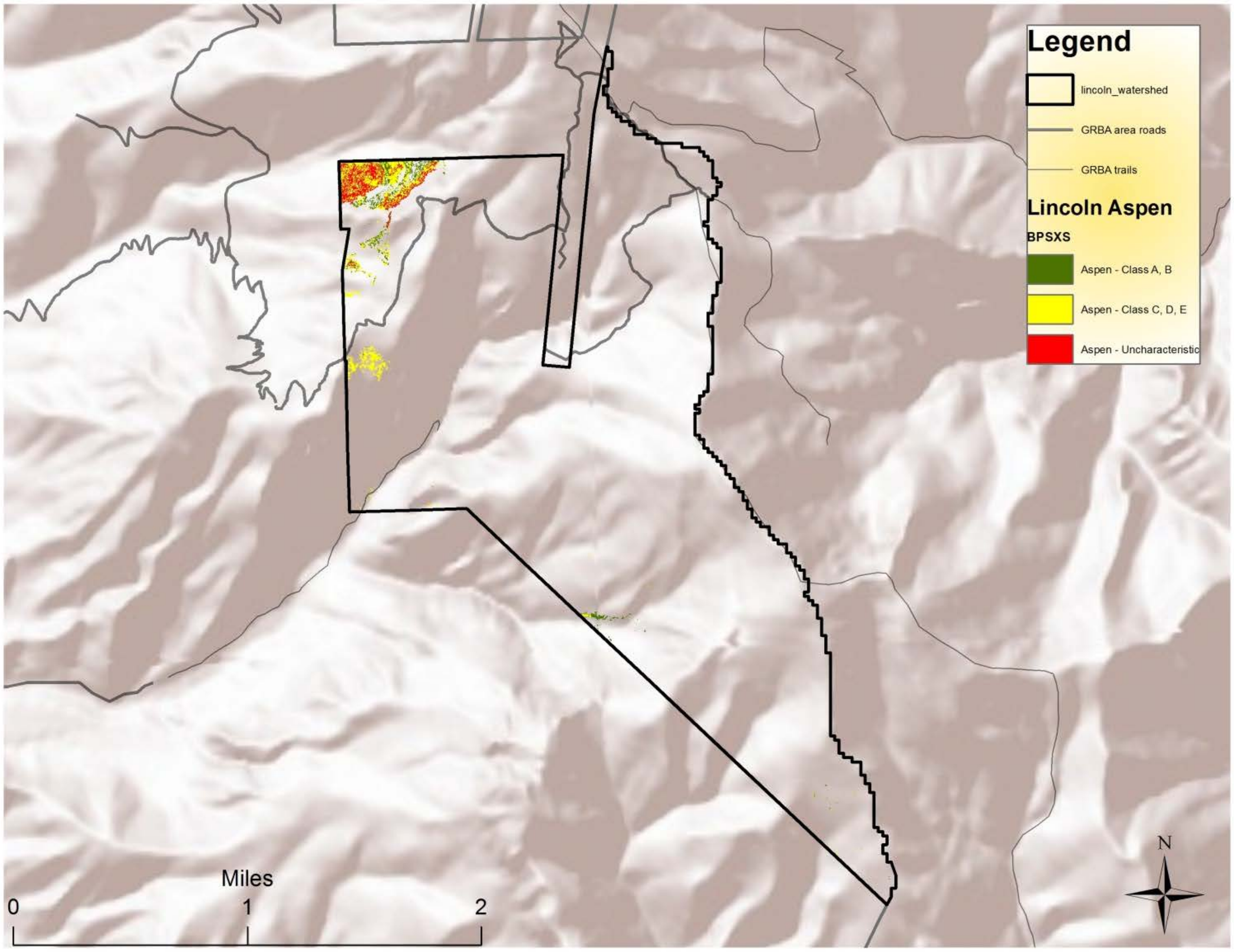

Figure 28. Lincoln Canyon aspen stand condition and health assessment.

Management Recommendations

Aspen throughout the park are in dire need of active management on a large scale. A century of fire exclusion, past livestock grazing and resulting conifer encroachment has led to the loss of aspen clones on at least 1, 229 acres and the virtual elimination of aspen regeneration on the landscape. The permanent conversion of aspen systems to conifer forest and the predicted loss of 10, 590 acres, would result in a 50% loss of aspen from the park in 50 years. Impacts to an ecosystem at this magnitude would likely be considered impairment under NPS policy.

The need for restoration of aspen systems in the park was first recognized in the early 1990s with the first landscape scale vegetation mapping effort (Eddleman and Jaindl 1994). This effort identified 43 vegetation community types and identified potential native plant communities on the landscape to a resolution of 30 meters. Six aspen vegetation types were identified. Conifer encroachment was identified as the major threat to aspen condition in the South Snake Range affecting 5, 520 acres. Beever et al. (2005) found that aspen abundance was negatively correlated with white fir and that aspen had decreased on four of five of their sampling sites. Great Basin National Park's 2004 Fire Management Plan (GRBA 2004) noted that aspen had suffered from conifer encroachment due to grazing and fire suppression and recommended that prescribed fire be used to restore aspen. Therefore, the general decline of aspen via conifer encroachment and the need for large scale aspen restoration in the park we identify is corroborated.

Immediate and large-scale reintroduction of fire is necessary to prevent continued loss of aspen stands, increase regeneration and bring aspen stands closer to natural range of variation. The extent of the park's aspen systems (almost 20, 000 potential acres) requires large scale ecological restoration. Aspen restoration projects have a high probability of success because they occur at high elevations, where higher rates of precipitation and productive soils create resistance to invasive species and increase post-disturbance resilience due to native seed banks. In fact, aspen regeneration requires frequent disturbance, to limit conifer encroachment and stimulate new stem production.

The primary goal of aspen management is to limit clone loss, minimize conversion of aspen to conifer, and return aspen stands to their natural range of variation (Appendix 2). The following points should be considered when planning management actions:

- Aspen stands that will successfully respond to restoration are in finite numbers. Careful selection of candidate stands is required to ensure restoration actions in encroached aspen stands are successful. If stands without an existing aspen component or remaining clone are treated, recovery and recruitment may not be possible (Jones et al. 2005b).

- A return to natural disturbance regimes would benefit these systems most, but localized restoration approaches can stimulate aspen recruitment and ensure stand persistence or expansion to meet management goals (Kuhn et al. 2011).

- Aspen management actions need to be conducted on a large scale to dilute intense browsing of suckers during the sensitive early-succession phase. Bartos and Campbell (1998) suggest 500 to 1,500 acres per treatment.

- Recovering aspen stands should be protected from domestic and wild ungulate grazing. Without fencing or other obstacles to browsing, aspen regeneration will fail if a recovering stand is heavily grazed (Utah Forest Restoration Working Group 2010, Bartos and Campbell 1998).

- Monitoring should be implemented throughout the restoration process and consistently follow published protocols (Campbell and Bartos 2001 or Jones et al. 2005a).

- Site visits and professional judgment are necessary to determine specific stand condition, understory vegetation condition and appropriate treatment actions before treatment prescriptions can be finalized.

- Poor aspen condition in the South Snake Range extends outside park boundaries. Habitat restoration projects should be cross-jurisdictional utilizing existing partnerships between the BLM and NPS to make the most of favorable topography for prescribed fire and to maximize aspen restoration efforts.

- Restoration strategies should be subject to adaptive management. If treatments do not meet restoration objectives, alternative restoration strategies should be considered to better meet objectives. Post-treatment monitoring will aid in directing management decisions toward alternatives that support aspen restoration and limit invasive species or other adverse effects.

Bartos and Campbell (1998) established risk factors for managers conducting aspen restoration projects. Factors that would warrant restoration include:

- Conifer cover greater than 25%
- Aspen cover less than 40%
- Individual aspen greater than 100 years old
- Sagebrush cover greater than 10%
- Aspen stems less than 500/acre

Nearly all park aspen stands meet one of the parameters above.

Aspen Treatment Objectives and Methods

The objective of aspen treatments is to decrease conifer canopy cover and increase aspen regeneration. These treatments will bring aspen stands closer to their natural range of variation, limit loss of aspen clones, and prevent the conversion of aspen to conifer. In general, aspen stands will be altered to early, herbaceous successional states in proportions representative of natural range of variation (Table 1). Treated aspen stands are expected to recover within 8-9 years (L. Provencher, personal communication, January 2013) with individual trees reaching pole size as new aspen patches are being treated in different locations in future years. Measureable objectives will vary by treatment location and will be subject to adaptive management based on local moisture regimes, soils, professional judgment, and best available science.

Baseline objectives for aspen treatments include:

- Decrease conifer canopy cover within treatment areas to less than 5%
- Increase aspen regeneration to greater than 1,000 aspen stems per acre (shrub phase) (Utah Forest Restoration Working Group 2010)

Great Basin National Park proposes to restore quaking aspen communities on park service administered lands in the South Snake Range and partner with adjacent land management agencies (BLM) to improve aspen condition on a landscape scale. Restoration will take place through a combination of hand-felling of conifers, prescribed fire, wildland fire use, seeding of native species, and herbicide application to control non-native plants. The exact combination of restoration techniques will be determined on a project basis.

Hand Felling

Targeted species of conifer within the aspen stand and within 75 feet of the edge (measured from the last standing, live aspen stem in the stand) of the aspen stand will be removed using a chain-saw. All targeted conifers will be removed within 50 feet of the edge of the aspen stand. The last 25 feet within the 75 foot perimeter will be reserved for variable density thinning to feather the edges of the stand and reduce visual impacts. Target species to be removed include the following:

- singleleaf pinyon pine (*Pinus monophylla*)
- Utah juniper (*Juniperus osteosperma*)
- white fir (*Abies concolor*)
- Engelmann spruce (*Picea engelmannii*)
- limber pine (*Pinus flexilis*)
- Douglas-fir (*Pseudotsuga menziesii*)
- Rocky Mountain juniper (*Juniperus scopulorum*)
- curlleaf mountain-mahogany (*Cercocarpus ledifolius*)

The following tree species, if present, will not be cut or removed:

- ponderosa pine (*Pinus ponderosa*)
- bristlecone pine (*Pinus longaeva*)

Target tree species will be felled by hand. Any material suitable for use as fuel wood may be set aside for that purpose. Limbs, branches and other slash will be used as a barrier fence, mechanical mulching or made available as biomass. Care must be taken with slash disposal. Lightly scattering slash offers some protection to new stems, but heavy slash in an aspen stand can inhibit suckering and regeneration. In the dry Great Basin climate, even at higher elevations, slash piles will persist for long periods. Burning piles too close to mature aspen trees or broadcast burning of slash piles over large areas to stimulate suckering can kill the older trees (Swanson et al. 2010).

Lightly scattered slash (limbs and branches) can be burned after thinning treatments are completed. A study in Arizona showed that burning logging slash after harvest of competing overstory conifers produced more aspen stems per acre than removal of overstory conifers alone (Shepperd 2001).

Felling mature aspen is an alternative management strategy to stimulate suckering of new stems. In some stands that do not respond to conifer removal, suckering returns only after felling of mature aspen. Girdling mature aspen is not an option. It not only kills the mature trees, it also prevents regeneration of new stems.

If an aspen stand contains non-target conifers listed above, those trees will be marked prior to tree removal to avoid cutting of non-target trees, unless a biologist or biological technician is on site during removal to ensure compliance.

Prescribed Fire and Pile Burning

Prescribed fire will be used as the primary tool to restore aspen stands. In general, prescribed fire will best be utilized in areas with significant conifer encroachment, and in areas with higher condition and health scores. Due to the size and location of aspen stands, helicopter ignitions will be required. Prescribed fire (management of natural ignitions, helicopter ignitions and ground ignitions) will prevent conversion of late-succession aspen to conifer and loss of aspen clones.

Pile burning is not recommended inside aspen stands. Hot fires will kill aspen roots (the platform for new stems), create hydrophobic soils and create invasion sites for weeds. Burning piles too close to mature aspen trees or broadcast burning large slash piles over large areas to stimulate suckering can kill the older trees (Swanson et al. 2010). Lightly scattered slash (limbs and branches) can be burned after thinning treatments are completed to help stimulate regeneration (Shepperd 2001).

Wildland Fire Use

Given the large scale of aspen treatments, management of natural ignitions is critical to restore aspen systems to their natural range of variation. All aspen stands in the park are recommended for wildland fire use (Figure 29). These stands are all in Fire Regime Conditions Class 1 or 2, meeting the requirements for wildland fire use in the current fire management plan.

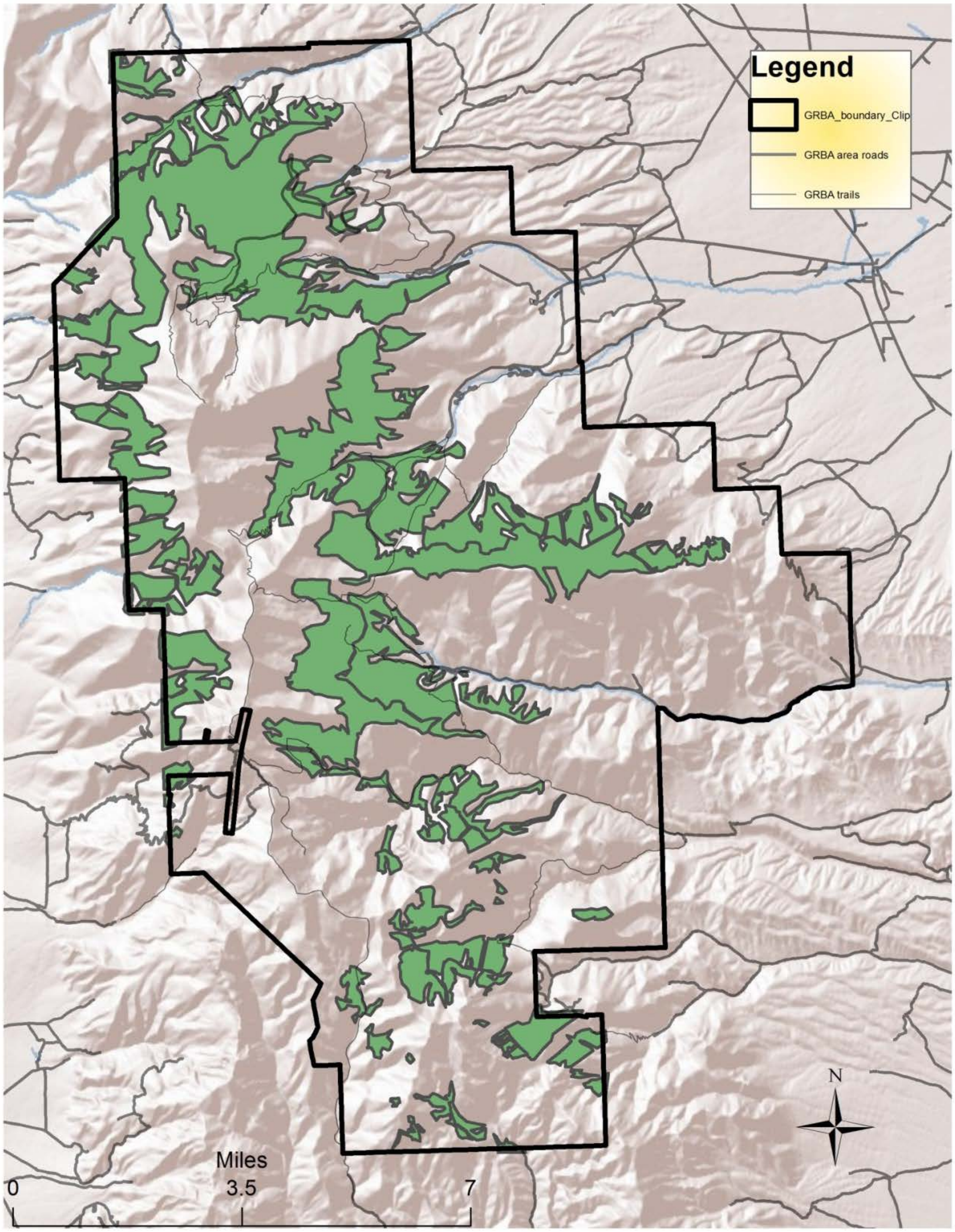

Figure 29. Aspen stands recommended for wildand fire use (19,608 acres).

Current Fire Management Plan

All prescriptions described above are consistent with the current Fire Management Plan. The current plan allows for aspen restoration using fire or mechanical treatments in order to restore aspen systems to historical fire regimes within FRCC 2. All park aspen stands currently fall into FRCC 1 or 2.

Effectiveness and Validation Monitoring

Monitoring will be used to determine if treatments were successful and adequately scaled, inform future restoration projects or management plans, and assess future restoration needs. Monitoring will take place in the form of pre-treatment vegetation surveys to determine current, baseline conditions; and post-treatment surveys to determine if project objectives were met, document changes in vegetation condition and composition, and determine the efficacy of treatment strategies. Pre and post-treatment monitoring will be an integral part of any project proposal or prescribed burn plan. Quantifiable vegetation objectives for desired conditions post-treatment should be established (Utah Forest Working Group 2010) and included in project proposals or burn plans to help determine the effect of treatment strategies and how well vegetation objectives have been met.

Current vegetation monitoring protocols used in sagebrush steppe systems and wildlife habitat condition assessments by Forbis et al. (2007) as modified from Herrick et al. (2005) will be used for pre and post-treatment monitoring. Vegetation cover, density, diversity, ground cover and slope will be assessed using line-point intercept and belt transects. A densitometer will be used to sample vegetation cover greater than the observer’s height. Creating species list for each monitoring site should also be completed. The species list will document plants present at monitoring sites the line-point intercept protocol may not, such as non-native plants. Permanent photo plots will also be established in project areas. Repeat photography provides a quick and inexpensive way to track regeneration and vegetation recovery.

Mapping post-treatment restoration areas will be conducted using Trimble GPS units. Polygons delineating treatment areas will be created. Spatial data on patches that did not burn, areas containing non-native plants, severely burned areas, and other information on vegetation condition will also be collected. Number of acres treated for each vegetation type or vegetation class will be an important metric for project reporting and assessing future restoration needs.

Pre-treatment wildlife surveys may be indicated for certain project areas or during certain times of the year. Prescribed burns or thinning projects in aspen stands with potential or known nesting sites for Northern goshawks should be surveyed before burning occurs. Conducting burns or mechanical treatments in the fall will help mitigate impacts to Northern goshawk.

Treatments that occur along streams containing populations of Bonneville cutthroat trout will require additional planning and mitigation measures. Stream bank vegetation plays an important role in maintaining suitable water temperature, providing cover for fish and stabilizing stream banks. Complete removal of stream bank vegetation through high intensity fire or thinning would be detrimental to sensitive fish populations.

Aspen vegetation surveys

Along with line-point intercept vegetation surveys and belt transects, treated aspen stands will require additional surveys to document regeneration (suckers or stems per acre).

Aspen regeneration levels are listed in Table 4 (Utah Forest Restoration Working Group 2010). Suckers are new aspen growth less than six feet in height; stems are individual aspen greater than six feet tall, but less than overall canopy height. Aspen stands with less than 500 stems per acre are not sustainable (Mueggler 1989, Campbell and Bartos 2001, Utah Forest Restoration Working Group 2010). These stands lack adequate recruitment or regeneration to be self-replacing.

Table 4. Recruitment levels for successful aspen regeneration.

Recruitment level	# suckers (<6 ft.)/acre	# suckers (<6 ft.)/ha	# stems (>6 ft. and < canopy height)/acre
Self-replacing	>1,000	>2,500	
Marginal	500-1,000	1,250-2,500	
Not self-replacing	<500	<1,250	<500

Several resources on monitoring aspen regeneration are available: Shepperd and Weixelman (2010), USDA Forest Service (2004), and Jones et al. (2005a). We recommend Shepperd and Weixelman (2010) for aspen regeneration monitoring.

Recommended Treatment Areas

All aspen stands in the park, except those in Decathon Canyon, require some level of disturbance to restore stands to their natural range of variation. Due to the scale of aspen treatments needed for aspen restoration, only a subset of watersheds were chosen for treatment with prescribed fire. However, all aspen stands in the park are recommended for wild land fire use and management of natural ignitions consistent with the existing Fire Management Plan (Figure 29). Baker, Snake, Strawberry, Lehman, Williams, Shingle, Pine/Ridge, Hub Basin and Dry Canyon watersheds were specifically chosen for restoration treatments using prescribed fire (Figure 30). Williams, Shingle, Pine/Ridge and Dry Canyon watersheds were grouped and analyzed together as the 'West Side' watersheds.

We recommend treating 14,174 acres of aspen across these nine watersheds (Table 5). The need for action is outlined below in the watershed descriptions.

Table 5. Recommended aspen treatment areas by park watershed.

Watershed	% park aspen	% departure from NRV (aspen condition score)	Acres recommended for treatment
Baker	18.2	62.3	3,801
Strawberry	12.5	73.1	2,412
Lehman	10.5	60.4	2,163
Snake	13.9	57.8	2,457
West Side	16.9	67.7	3,341
Total	72	-	14,174

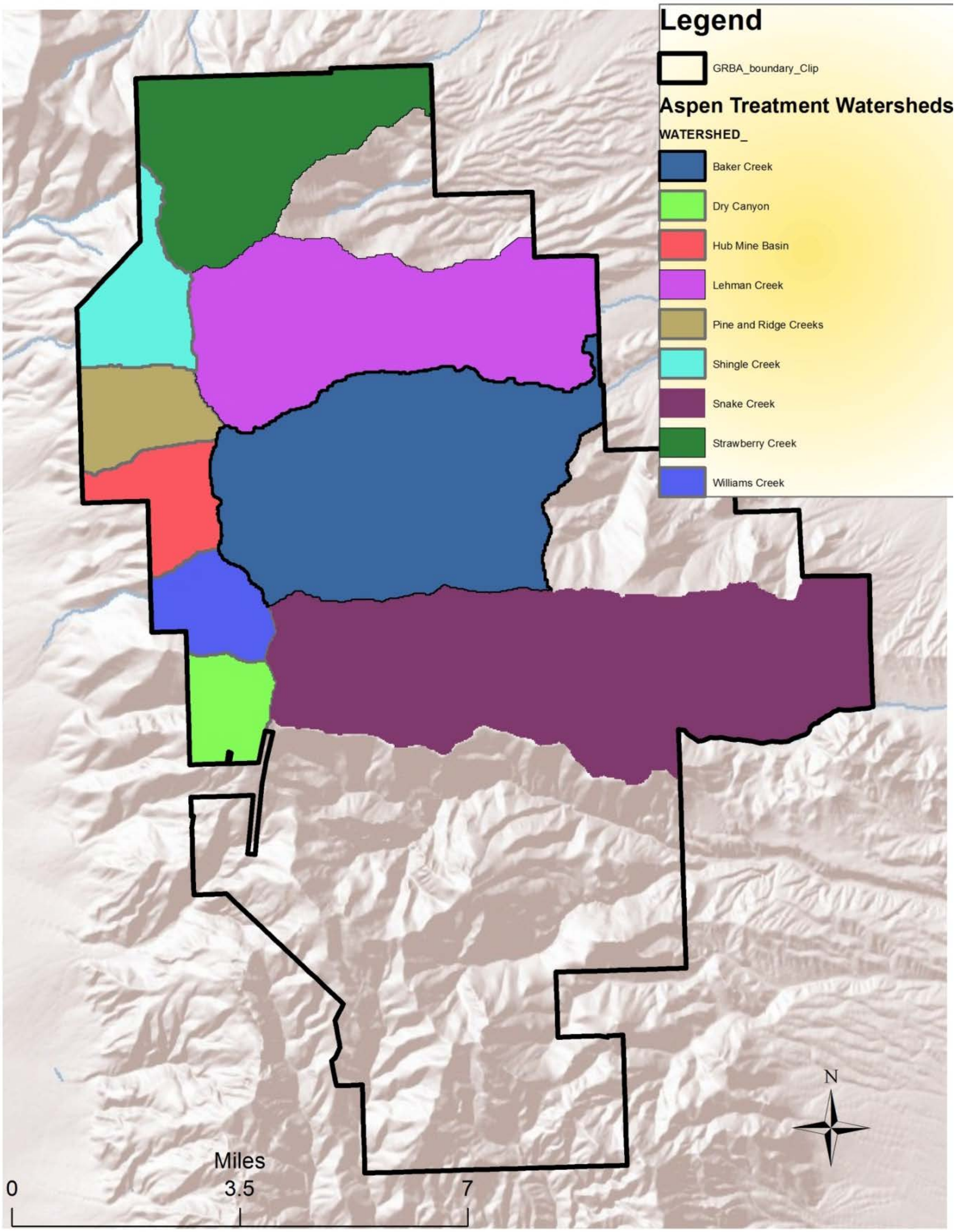

Figure 30. Watersheds recommended for treatment with prescribed fire.

Baker Creek

This watershed was chosen for treatment because of its large size, high proportion of aspen (18.2% of park aspen), infrastructure (two campgrounds, trailhead and maintained road), and aspen condition. Recommended treatment areas in the Baker Creek Watershed include 3,801 acres. These treatments would be phased over a ten year period to allow the development of early and mid-successional classes.

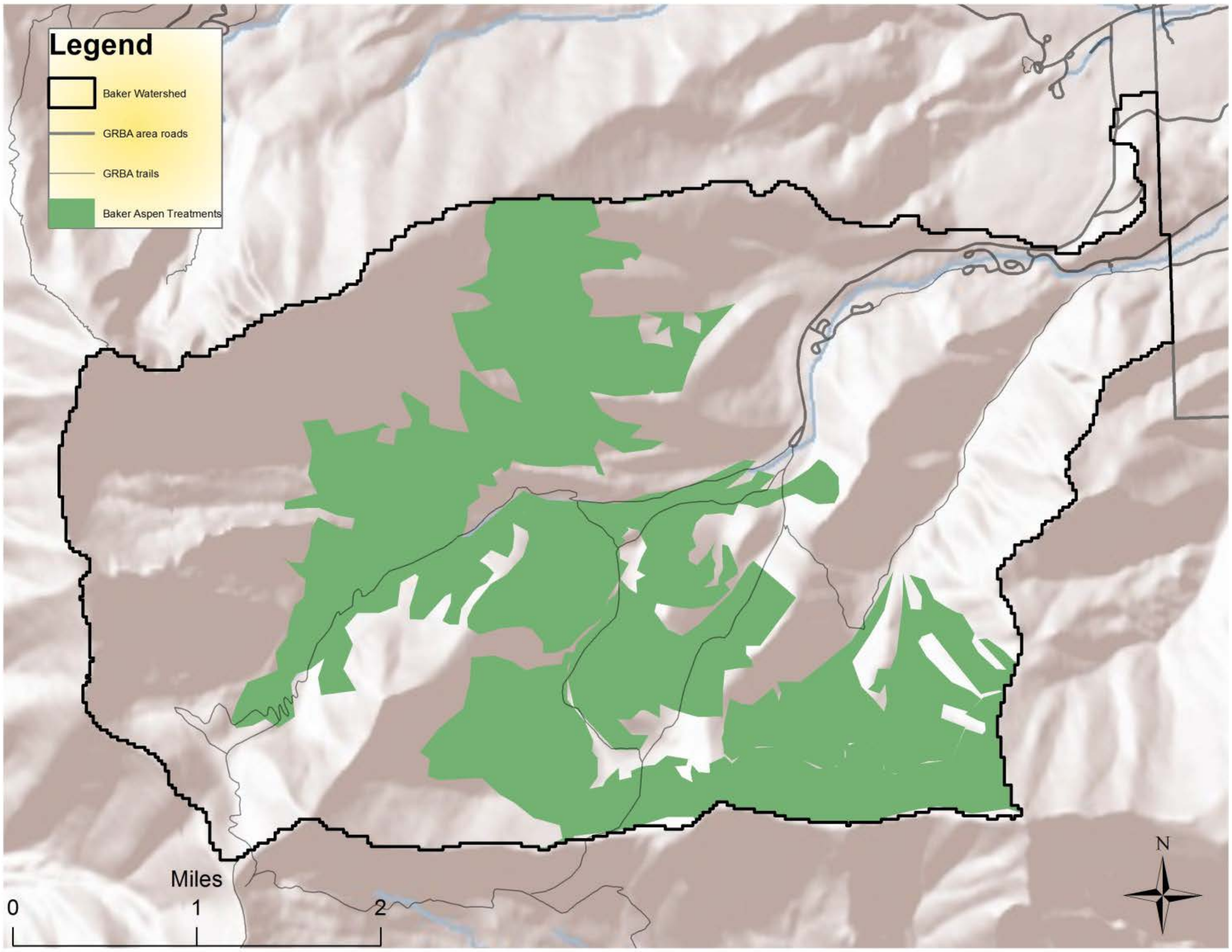

Figure 31. Recommended aspen treatment areas in the Baker Creek Watershed.

Strawberry Creek

This watershed was chosen for treatment because its high proportion of aspen (12.5% of park aspen), accessibility, infrastructure, and aspen condition. Recommended treatment areas in the Strawberry Creek Watershed are 2,412 acres. These treatments would be phased over a ten year period to allow the development of a variety of successional classes.

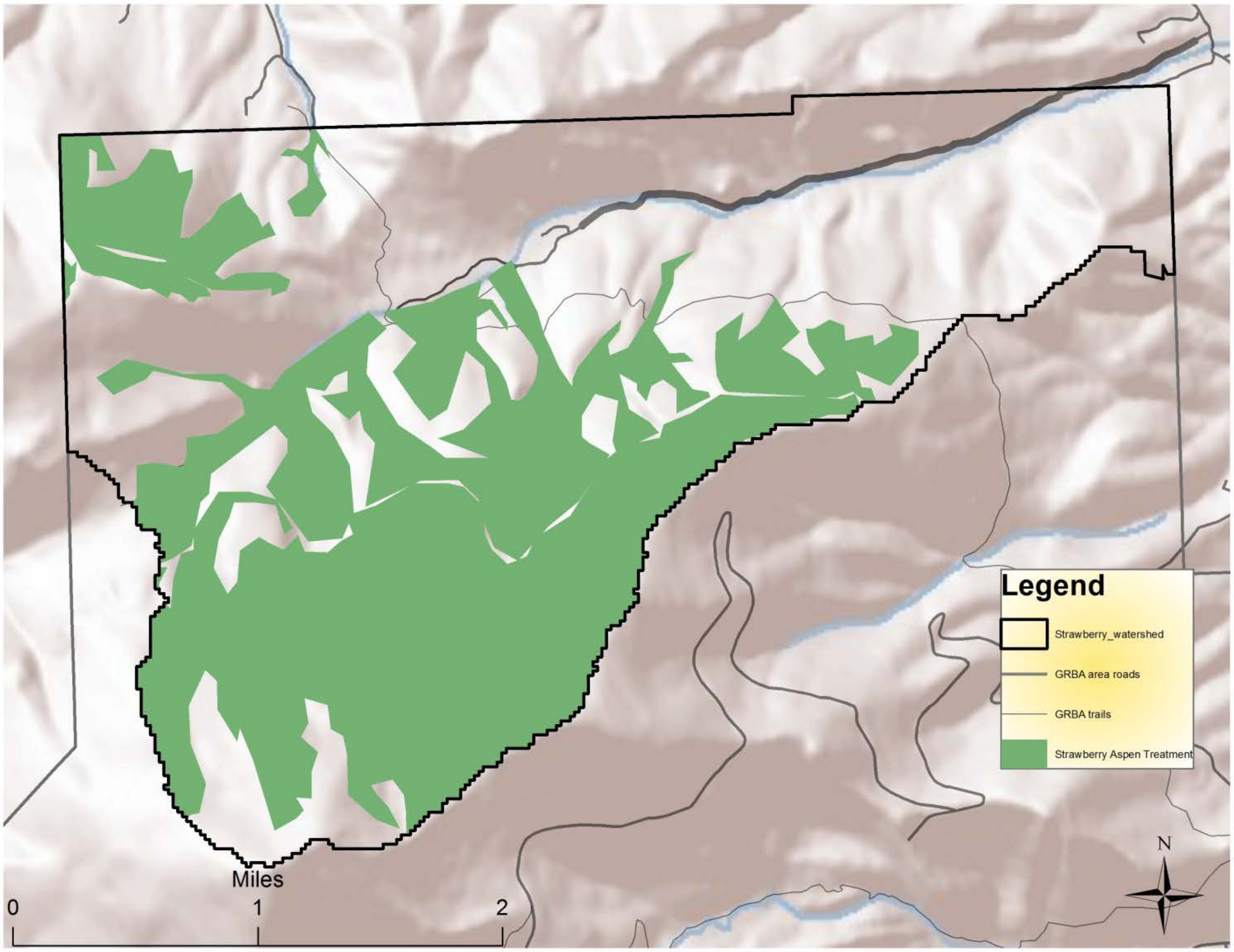

Figure 32. Recommended treatment areas for Strawberry Creek.

Lehman Creek

This watershed was chosen for treatment because its large area, high proportion of aspen (10.5% of park aspen), accessibility, infrastructure, and aspen condition. Recommended treatment areas in the Lehman Creek Watershed are 2,163 acres. These treatments would be phased over a ten year period to allow the development of a variety of successional classes.

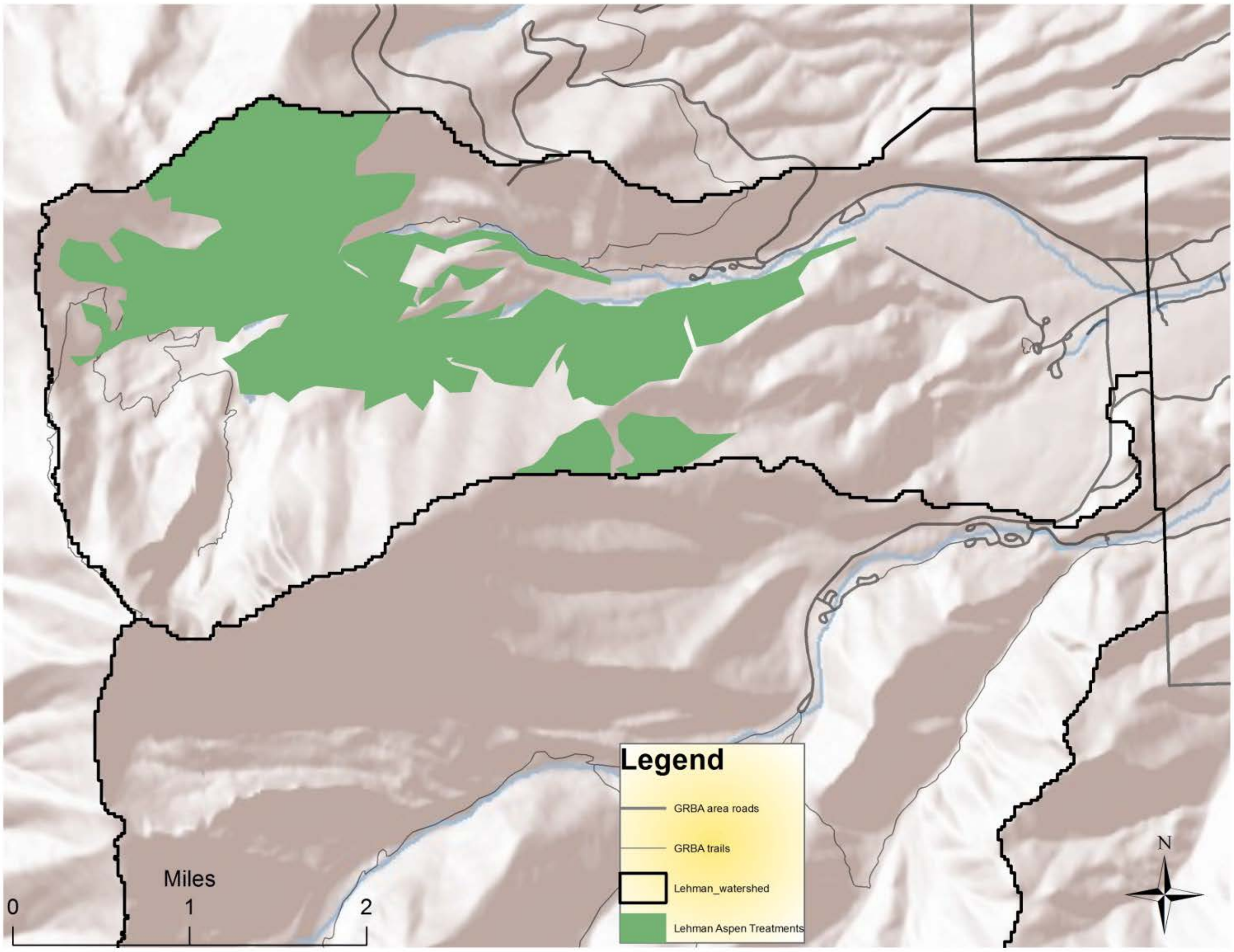

Figure 33. Lehman Creek aspen stand recommended treatment areas.

Snake Creek

This watershed was chosen for treatment because its large area, high proportion of aspen (13.9% of park aspen), accessibility, infrastructure, and aspen condition. Recommended treatment areas in the Snake Creek Watershed are 2,457 acres. These treatments would be phased over a ten year period to allow the development of a variety of successional classes.

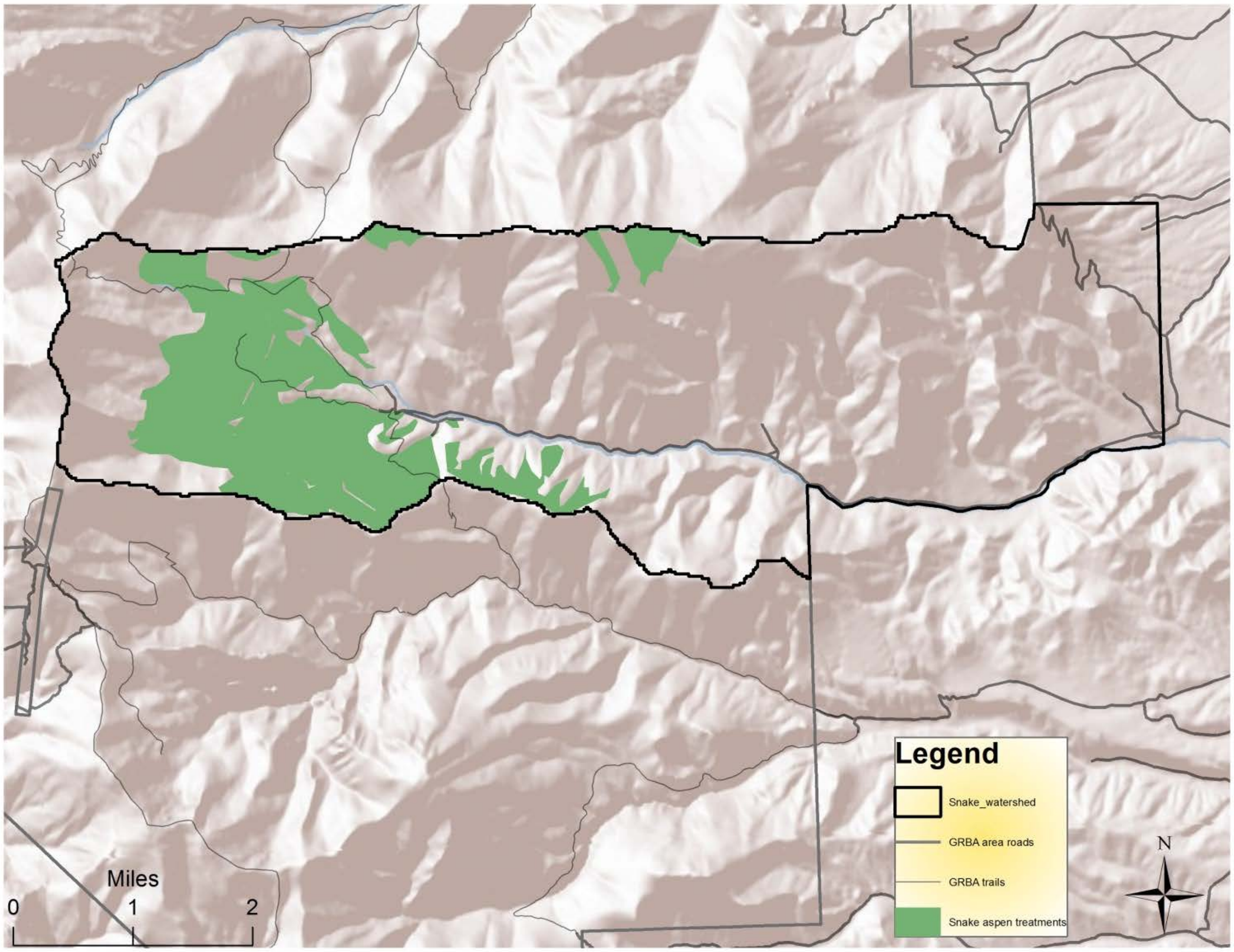

Figure 34. Snake Creek aspen stand recommended treatment areas.

West Side Watersheds

Several watersheds on the west side of the park were chosen for treatments. For simplicity, these five watersheds were grouped (Shingle, Pine/Ridge, Hub, Williams, and Dry Canyon).

These watersheds comprise 10.5% of the park (8,070 acres). 3,308 acres (40% of the five watersheds) are seral or stable aspen. The average departure score for these five watersheds was 67.7%. These watersheds were chosen for treatment because of their large area, high proportion of aspen (16.9% of park aspen), accessibility, and aspen condition. Recommended treatment areas in these watersheds are 3,341 acres. These treatments would be phased over a ten year period to allow the development of a variety of successional classes.

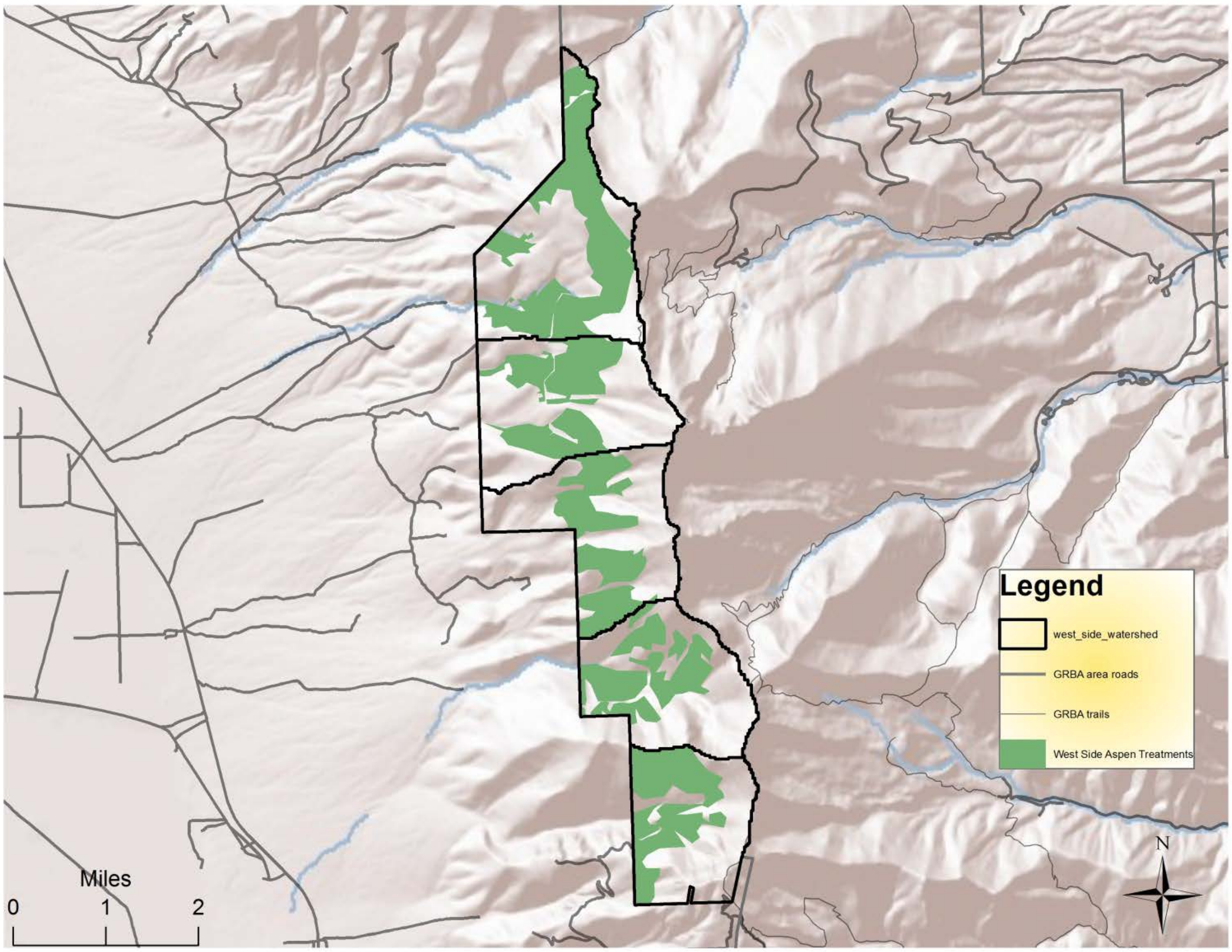

Figure 35. West Side aspen stand recommended treatment areas.

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Appendix A: Description of TNC Landscape Conservation ForecastingTM Methodology

TNC modified the Fire Regime Condition methodology (hereafter referred to as ecological departure) developed under the national LANDFIRE program to assess the project area's ecological condition. Ecological departure is an integrated, landscape-level estimate of the ecological condition of terrestrial, riparian, and wetland ecological systems. Ecological departure incorporates species composition, vegetation structure, and disturbance regimes to estimate an ecological system's departure from its natural range of variability (NRV). NRV is the percentage of each vegetation succession class that would be expected under a natural disturbance regime. Ecological departure is then measured using a scale of 0 to 100 where higher numbers indicate higher departure from NRV. In addition, since the cost and management urgency to address different uncharacteristic vegetation classes vary greatly, a separate designation and calculation of "high-risk" vegetation classes was also applied. High-risk vegetation classes include invasive species, conversions of vegetation type, or other uncharacteristic vegetation that is very expensive to restore.

Vegetation Mapping

The fundamental elements of ecological departure analysis include: 1) mapping the distribution of biophysical settings (potential ecological system) – i.e., the dominant vegetation types expected in the physical environment under a natural disturbance regime; 2) mapping current vegetation succession classes of each biophysical setting; and 3) for each biophysical setting, comparing the current vegetation class distribution with the expected "natural" distribution and calculating each system's departure from its NRV. NRV is the percentage of each vegetation succession class that would be expected under a natural disturbance regime. Ecological departure mapping with remote sensing of Great Basin National Park started during June 2009.

Remote Sensing Analysis of Biophysical Settings and Current Vegetation Classes

Spatial Solutions was contracted by TNC to conduct remote sensing analysis of the project area. TNC provided Spatial Solutions with a description of biophysical settings and assisted in remote sensing field surveys. Spatial Solutions used the software Imagine® from Leica Geosystems to conduct the unsupervised classification of QuickBird imagery (pixels are 2.4m multispectral imagery) captured on 7/1/07 for the western portion and on 6/26/07 for the eastern portion. Imagery was cloud free. The imagery was initially clipped to the park boundary, which proved to be inaccurate. One year after the initial remote sensing field work, a revised boundary was supplied by Park staff, which was buffered outwards by 100-m. Additional remote sensing and field work were completed for areas missed by the first mapping.

The unsupervised classification of the satellite imagery is described in Provencher et al. (2008, 2009a, b) and Low et al. (2010). To support interpretation of spectral classes (Lillesand and Kiefer 2000), TNC and Spatial Solutions conducted an initial field trip to establish training plots and rapid observations from July 19-25, 2009. Spatial Solutions collected formal training plots and 1,000+ geo-referenced rapid road and hiking observations. A large proportion of the project area was visited.

The field and geo-referenced road data were combined, when necessary, with the U.S. Geological Survey's Digital Elevation Model, vegetation plot data, and drainage map to create draft maps of biophysical settings and current vegetation classes. Vegetation classes could only be defined after the biophysical setting was assigned to a group of pixels. The short description of each vegetation class by biophysical setting used for remote sensing is presented in Appendix B. A draft map of biophysical settings and vegetation classes were verified and improved during a second field trip from 15-18 October, 2009. At each pre-selected field location, TNC verified the mapped biophysical setting and current vegetation class. The same verification process was conducted for "road and hiking observations." This final field trip allowed Spatial Solutions to complete the biophysical setting map and the current vegetation class map. The last iteration in the final draft map of current vegetation classes was used to calculate draft ecological departure scores. The current vegetation class map and the ecological departure score were revised after the first workshop with Park staff.

Mapping Biophysical Settings

The foundation of ecological departure mapping is the stratification of a landscape via biophysical settings, which represent potential vegetation. Preferably, biophysical settings are mapped by interpreting ecological sites from Natural Resource Conservation Service (NRCS) soil surveys to major vegetation types assuming that NRCS's soil associations do not contain too many ecological sites (USDA 2003). The NRCS defines ecological site as "a distinctive kind of land with specific physical characteristics that differs from other kinds on land in its ability to produce a distinctive kind and amount of vegetation." (National Forestry Manual, www.nrcs.usda.gov/technical/ECS/forest/2002_nfm_complete.pdf). Biophysical settings are composed of one or more ecological sites sharing the same dominant upper-layer species, whereas NRCS soil polygons generally contain several ecological sites that do not always share the same dominant upper-layer species; thus the need for splitting soil association polygons using remote sensing. The Great Basin National Park soil survey was used to first approximate associations of biophysical settings. Twenty-four biophysical settings were finally mapped to reflect the influence of geology, landforms, soils, elevation, and ecological processes (for examples, fire, flooding, insect outbreaks) (Provencher et al. 2010).

Difficulties were encountered during remote sensing. It was immediately apparent that soil association polygons a) were too large to be useful, b) contained different biophysical settings that were hard to separate because of the spectral characteristics of similar current vegetation classes, c) did not always contain biophysical settings they were supposed to have, or d) contained biophysical settings that were not in the soil association polygon. Therefore, to facilitate a more refined mapping of biophysical settings, a two-step process was used. First, those biophysical settings whose dominant upper-layer species were not prone to moderately rapid expansion or contraction due to limiting soil characteristics were mapped as representative of pre-settlement vegetation. Rules were then applied to map those biophysical settings whose dominant upper-layer species were prone to moderately rapid expansion or contraction. Aspen biophysical settings belonged to the second group with rule-based mapping.

Rule-based mapping

Other biophysical settings mapped with current, high-resolution imagery using a set of rules were:

• Aspen woodland (stable aspen) may appear smaller than its potential due to historic ungulate grazing. Decadent, open clones of aspen woodland (*Populus tremuloides*) with an uncharacteristic understory encroached by mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana*), had the same spectral classes as montane sagebrush steppe. Aspen clones are known to decrease under grazing pressure (Bartos and Campbell 1998, Debyle et al. 1987, Kay 1997, Kay 2001a, b, Mueggler 1988); therefore clones are likely smaller than they were before European settlement since the Park has been grazed for at least a century. Therefore, all visible patches of aspen were "generously" mapped (i.e., if aspen was detected, all pixels with appropriate spectral classes in the immediate area were labeled as aspen) and field observations confirmed new pixels and patches. It is highly conceivable that soils that formerly supported aspen were mapped as montane sagebrush steppe.

• Aspen-mixed conifer woodland (seral aspen) may appear smaller than its potential due to white fir or Douglas-fir dominance and historic ungulate grazing. Aspen-mixed conifer was frequently in proximity to aspen woodland patches. Any substantial evidence of white fir or Douglas-fir from saplings to larger trees revealed the aspen-mixed conifer status. The greatest difficulty was to distinguish late-succession aspen-mixed conifer from true mixed conifer. As a rule, any evidence of aspen stems dead or alive caused us to classify a pixel as aspen-mixed conifer, whereas biophysical setting was called mixed conifer if no dead down or standing aspen boles, or any aspen sprouts were observed. This type of detail cannot be seen from imagery alone. An aspen-mixed conifer pixel that had lost all aspen was technically modeled as mixed conifer (the uncharacteristic class of aspen-mixed conifer). Ground-truthing was required to distinguish both cases, which were both confirmed. Most mixed conifer patch visited were actually aspen-mixed conifer. Therefore, we might have slightly over-estimated true mixed conifer, especially in areas well covered with aspen-mixed conifer.

• Aspen-subalpine conifer woodland (subalpine seral aspen) shared many attributes with aspen-mixed conifer, with the exception being that slower conifer succession prevails in the subalpine zone. We found it easier to separate the late-succession class of aspen-subalpine conifer from true Engelmann spruce or mesic limber-bristlecone pine than for mixed conifer because the more open subalpine canopies increase the detection of aspen. Given the greater ease of mapping, we still committed many field hours to visited "pure" spruce and mesic limber-bristlecone pine to confirm the biophysical setting.

Biophysical Setting Descriptions and Natural Range of Variability (NRV)

In order to measure the current (or future) ecological condition of each ecological system, it was first necessary to define the Natural Range of Variability (NRV) per biophysical setting. NRV is the relative amount (percentage) of each vegetation class in a landscape that would be expected to occur in a biophysical setting under natural disturbance regimes and post-European settlement climate (Hann and Bunnell 2001, Provencher et al. 2007, Provencher et al. 2008, Rollins 2009).

The NRV was calculated with the state-and-transition modeling software Vegetation Dynamics Development Tool (VDDT, ESSA Technologies, Barrett 2001, Beukema et al. 2003). To determine the NRV for each ecological system in the project area, we modified models from a TNC Great Basin and Mojave Desert ecoregion library developed in northwestern Utah, eastern Nevada, and California (Forbis et al. 2006, Provencher et al. 2007, Provencher et al. 2008, Provencher et al. 2009a, b, Low et al. 2010) The NRV for each ecological system is listed in Appendix B.

Ecological departure is a broad-scale measure of biophysical setting condition – an integrated, landscape-level estimate of the ecological condition of terrestrial and wet biophysical settings. Ecological departure incorporates species composition, vegetation structure, and disturbance regimes to estimate a biophysical setting's departure from its NRV.

Technically, ecological departure is a measure of dissimilarity between the NRV (expected "natural" distribution of vegetation classes; Appendix B) and the current vegetation class distribution.

Ecological departure is scored on a scale of 0% to 100%: Zero percent represents NRV while 100% represents total departure [i.e., the higher the number, the greater the departure].

Further, a coarser-scale metric known as Fire Regime Condition Class (FRCC) is used by federal agencies to group ecological departure scores into three classes: FRCC 1 represents biophysical setting with low (<34%) departure; FRCC 2 indicates biophysical setting with moderate (34 to 66%) departure; and FRCC 3 indicates biophysical settings with high (>66%) departure (Hann et al. 2004).

Refinement of Predictive Ecological Models

Landscape conservation forecasting includes the simulation of management scenarios using state-and-transition models that include reference and management vegetation classes for each biophysical setting. A state-and-transition model is a discrete, box-and-arrow representation of the continuous variation in vegetation composition and structure of an ecological system (Bestelmeyer et al. 2004). An example of an older state-and-transition model for mountain big sagebrush from eastern Nevada is shown in Forbis et al. (2006). Different boxes in the model belong either: (a) to different states, or (b) to different phases within a state. States are formally defined in rangeland literature (Bestelmeyer et al. 2004) as: persistent vegetation and soils per potential ecological sites that can be represented in a diagram with two or more boxes (phases of the same state). Different states are separated by "thresholds." A threshold implies that substantial management action would be required to restore ecosystem structure and function. Relatively reversible changes (e.g., fire, flooding, drought, insect outbreaks, and others), unlike thresholds, operate between phases within a state.

Aspen models included disturbance inputs (e.g., fire) expressed as a rate (probability per year). Future conditions were based on estimated disturbance intervals (e.g. mean fire return interval) and potential management actions (e.g., prescribed fire). Three management scenarios – minimum management, maximum management and preferred management – were modeled for selected biophysical settings (50 year simulations). Five replicates were run for each scenario to capture variability in fire activity.

Disturbance in park aspen systems was limited to: fire, avalanches, insect/disease outbreaks, drought, native grazing, and clone loss. Natural disturbance was the same for each aspen system. Clone loss was a threat in each system due to a lack of fire or other disturbance to remove conifers. Continued dominance by conifers eventually resulted in the loss of the clone and permanent conversion of aspen to another biophysical setting (mixed-conifer or spruce). A counterintuitive but possible aspen conversion was from late-successional aspen woodland to early-succession montane sagebrush steppe-upland. The canopy in aspen woodlands in the late-succession open class can substantially open up when larger, older trees die allowing mountain big sagebrush to encroach and eventually lead to clone loss.

Models and Descriptions

At their core, all models had the LANDFIRE reference condition represented by some variation around the A-B-C-D-E succession classes (Low et al. 2010). The A-E class models typically represented succession, usually from herbaceous vegetation to increasing woody species dominance where the dominant woody vegetation might be shrubs or trees. The vegetation classes of pre-settlement vegetation described in the NRV were considered to be each biophysical setting's core reference condition. As such, the reference condition does not describe vegetation condition caused by post-settlement management or unintentional actions (e.g., release of cheatgrass).

In addition to modeling reference conditions, the predictive models included a management component to allow managers to simulate future conditions under alternative management strategies and scenarios (Low et al. 2010). The vegetation classes of all aspen systems are briefly defined in Appendix 2B. Future conditions were based on estimated disturbance intervals (e.g. mean fire return interval) and potential management actions (e.g. prescribed fire). Three management scenarios – minimum management, maximum management and preferred management – were modeled for selected biophysical settings (50 year simulations). Management strategies were rated using return-on-investment (ROI) analyses. The ROI metric was used to determine which management scenario produced the greatest ecological benefit per dollar invested. A complete description of the models (model dynamics) can be found in Provencher et al. (2010).

High-Risk Vegetation Classes

The models for most biophysical settings included uncharacteristic (U) classes. Uncharacteristic classes are classes that would not be expected under a natural disturbance regime (i.e., outside of reference conditions), such as shrublands or wet areas invaded by non-native plant species, tree-encroached shrublands, and entrenched riparian areas. Ecological departure calculations do not differentiate among the uncharacteristic classes – i.e. all uncharacteristic classes are treated equally outside of NRV. However, the cost and management urgency to restore different uncharacteristic classes varies greatly. TNC therefore recommended that ecological departure should not be the only metric used to assess future conditions (described later in this report). TNC developed a separate designation and calculation of high-risk vegetation classes in consultation with partners. A high-risk class was defined as an uncharacteristic vegetation class that met at least two of the three following criteria: (1) ≥5% cover of invasive non-native species, (2) very expensive to restore, or (3) a direct pathway to one of these classes (invaded or very expensive to restore). Park staff modified the definition of high-risk class to include the area of aspen clone lost. The loss of aspen clones causes a permanent vegetation conversion to another biophysical setting and, in retrospect, should have been single out as a third metric of ecological condition because it cannot be restored to the original aspen biophysical setting.

Reference conditions were determined for each biophysical setting based on the natural range of variability (NRV) for each vegetation class. Uncharacteristic classes were defined as those not expected under natural disturbance regimes.

Accounting for Variability in Disturbances and Climate

The basic VDDT state-and-transition models incorporate by default stochastic disturbance rates that vary around a mean value for a particular disturbance associated with each succession class for each ecological system. For example, fire is a major disturbance factor for most ecological systems, including replacement fire, mixed severity fire and surface fire. These fire regimes have different rates (i.e., mean fire return interval) that are incorporated into the models for each ecological system where they are relevant. VDDT automatically supplies variability around these rates. However, in real-world conditions the disturbance rates are likely to vary appreciably over time and more than provided by VDDT's default variability. To simulate strong yearly variability for fire activity, drought-induced mortality, non-native species invasion rates, tree encroachment rate, loss of herbaceous understory, and flooding, TNC incorporated temporal multipliers in the model run replicates.

A temporal multiplier is a number in a yearly time series that multiplies a base disturbance rate in the VDDT models: e.g., for a given year, a temporal multiplier of one implies no change in a disturbance rate, whereas a multiplier of zero is a complete suppression of the disturbance rate, and a multiplier of three triples the disturbance rate. Temporal multipliers can be obtained from data, statistical projections, mechanistic equations, and heuristic equations.

Fire Activity

Data were available for fire activity between 1980 and 2009 for the ca. 77,000-acre Great Basin National Park, and four nearby higher elevation areas. The four other areas were Mount Moriah located is the north Snake Range, two areas in the Schell Creek Range north of Highway 50 and one area south of Highway 50 again in the Schell Creek Range. Data from the Federal Fire Occurrence Website were downloaded for the whole western U.S.A. and time series of fire size from 1980 to 2006 were extracted from five "clipped" areas each the same size and shape as Great Basin National Park with ArcGIS 9.3. Five time series of fire activity were used as replicates for all scenarios. The Mount Moriah fire time series contained no data from 1980 to 1984. Time series were 29 years long; time series for 75 years were created for years 30 to 75 by re-sampling the fire series data using the yearly total area burned divided by the temporal average of total area burned. The first four years of Mount Moriah was similarly created.

Different fire temporal multipliers were used for shrubland and woodland types compared to forest types (spruce, limber-bristlecone pine, mixed conifer, and ponderosa pine). The shrubland and woodland multipliers assumed that 98% of the temporal multiplier was allocated to replacement fire, 1% to mixed severity fire, and 1% to surface fire. The forest temporal multiplier was allocated as 7% replacement fire, 45% mixed severity fire, and 48% surface fire based on the average relative importance of the different disturbance rates of fire severity in the forest models.

The 15 time series (i.e., 5 replicates × 3 fire severities) were uploaded into VDDT for shrubland-woodland temporal multipliers and another 15 for forest temporal multipliers. Each yearly value in a replicate temporal multiplier multiplied the average wildfire rate in the models for a specific time step. All replicates had several peaks of fire activity with the third replicate being the most severe. See Provencher et al. 2010.

Upland Variability

Non-fire temporal multipliers were inter-related and dependent on measurements of Snow-Water-Equivalent (SWE) from a NRCS-maintained weather station since 1980 (Bostetter, ID) close to the intersection of Nevada, Idaho, and Utah. Although this station may not be well correlated to the SWE values from Baker Creek (station #2) due to the 2005-2006 mismatch in peak snow years, the variability needed for simulations was adequate (we were not aware of Snake Range NRCS's snow course data). We assumed that rates of annual grass-invasion and exotic forb-invasion were greatest in wetter years and least in drier years. Therefore, these parameters had temporal multipliers equal to the value of SWE for a given year divided by the average SWE. Tree encroachment (Tree-Invasion parameter in the model) similarly responded to SWE, but we assumed a much slower process. The temporal multiplier for tree encroachment was, therefore, the square-root of the SWE temporal multipliers when ≥ 1, but simply 0.9×SWE temporal multiplier when it was <1. Drought, insect/disease, and understory-loss rates were all expressions of stress incurred during dry years. We assumed that drought was positively correlated to temperature and inversely correlated to SWE. We used a temperature temporal multiplier obtained from a re-sampled temperature time series (1871 to 1999) for the northern Sierra Nevada as eastern Nevada is strongly influenced by the Pacific Ocean (personal communication, Dr. M. Dettinger, USGS, 2008). The equation for drought was heuristic and somewhat complicated because we wanted the temperature temporal multiplier to modify the SWE temporal multiplier and assumed that SWE had a much greater effect than temperature on drought levels: Yearly drought temporal multiplier = 1/(TMSWE*EXP{-3.46*(MAX{1,TMtemp}-1)}), where TMSWE and TMtemp are the temporal multipliers, respectively, for SWE and temperature (Figure 3). As temperature increases, the TMSWE becomes a smaller number, and drought level increases. For years colder than average (TMtemp < 1), only SWE has an influence because the exponential function equals one due to the zero value of (MAX – 1) function. The temporal multipliers for insect/disease and loss of understory rates were equal to the drought temporal multiplier.

Appendix B: Vegetation Class Descriptions for Aspen Biophysical Settings and Reference Condition

Stable Aspen (Aspen woodland)

Class Code[1]	Class Abbreviation and description
A	*Early*; 0-100% cover of aspen <5m tall; 0-9 yrs.
B	*Mid1-closed*; 40-99% cover of aspen <5-10m; dense herbaceous and non-sagebrush shrub understory and midstory; 10-39 yrs.
C	*Late1-closed*; 40-99% cover of aspen 10-25m; few conifers in mid-story; dense herbaceous and non-sagebrush shrub understory and mid-story; >39 yrs.
D	*Late1-open*; 10-39% cover of aspen 10-25 m; 0-25% conifer cover 10-25 m; moderately dense herbaceous and non-sagebrush shrub understory and mid-story; >99 yrs.
U	*DP-Open*: 10-39% cover of older aspen 10-25m; no or little aspen regeneration; few conifers in mid-story; sparse understory and sagebrush often present
MSu-A to B	*Early & Mid1-Open*: Conversion to Montane Sagebrush Steppe-upland biophysical setting (see 1126u); 0-30% mountain big sagebrush or bitterbrush cover, 10-80% grass and forb cover.
Reference Condition: Natural Range of Variation	16%: A-Early 41%: B-Mid-closed 33%: C-Late-close 10%: D-Late-open 0%: U

Seral Aspen (Aspen-mixed conifer)

Class Code[1]	Class Abbreviation and description
A	*Early*; 0-100% cover aspen <5m; mountain snowberry and ribes common; 0-19 yrs.
B	*Mid1-closed*: 40-99% cover aspen <5-10m; mountain snowberry and ribes common; 11-39 yrs.
C	*Mid2-closed*: 40-99% cover aspen 10-24m; conifer saplings visible in mid-story; mountain snowberry and ribes common; 40-79 yrs.
D	*Late1-open*: 10-39% cover aspen 10-25 m; 0-25% mixed conifer cover 5-10 m; mountain snowberry and ribes common; >80 yrs.
E	*Late1-closed*: 40-80% cover of mixed conifer 10-50m; <40% cover of aspen 10-25m; mountain snowberry and ribes present; >100 yrs.
MC-E	*Closed*: Conversion to Mixed Conifer (1052); 35-90% cover of mixed conifers 10-49m; mountain snowberry and ribes present; conifer litter abundant
Reference Condition: Natural Range of Variation	19%: A-Early 43%: B-Mid1-Closed 24%: C-Mid2-closed 9%: D-Late-open 5%: E-Late-closed 0%: U

Seral Subalpine Aspen (Aspen-subalpine conifer)

Class Code[1]	**Class Abbreviation and description**
A	*Early*: 50-100% cover aspen <2m; mountain snowberry and ribes common; 0-9 yrs.
B	*Mid1-closed*: 40-99% cover aspen <5-10m; mountain snowberry and ribes common; 10-39 yrs.
C	*Mid2-open*: 10-30% cover aspen 10-24m; 10% cover of white fir and Engelmann spruce; mountain snowberry and ribes common; 40-169 yrs.
D	*Late1-closed*: 40-50% cover of white fir and Engelmann spruce cover 25-50m; <40% cover of aspen; mountain snowberry and ribes common; >169 yrs.
SP-D	*Late1-Closed*: Conversion to Spruce biophysical setting (1056); 40-100% cover of Engelmann spruce 25-49m; >129 yrs.
Reference Condition: Natural Range of Variation	12% A-Early 33% B-Mid-closed 47% C-Mid-open 8%: D-Late-closed 0%: U

[1]Standard LANDFIRE coding for the 5-box vegetation model: A = early-development; B = mid-development, closed; C = mid-development, open; D = late-development, open; E = late-development, closed; U = Uncharacteristic class (*DP* = depleted); MSu-A to B = conversion to montane sagebrush steppe-upland class A to B; MC-E = conversion to mixed conifer class E; and SP-D = conversion to spruce class D.

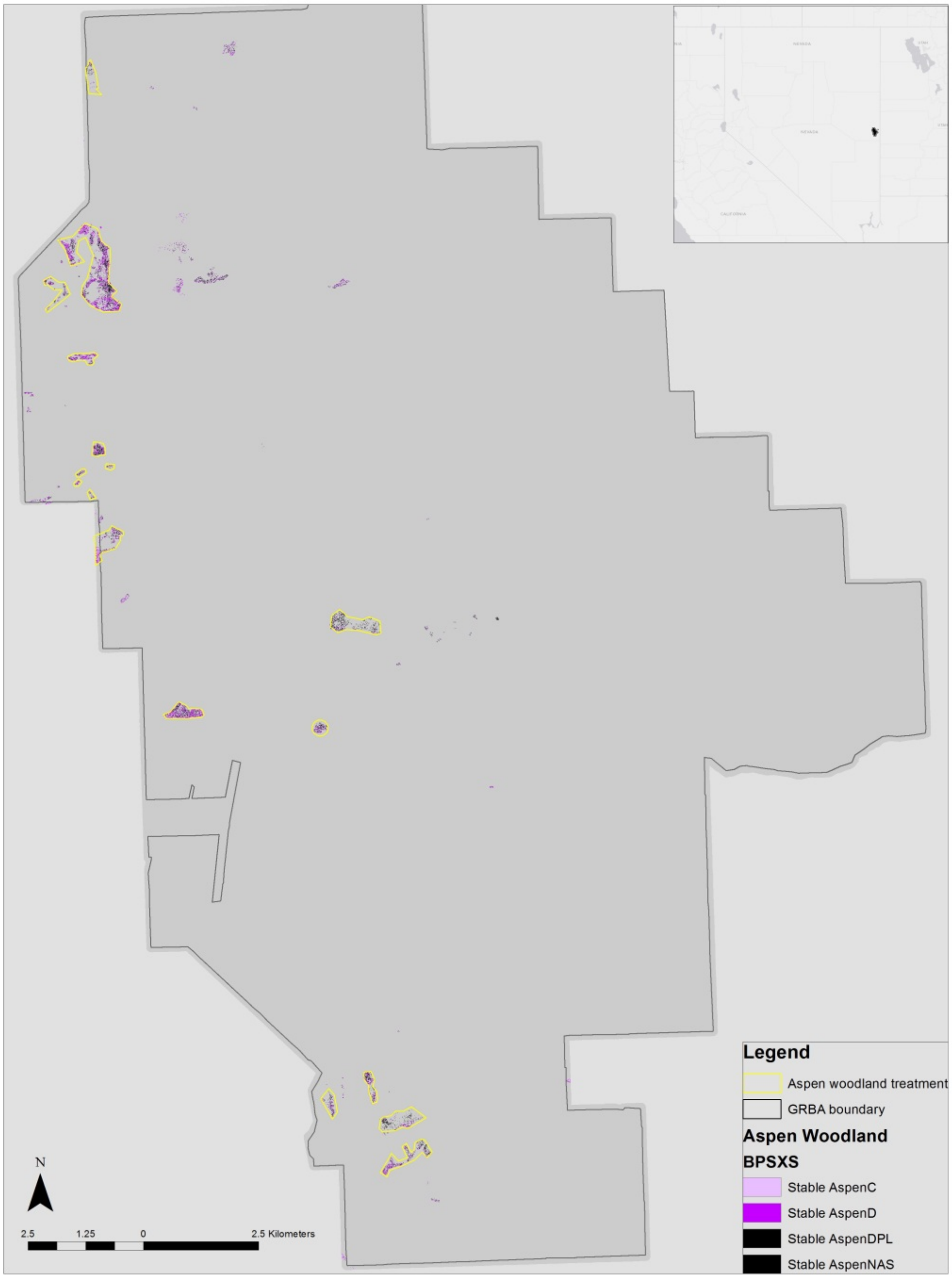
Appendix C: Regional Wildlife Species that Utilize Aspen Systems and their Conservation Status

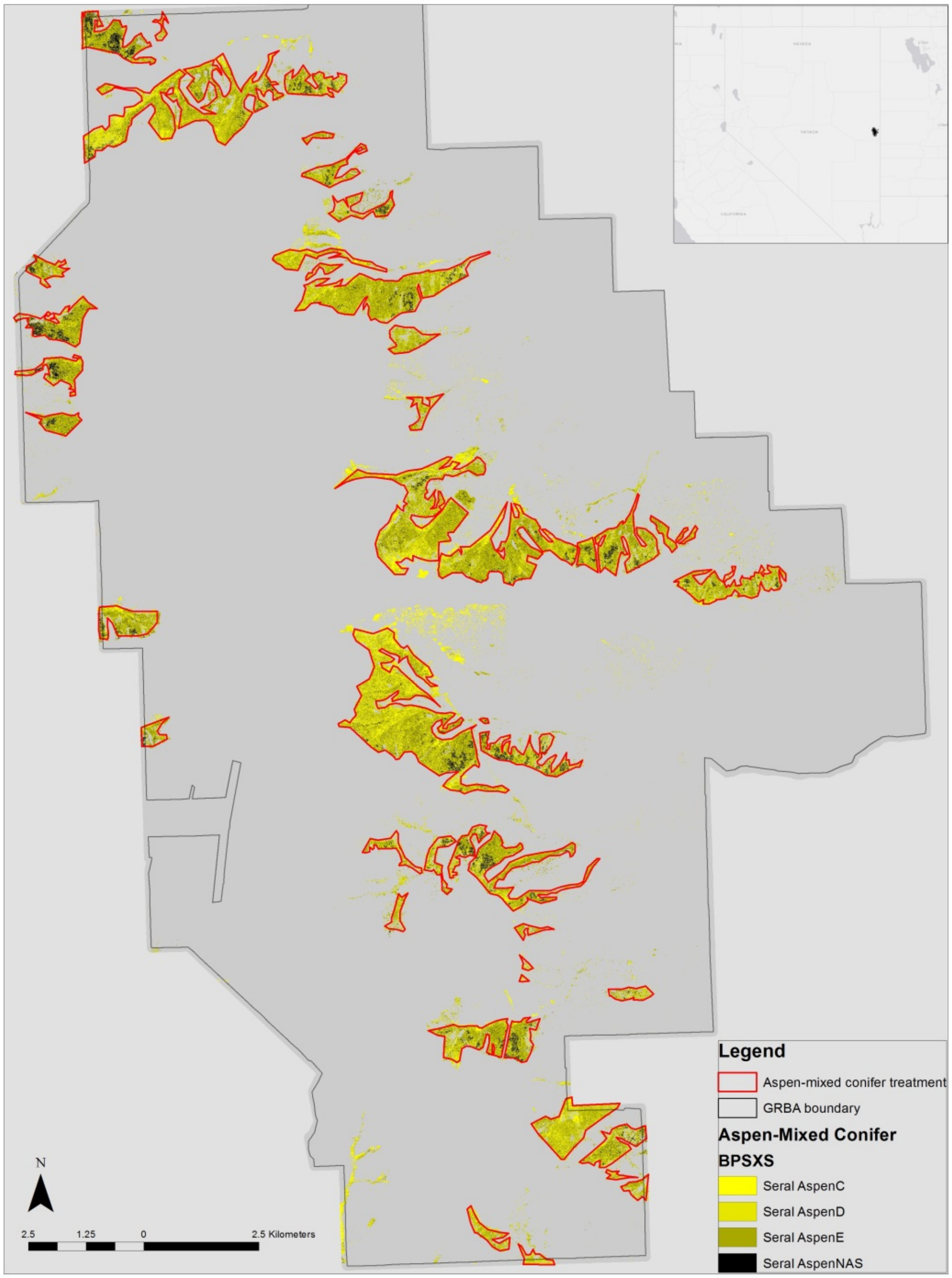
Most species are migrants and their use of aspen is transitory except for beaver, small mammals and some mesocarnivores.

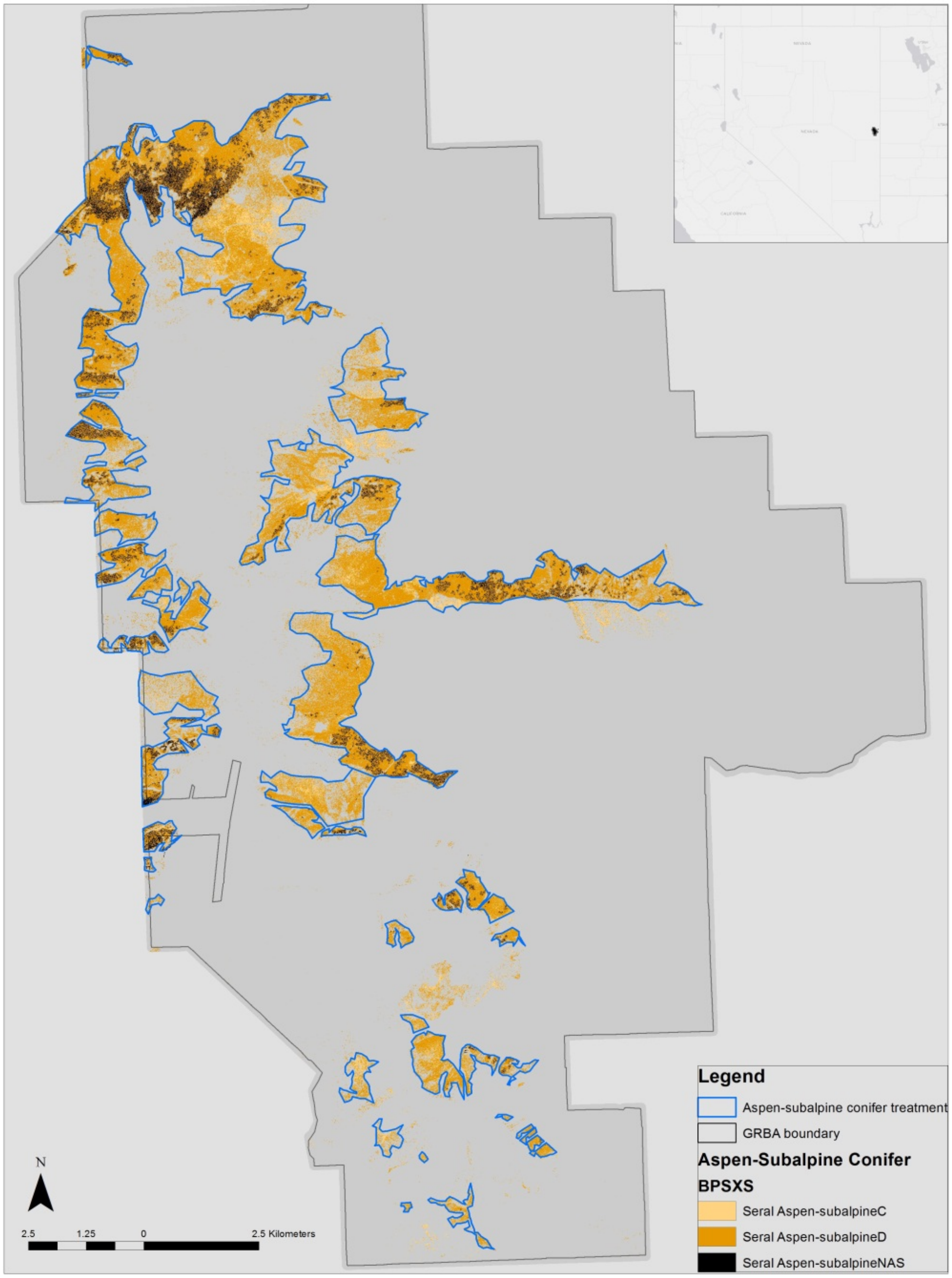
Species	Conservation Status[1]
Sooty Grouse	NV NHP Vulnerable
Flammulated Owl	NV NHP Long-term concern; USFW Bird of Conservation Concern, Migratory bird; BLM, USFS and NPS Sensitive species; NDOW Stewardship species
Rufous Hummingbird	NV NHP Vulnerable; USFWS Migratory bird; NDOW Conservation Priority
Williamson's Sapsucker	NV NHP Imperiled; USFWS Bird of Conservation Concern, Migratory bird; USFS Management indicator; NDOW Stewardship species
Greater Sage-Grouse	NV NHP Vulnerable; USFWS Candidate Species; BLM, USFS and NPS Sensitive Species; NDOW Conservation Priority
Orange-crowned Warbler	None
Red-naped Sapsucker	NV NHP Long-term concern
Dusky Grouse	NV NHP Vulnerable
Northern Goshawk	NV NHP Imperiled; USFWS Migratory bird; BLM, USFS and NPS Sensitive Species; NDOW Conservation Priority
Calliope Hummingbird	USFWS Bird of Conservation Concern, Migratory bird; NDOW Stewardship species
Lewis's Woodpecker	NV NHP Vulnerable; NPS Sensitive species
Green-tailed Towhee	USFWS Bird of Conservation Concern, Migratory species; NDOW Stewardship species
Dusky Flycatcher	None
MacGillivray's Warbler	NPS Sensitive species
Elk	None
Mule Deer	None
Porcupine	NPS Sensitive species
Beaver	NPS Sensitive species
Montane vole	None
Long-tailed vole	None
Great Basin pocket mouse	None
Harvest mouse	None
Merriam's shrew	NV NHP Vulnerable; NPS Sensitive species
Cliff chipmunk	None
Uinta chipmunk	None
Least chipmunk	None
Long-tailed weasel	NPS Sensitive Species
Ermine	NPS Sensitive Species
Striped skunk	NPS Sensitive species
Spotted skunk	NPS Sensitive species
Ringtail	NPS Sensitive species
Mountain lion	None
Gray fox	None

1NV NHP = Nevada Natural Heritage Program; USFWS = U.S. Fish and Wildlife Service; BLM = Bureau of Land Management; USFS = U.S. Forest Service; NPS = National Park Service, Great Basin National Park; NDOW = Nevada Division of Wildlife. Data from Nevada Natural Heritage Program Database (2010). Nevada Rare Species List. http://heritage.nv.gov/lists.htm and GBBO (2010). Nevada Comprehensive Bird Conservation Plan, ver. 1.0. www.gbbo.org/bird_converstion_plan.html.

Appendix D: Potential Aspen Treatment Areas and Target Vegetation Classes by Biophysical Setting




Legend
Aspen-mixed conifer treatment
GRBA boundary
Aspen-Mixed Conifer
BPSXS
Seral AspenC
Seral AspenD
Seral AspenE
Seral AspenNAS
N
2.5
1.25
0
2.5 Kilometers


Legend
Aspen-subalpine conifer treatment
GRBA boundary
Aspen-Subalpine Conifer
BPSXS
Seral Aspen-subalpineC
Seral Aspen-subalpineD
Seral Aspen-subalpineNAS
N
2.5
1.25
0
2.5 Kilometers

Appendix E: Management Scenario Descriptions*

Ecological System	Management Action	Management Action Description	From Class	To Class	Cost/Acre	Comment
Aspen-mixed conifer	Rx Fire	Prescribed fire to restore early succession classes	D, E	A	$250	
Aspen-mixed conifer	Chainsaw Thinning	Hand thin conifer trees in late succession classes	C, D, E	E to A A, D to C C to C	$800	25% from class E to class A, remainder stays in class
Aspen-subalpine conifer	Rx Fire	Prescribed fire via helicopter to restore early succession class	C, D	A	$50	80% from class D to class A, remainder stays in class D; lower cost than aspen-mixed conifer due to helicopter ignitions and natural fire breaks
Aspen woodland	No action	No treatment necessary to increase underrepresented mid-succession class	B	C	$0	Starting at 40 years, natural succession of class B to class C
Aspen woodland	Rx Fire	Prescribed fire to restore early succession class	D	A	$250	

*Provencher et al 2010.

Appendix F: Ecological Forecasts for TNC Management Scenarios

	Ecological Departure (%)			High Risk Classes						
Biophysical Setting	**Current Condition**	**Minimum Mgmt-50 yrs.**	**TNC Preferred Mgmt-50 yrs.**	**Current Condition**	**Minimum Mgmt-50 yrs.**	**TNC Preferred Mgmt-50 yrs.**	**Treated Area (Total Area)**	**Preferred Mgmt annual cost* (years of implementation)**	**Mean ROI**	**Preferred Mgmt total cost***
Seral Subalpine Aspen	60	27	11	7	20	10	8,850 (11,316)	$147,500 (3)	92	$442,500
Seral Aspen	66	33	22	6	12	8	3,250 (8,114)	$81,250 (10)	15	$812,500

*TNC simulations for management strategies were extended over 50 years altering average annual cost and average total cost for preferred management strategies: Seral subalpine aspen- $108,920 avg. annual cost and $326,755 avg. total cost (3 year implementation); Seral aspen - $82,834 avg. annual cost and $828,340 avg. total cost (10 year implementation).

Appendix G: Return-on-Investment Analyses, Ecological Departure and Conversion (clone loss) for Seral Aspen and Seral Subalpine Aspen Management Scenarios

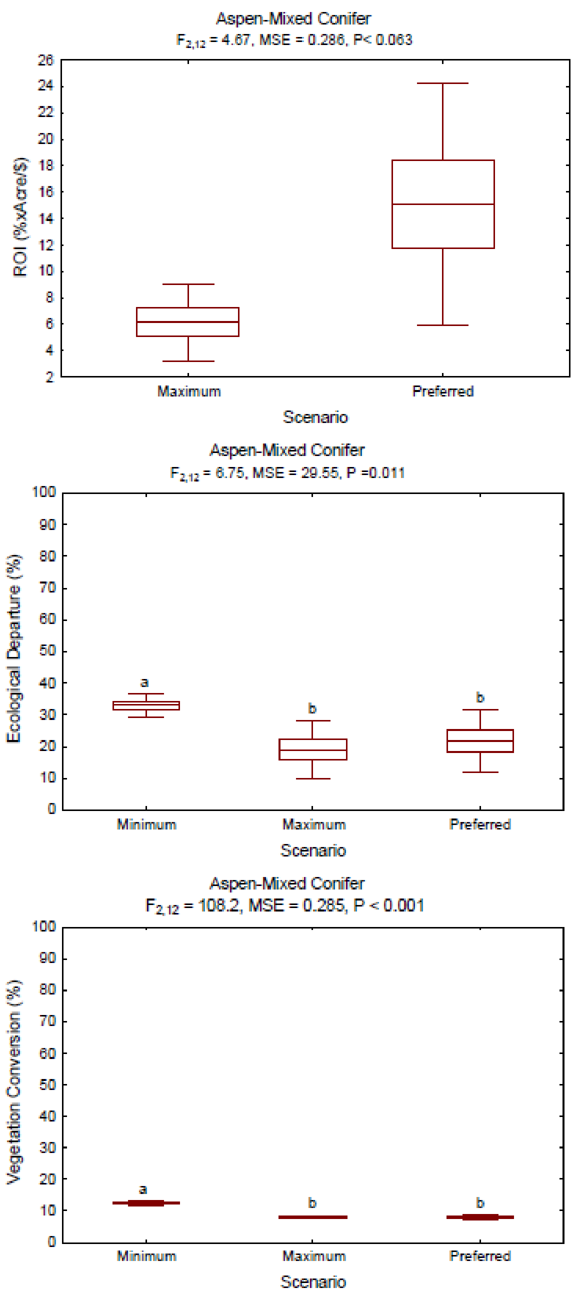


Figure 8. Return-on-Investment, ecological departure, and vegetation conversion for the Aspen-Mixed Conifer biophysical setting with Minimum, Maximum, and Preferred Management scenarios for Great Basin National Park. The Minimum Management scenario is not shown in the ROI graph because this scenario is used in the ROI calculation. Center of box is the mean, edges of box are ± 1 SE, and bars are 95% confidence interval limits. N = 5 replicates. Different letters above two different boxes indicate significantly different means. Ecological departure required transformation: .

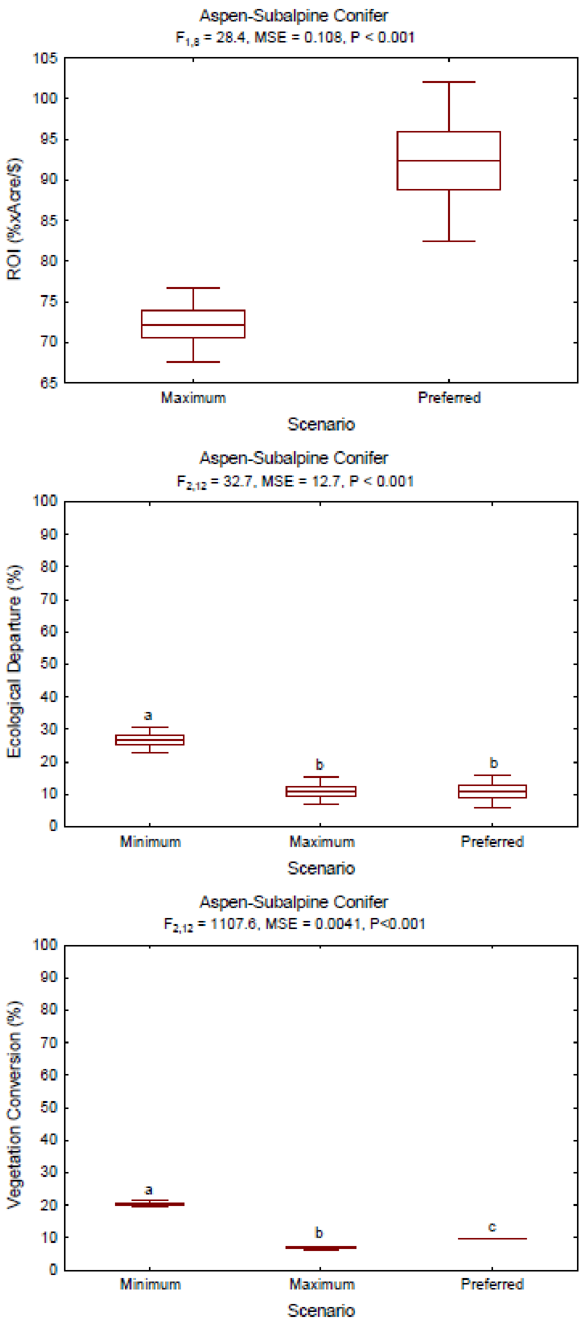


Figure 9. Return-on-Investment, ecological departure, and vegetation conversion for the Aspen-Subalpine Conifer biophysical setting with MINIMUM, MAXIMUM, and PREFERRED MANAGEMENT scenarios for Great Basin National Park. The MINIMUM MANAGEMENT scenario is not shown in the ROI graph because this scenario is used in the ROI calculation. Center of box is the mean, edges of box are ± 1 SE, and bars are 95% confidence interval limits. N = 5 replicates. Different letters above two different boxes indicate significantly different means. Vegetation conversion required transformation: (1 + vegetation conversion).

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