Landscape Conservation Forecasting™

Report to Great Basin National Park
December 2010

Photos: Southern Snake Range & Mt. Washington bristlecone grove; L. Provencher, 2009

By
Louis Provencher, Greg Low, and Tanya Anderson
The Nature Conservancy
Reno, Nevada

Table of Contents

Executive Summary 1
- Introduction 1
- Process and Methodologies 2
- Key Findings 4

Introduction 7
- Background 7
- Project Area 9
- Objectives 11

Process and Methods 11
- Vegetation Mapping 12
  - Remote Sensing Analysis of Biophysical Settings and Current Vegetation Classes 13
  - Mapping Biophysical Settings 15
  - Biophysical Setting Descriptions and Natural Range of Variability (NRV) 19
- Assessment of Current Ecological Condition – Calculating Ecological Departure 20
  - Refinement of Predictive Ecological Models 21
  - Models and Descriptions 22
  - High-Risk Vegetation Classes 22
  - Accounting for Variability in Disturbances and Climate 23
- Assessment of Future Ecological Condition – Minimum Management 27
- Assessment of Future Ecological Condition – Alternative Management Strategies 28
  - Management Strategies 29
  - Management Scenarios 30
  - Computer Simulations and Reporting Variables 31
- Return-On-Investment Analysis 31

Findings 33
- Biophysical settings 33
- Current Ecological Departure 33
- Current High-Risk Vegetation Classes 34
- Predicted Future Ecological Condition – Minimum Management 35
  - Ecological Departure 35
  - High-Risk Vegetation Classes 35
- Management Strategies and Scenarios 39
  - Introduction 39
  - Antelope Bitterbrush Biophysical Setting 40
  - Aspen-Mixed Conifer Biophysical Setting 43
  - Aspen–Subalpine Conifer Biophysical Setting 46
  - Basin Wildrye Biophysical Setting 49
  - Black Sagebrush Biophysical Setting 52
  - Limber-Bristlecone Pine-mesic Biophysical Setting 55
  - Low Sagebrush Steppe Biophysical Setting 58
  - Montane Riparian Biophysical Setting 61

Montane Sagebrush Steppe-upland Biophysical Setting 64
Wet Meadow Biophysical Setting 67
Prioritizing Actions among Biophysical Settings: Return-on-Investment 70
Recommended Treatment Areas 72
Prescribed Fire 72
Chainsaw lopping 74
Chainsaw thinning 74
Treatment combinations with seeding 77
Annual grass herbicides 80
Weed inventory 80
Conclusions 83
Acknowledgements 86
Literature Cited in Text and Appendices 87
Appendix 1. Descriptions of vegetation classes within biophysical settings for Great Basin National Park 91
Appendix 2. Description of ecological model dynamics for Great Basin National Park. 99
Introduction 99
Appendix 3. Probabilistic transitions for biophysical settings of Great Basin National Park. Output obtained from VDDT database. Legend: AB = Antelope Bitterbrush; ALP = Alpine; ASC = Aspen-Subalpine Conifer; ASM = Aspen-Mixed conifer; ASP = Aspen Woodland; BS = Black Sagebrush; BW = Basin Wildrye; LB = Limber-Bristlecone Pine; LBm = Limber-Bristlecone Pine-mesic; LSS = Low Sagebrush Steppe; MC = Mixed Conifer; MG = Montane-Subalpine Grassland; MM = Mountain Mahogany; MR = Montane Riparian; MSb = Mountain Shrub; MSm = Montane Sagebrush Steppe-mountain sites; MSu = Montane Sagebrush Steppe-upland sites; PJ = Pinyon-Juniper woodland; PP = Ponderosa Pine; RPP = Riparian Ponderosa Pine; SP = Spruce; SR = Subalpine Riparian; and WM = Wet Meadow 191
Appendix 4. Management actions and cost by biophysical settings. 218
Appendix 5. Current acres by vegetation class, natural range of variability (NRV) and ecological departure (ED) calculations for biophysical settings on Great Basin National Park. 221
Appendix 6. MINIMUM MANAGEMENT scenario areas (acre) by vegetation class for biophysical settings on Great Basin National Park. 226
Appendix 7. (A) MAXIMUM MANAGEMENT scenario strategy details (acres/years of implementation) and (B) 50-year area results (acre) by vegetation class for biophysical settings on Great Basin National Park. 229
Appendix 8. PREFERRED MANAGEMENT scenario areas (acre) by vegetation class for biophysical settings on Great Basin National Park. 233

List of Figures & Tables

FIGURE 1. GREAT BASIN NATIONAL PARK. LONGNOW'S "T"-SHAPED KEYHOLE PROPERTY LOCATED ON THE CENTRAL WESTERN SLOPE AND SURROUNDED BY PARK LAND ON THREE SIDES WAS INCLUDED IN THE ASSESSMENT. 10
TABLE 1. CHRONOLOGY OF PROJECT. 14
TABLE 2. BIOPHYSICAL SETTINGS OF GREAT BASIN NATIONAL PARK. 16
TABLE 3. THE NATURAL RANGE OF VARIABILITY FOR BIOPHYSICAL SETTINGS OF GREAT BASIN NATIONAL PARK. 20
TABLE 4. EXAMPLE OF CALCULATION OF ECOLOGICAL DEPARTURE AND FRCC. 21
FIGURE 3. FIVE REPLICATES OF TEMPORAL PROBABILITY MULTIPLIERS FOR DROUGHT, INSECT/DISEASE AND UNDERSTORY LOSS; ANNUAL GRASS AND EXOTIC FORB INVASION; AND TREE ENCROACHMENT RATES. EACH REPLICATE IS NUMBERED AND REPRESENTED BY 75-YEAR PERIOD. THE HORIZONTAL GRAY LINE FOR TEMPORAL MULTIPLIER = 1 REPRESENTS THE "NO-CHANGE" OR NEUTRAL PARAMETER LINE. 26
FIGURE 4. RIPARIAN TEMPORAL MULTIPLIERS FOR 7-YEAR, 20-YEAR, 100-YEAR FLOOD EVENTS, AND LATERAL ROAD FLOW. FOR THE 20-YEAR AND 100-YEAR FLOOD EVENTS, AND LATERAL ROAD FLOW, ALL VALUES BELOW THEIR THRESHOLD ARE ZERO. DATA OBTAINED FROM THE LAMOILLE CREEK (RUBY MOUNTAINS, NV) U.S. GEOLOGICAL SURVEY GAGE. THE HORIZONTAL GRAY LINE FOR TEMPORAL MULTIPLIER = 1 REPRESENTS THE "NO-CHANGE" OR NEUTRAL PARAMETER LINE. 27
TABLE 5. DESCRIPTIONS OF MANAGEMENT SCENARIOS FOR GREAT BASIN NATIONAL PARK. 30
TABLE 6. ECOLOGICAL DEPARTURE (%) AND PERCENT OF HIGH-RISK CLASSES OF GREAT BASIN NATIONAL PARK'S BIOPHYSICAL SETTINGS. ECOLOGICAL DEPARTURE SCORES WERE CLASSED AS GOOD (0-33%, CLASS 1, GREEN); FAIR (34-66%, CLASS 2, YELLOW); AND POOR (>66%, CLASS 3, RED). STRESS (LEVELS OF HIGH-RISK CLASSES) TO ECOLOGICAL SYSTEMS WAS RANKED AS: LOW (0%, DARK GREEN); MEDIUM (1-10%, LIGHT GREEN); HIGH (11-30%, YELLOW), AND VERY HIGH (>30%, RED). 34
FIGURE 5. BIOPHYSICAL SETTINGS OF GREAT BASIN NATIONAL PARK. 36
FIGURE 6. FIRE REGIME CONDITION CLASS (FRCC) MAP FOR GREAT BASIN NATIONAL PARK'S BIOPHYSICAL SETTINGS. 37
TABLE 7. CURRENT AND PREDICTED FUTURE (UNDER MINIMUM MANAGEMENT) ECOLOGICAL DEPARTURE AND HIGH-RISK VEGETATION CLASSES OF ECOLOGICAL SYSTEMS OF GREAT BASIN NATIONAL PARK; SYSTEMS IN BOLDFACE TYPE ARE THE 10 SELECTED FOR ACTIVE MANAGEMENT ANALYSES. ECOLOGICAL DEPARTURE SCORES WERE CLASSED AS GOOD (0-33%, CLASS 1, GREEN); FAIR (34-66%, CLASS 2, YELLOW); AND POOR (>66%, CLASS 3, RED). STRESS (LEVELS OF HIGH-RISK CLASSES) TO ECOLOGICAL SYSTEMS WAS RANKED AS: LOW (0%, DARK GREEN); MEDIUM (1-10%, LIGHT GREEN); HIGH (11-30%, YELLOW), AND VERY HIGH (>30%, RED). 38
FIGURE 7. RETURN-ON-INVESTMENT, ECOLOGICAL DEPARTURE, AND HIGH-RISK CLASSES FOR THE ANTELOPE BITTERBRUSH 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. DATA TRANSFORMATIONS WERE: AND (1 + HIGH-RISK CLASS). 42
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: . 45
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). 48
FIGURE 10. RETURN-ON-INVESTMENT, ECOLOGICAL DEPARTURE, AND HIGH-RISK CLASSES FOR THE BASIN WILDRYE 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. DATA TRANSFORMATIONS WERE: AND (HIGH-RISK CLASS). 51
FIGURE 11. RETURN-ON-INVESTMENT, ECOLOGICAL DEPARTURE, AND HIGH-RISK CLASSES FOR THE BLACK SAGEBRUSH 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: . 54
FIGURE 12. RETURN-ON-INVESTMENT, ECOLOGICAL DEPARTURE, AND HIGH-RISK CLASSES FOR THE LIMBER-BRISTLECONE PINE-MESIC 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 BARS ± 1 SE, AND BARS ARE 95% CONFIDENCE INTERVAL LIMITS. N = 5 REPLICATES. DIFFERENT LETTERS ABOVE TWO DIFFERENT BOXES INDICATE SIGNIFICANTLY DIFFERENT MEANS. 57
FIGURE 13. RETURN-ON-INVESTMENT, ECOLOGICAL DEPARTURE, AND HIGH-RISK CLASSES FOR THE LOW SAGEBRUSH STEPPE 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 BARS ± 1 SE, AND BARS ARE 95% CONFIDENCE INTERVAL LIMITS. N = 5 REPLICATES. DIFFERENT LETTERS ABOVE TWO DIFFERENT BOXES INDICATE SIGNIFICANTLY DIFFERENT MEANS. HIGH-RISK CLASS DATA REQUIRED TRANSFORMATION: LOG(1 + HIGH-RISK CLASS). 60
FIGURE 14. RETURN-ON-INVESTMENT, ECOLOGICAL DEPARTURE, AND HIGH-RISK CLASSES FOR THE LOW SAGEBRUSH STEPPE 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 BARS ± 1 SE, AND BARS ARE 95% CONFIDENCE INTERVAL LIMITS. N = 5 REPLICATES. DIFFERENT LETTERS ABOVE TWO DIFFERENT BOXES INDICATE SIGNIFICANTLY DIFFERENT MEANS. 63
FIGURE 15. RETURN-ON-INVESTMENT, ECOLOGICAL DEPARTURE, AND HIGH-RISK CLASSES FOR THE LOW SAGEBRUSH STEPPE 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 BARS ± 1 SE, AND BARS ARE 95% CONFIDENCE INTERVAL LIMITS. N = 5 REPLICATES. DIFFERENT LETTERS ABOVE TWO DIFFERENT BOXES INDICATE SIGNIFICANTLY DIFFERENT MEANS. 66
FIGURE 16. RETURN-ON-INVESTMENT, ECOLOGICAL DEPARTURE, AND HIGH-RISK CLASSES FOR THE LOW SAGEBRUSH STEPPE 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 BARS ± 1 SE, AND BARS ARE 95% CONFIDENCE INTERVAL LIMITS. N = 5 REPLICATES. DIFFERENT LETTERS ABOVE TWO DIFFERENT BOXES INDICATE SIGNIFICANTLY DIFFERENT MEANS. HIGH-RISK CLASS DATA REQUIRED TRANSFORMATION: . 69
FIGURE 18. MEDIAN ECOLOGICAL SYSTEM-WIDE RETURN ON INVESTMENT (ROI) FOR THE 10 ECOLOGICAL SYSTEMS OF GREAT BASIN NATIONAL PARK SELECTED FOR ACTIVE MANAGEMENT ANALYSES. THE LINE IN

THE BOX IS THE MEDIAN, EDGES OF THE BOX ARE THE 25% AND 75% QUARTILE, BARS ARE NON-OUTLIER RANGE, CIRCLES ARE OUTLIERS, AND * IS EXTREME VALUES. WE CHOSE THE MEDIAN'S STATISTICS BECAUSE IT CONVEYED MORE INFORMATION THAN GRAPHS BASED ON THE MEAN, WHICH ARE SHOWN IN PREVIOUS FIGURES. LEGEND: AB = ANTELOPE BITTERBRUSH, ASC = ASPEN-SUBALPINE CONIFER, ASM = ASPEN-MIXED CONIFER, BS = BLACK SAGEBRUSH, BW = BASIN WILDRYE, LBM = LIMBER-BRISTLECONE PINE-MESIC, LSS = LOW SAGEBRUSH STEPPE, MR = MONTANE RIPARIAN, MSU = MONTANE SAGEBRUSH STEPPE-UPLAND, AND WM = WET MEADOW. 70

TABLE 8. SUMMARY OF ECOLOGICAL FORECASTS FOR MANAGEMENT SCENARIOS IN 10 BIOPHYSICAL SETTING OF GREAT BASIN NATIONAL PARK ECOLOGICAL DEPARTURE SCORES WERE CLASSED AS GOOD (0-33%, CLASS 1, GREEN); FAIR (34-66%, CLASS 2, YELLOW); AND POOR (>66%, CLASS 3, RED). STRESS (LEVELS OF HIGH-RISK CLASSES) TO ECOLOGICAL SYSTEMS WAS RANKED AS: LOW (0%, DARK GREEN); MEDIUM (1-10%, LIGHT GREEN); HIGH (11-30%, YELLOW), AND VERY HIGH (>30%, RED). 71

FIGURE 19. RECOMMENDED AREAS FOR IMPLEMENTATION OF PRESCRIBED FIRE. MAP SHOWS BOTH THE COMBINATIONS OF BIOPHYSICAL SETTING AND VEGETATION CLASSES WERE PRESCRIBED FIRE APPLIED AND THE AREAS OF IMPLEMENTATION BY BIOPHYSICAL SETTING. 73

FIGURE 20. RECOMMENDED AREAS FOR IMPLEMENTATION OF CHAINSAW LOPPING. MAP SHOWS BOTH THE COMBINATIONS OF BIOPHYSICAL SETTING AND VEGETATION CLASSES WERE CHAINSAW LOPPING APPLIED AND THE AREAS OF IMPLEMENTATION BY BIOPHYSICAL SETTING. 75

FIGURE 21. RECOMMENDED AREAS FOR IMPLEMENTATION OF CHAINSAW THINNING IN THE LATE-SUCCESSION CLOSED CLASS OF ANTELOPE BITTERBRUSH BIOPHYSICAL SETTING. 76

FIGURE 22. RECOMMENDED AREAS FOR IMPLEMENTATION OF VARIOUS TREATMENTS REQUIRING NATIVE SPECIES SEEDING. MAP SHOWS BOTH THE COMBINATIONS OF BIOPHYSICAL SETTING AND VEGETATION CLASSES WERE TREATMENTS APPLIED AND THE AREAS OF IMPLEMENTATION BY BIOPHYSICAL SETTING. 78

FIGURE 23. RECOMMENDED AREAS FOR IMPLEMENTATION OF VARIOUS TREATMENTS REQUIRING NATIVE SPECIES SEEDING. MAP SHOWS BOTH THE COMBINATIONS OF BIOPHYSICAL SETTING AND VEGETATION CLASSES WERE TREATMENTS APPLIED AND THE AREAS OF IMPLEMENTATION BY BIOPHYSICAL SETTING. 79

FIGURE 24. ALTERNATIVE AREAS FOR HERBICIDE APPLICATION TO CONTROL ANNUAL GRASSES IN THE ANTELOPE BITTERBRUSH AND MONTANE SAGEBRUSH STEPPE-UPLAND BIOPHYSICAL SETTINGS IN THE SHRUB WITH A MIXED UNDERSTORY OF ANNUAL AND PERENNIAL GRASSES. 81

FIGURE 25. ALTERNATIVE AREAS FOR EXOTIC FORB INVENTORY IN THE BASIN WILDRYE, MONTANE RIPARIAN, AND WET MEADOW BIOPHYSICAL SETTINGS. CURRENTLY, THE WHOLE BIOPHYSICAL SETTINGS WERE PROPOSED FOR INVENTORY. 82

Executive Summary

Introduction

In 2009, Great Basin National Park (Park) and The Nature Conservancy (TNC) entered into a Cooperative Agreement to collaborate on fire and vegetation management issues at the Park. In 2010, the Cooperative Agreement was amended to incorporate climate change effects and adaptation strategies into the development of management strategies. A supplemental report addressing climate change will be delivered independently of this report. TNC applied Landscape Conservation Forecasting -- including satellite imagery, remote sensing, predictive ecological models, and cost-benefit assessments (Provencher et al. 2008, 2009a; Low et al. 2010) -- to accomplish the Agreement's objectives. Several workshops were held during 2010 with the Park's natural resource managers to review and refine ecological models, review findings, and identify and explore potential vegetation management scenarios. Workshops included one session via WebEx conference, one modeling workshop, and two multi-day planning workshops at the Park offices in Baker.

Objectives for Great Basin National Park Ecological Assessment

- ✓ Develop high-resolution maps of the Park's ecological systems using satellite imagery & interpretation.
- ✓ Determine current condition of all ecological systems in the Park, using Fire Regime Condition Class (FRCC) metrics.
- ✓ Refine and use ecological models to forecast anticipated future condition with minimum management.
- ✓ Use ecological models to forecast anticipated future condition with alternative management strategies.
- ✓ Forecast future conditions with anticipated climate change.
- ✓ Use Return-on-Investment analysis to assess which strategies for which ecological systems yield the most advantageous results.
- ✓ Use GIS analysis to help determine and map recommended treatment areas.

Great Basin National Park is a mostly unfragmented landscape that includes a wide diversity of Great Basin ecological systems in the Snake Range and adjoining valleys, ranging from desert shrublands, subalpine bristlecone pines, and alpine. A privately owned "T-shaped" parcel intrudes into the central western border of the Park to form the "Keyhole", which was included in the project assessment area thanks to private funding. The cooperative agreement reflects the mutual desire of the Park, TNC and other stakeholders to conserve and restore the area.

Process and Methodologies

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.

TNC completed the following tasks that were reviewed at the workshops with the Park's natural resource managers:

- Worked with Spatial Solutions, Inc. to obtain high-resolution satellite imagery, ground-truth the imagery via two field surveys, and conduct remote sensing to interpret and map current ecological systems and their succession classes across the project area.
- Refined ecological models for each ecological system, using reference and management models initially developed by staff from Great Basin National Park, the Bureau of Land Management, U.S. Forest Service, Utah Partners for Conservation and Development, and TNC. These models incorporated vegetation composition, structural classes and disturbance regimes to predict the natural range of succession classes.
- Mapped the project area's biophysical settings (the dominant vegetation types expected in the physical environment under a natural disturbance regime or the *potential* ecological system).
- For each biophysical setting, compared current vegetation class distributions with the biophysical setting and calculated each system's departure from its NRV. Each biophysical setting was assigned an ecological departure score (0% to 100% departure from NRV) and an associated Fire Regime Condition Class (1, 2 or 3) rating.
- Identified which biophysical settings are likely to suffer future impairment over the next 50 years, based on computer simulations using the predictive ecological models.

At the March 2010 workshop, the Park's natural resources managers confirmed a set of key conservation and restoration objectives for the area, as follows:

Conservation and Restoration Objectives

- Maintain Park resources unimpaired and prevent future degradation of native biophysical settings and wildlife.
- Restore currently degraded biophysical settings to their natural range of variability across the landscape (or achieve an "acceptable" range if NRV is not feasible).
- Reduce and prevent expansion of high-risk vegetation classes (e.g., exotic species) and vegetation conversions.
- Reduce fuel loads to help protect human settlements and cultural resources in and around the park from wildfire.
- Provide science-based information to park managers to use in management documents; vegetation management, fire management and other plans; and funding proposals.

Ten focal biophysical settings were selected for active treatment, based upon their high departure from NRV, likelihood of high future departure and/or presence of high-risk vegetation classes. These included important, rare or highly valued vegetation types to the Park, including high values to wildlife. A number of other systems were not selected for active management because their forecasted condition improved with minimum management. The ten focal systems for active management included:

Montane sagebrush steppe (≤9500 ft)	12,720 acres
Aspen-subalpine conifer	11,320 acres
Aspen-mixed conifer	8,120 acres
Limber-Bristlecone pine – mesic	4,500 acres
Black sagebrush	1,880 acres
Montane riparian	440 acres
Low sagebrush steppe	420 acres
Antelope bitterbrush	340 acres
Basin wildrye	280 acres
Wet meadow	90 acres

At and between workshops, management strategies were explored to achieve the objectives for these focal biophysical settings. Predictive state-and-transition computer models were used to simulate conditions under alternative future management scenarios. Using computer-based models, the likely future condition of the twelve focal biophysical settings was assessed after 50 years under three primary scenarios:

(1) MINIMUM MANAGEMENT – e.g., no treatment of invasive species, no prescribed fire.

(2) MAXIMUM MANAGEMENT – management treatments to restore ecological condition to the greatest possible degree, regardless of budget.

(3) PREFERRED MANAGEMENT – management strategies identified by workshop participants as feasible to implement to improve ecological condition at reduced cost or relatively low investment.

Return on investment was calculated to compare ecological benefits to costs, both *within* and *across* biophysical settings. Maps were developed to show potential treatment areas for each recommended strategy for each focal biophysical setting. The Park's natural resource managers may select final strategies or treatment areas based upon a variety of additional factors, such as availability of financial resources, policy constraints, and non-ecological objectives.

Key Findings

The primary findings of the ecological assessment are summarized as follows:

1. **Most biophysical settings are only slightly or moderately departed from their natural range of variability.** Of the area's 21 biophysical settings that were measured, nine are slightly departed from NRV, ten are moderately departed, and only two smaller systems are highly departed. Accordingly, virtually the entire Park falls within Ecological Departure Class (a.k.a., Fire Regime Condition Class) 1 or 2.
2. **The primary cause of ecological departure across the landscape is due to sagebrush systems which lack the earliest succession classes and aspen-conifer systems which are over-represented by late succession classes.** For example, montane sagebrush steppe below ~9500 feet elevation comprises almost 13,000 acres, approximately 17% of the project area. There is virtually no presence of the early succession classes; moreover, conifer tree species have encroached upon a large portion of the native sagebrush. In the aspen-subalpine conifer, approximately 11,000 acres, over 60% of the system is in the late-closed succession class, as compared to a targeted 8% late-closed under natural conditions.
3. **Two small systems (antelope bitterbrush and basin wildrye) are highly departed from NRV, primarily due to the presence of cheatgrass and conifer encroachment.**
4. **High-risk vegetation classes are projected to increase substantially in several systems without active management.** Computer simulations show the two aspen-conifer systems are both projected to lose aspen clones in their current late-closed vegetation classes; exotic forbs will invade basin wildrye, riparian, and wet meadow systems; and annual grasses will increase in most shrubland systems.
5. **Ten biophysical settings were chosen for specific management.** The key ecological management issues include:
    - ***Sagebrush systems (montane sagebrush-upland, black sagebrush, low sagebrush steppe, antelope bitterbrush, basin wildrye)*** – lack of early succession classes, pinyon-juniper encroachment, and increasing cover of cheatgrass.

- ***Aspen-conifer systems (aspen-subalpine conifer and aspen-mixed conifer)*** -- high percentage of conversion to conifers and permanent loss of aspen clones.
- ***Mesic limber-bristlecone pine*** – high percentage of late-succession classes at the expense of mostly mid-succession forests.
- ***Riparian, wet meadow, and basin wildrye systems*** – invasion by exotic forbs.

6. **A variety of strategies were modeled for each biophysical setting targeted for management. Multiple strategies are required for most ecosystems;**
   - ***Sagebrush*** management strategies include: prescribed fire to restore early succession classes; chainsaw lopping of encroached conifer trees; chainsaw thinning of late succession classes or tree-encroached sagebrush, variously combined with chipping, mastication, pile burning, herbicide and/or seeding of native species; and varied applications of herbicide and/or native seeding to uncharacteristic vegetation classes.
   - ***Aspen-conifer*** management strategies include prescribed fire to prevent transition to conifers and loss of aspen clone.
   - ***The mesic limber-bristlecone pine*** forest management strategy includes prescribed fire to reduce the area of late-succession classes and increase those of early and mid-succession classes.
   - ***Riparian and wet meadow*** management strategies include cyclic weed inventory and spot application of herbicides.
7. **Eleven biophysical settings were not targeted for active management in the Park because they are projected to benefit from periodic wildfires: curl-leaf mountain mahogany, pinyon-juniper woodland, spruce, limber-bristlecone pine, montane sagebrush steppe-mountain sites, mixed conifer, aspen woodland, montane-subalpine grassland, ponderosa pine, riparian ponderosa pine, mountain shrub, and subalpine riparian.** With the exception of alpine, fire is present to different degrees in all biophysical settings of the Snake Range. The 11 biophysical settings with no or few uncharacteristic classes benefitted enough from simulated fire as to not require further management to achieve low ecological departure. Simulated fire, although beneficial to ecological condition, was not enough for the remaining 10 biophysical settings with high levels of ecological departure or uncharacteristic classes.
8. **The computer simulations captured five different wildfire patterns over a 50 year period, with varying outcomes; however, in all cases the introduction of prescribed fire in early years additionally had beneficial ecological effect for the targeted biophysical settings.** For an aspen-subalpine conifer simulation, one “replicate” created a total of 4,500 acres of wildfire over 50 years in the 11,300 acre system, based on two years where very large fires occurred after decades of fire suppression. Another replicate had about half as much total wildfire, only 2,300 acres. One replicate had more frequent fire years. Two replicates had large fires in later years (Year 47), thereby producing a larger percentage of the early succession class. However, with prescribed fire introduced in the first three years, all replicates had more wildfire in subsequent years and generated low ecological departure (FRCC 1) after 50 years.

9. **The Preferred Management scenarios achieved lower ecological departure (seven in FRCC 1 and three at the lower end of FRCC 2) for all ten focal biophysical settings -- as compared to current condition and/or minimum management scenarios. Moreover, the preferred management strategies reduced or contained high-risk vegetation classes for all 10 biophysical settings.**

10. **Most preferred management strategies were implemented over a three-year up-front period, but achieved long term (50 year) results.** The time horizon for implementing strategies varied by biophysical setting and treatment, but the large majority of preferred treatments were for three years, with a few for a period of five or ten years. Only weed inventory and exotic species control treatments required ongoing implementation over a 50 year time horizon.

11. **The Preferred Management scenario significantly accrued the highest return-on-investment (ROI) for five biophysical settings, as compared to the Maximum Management scenario.** For the five other biophysical settings, the average ROI of the Preferred Management scenario was higher but not statistically different from the ROI of the Maximum Management scenario. The Preferred Management scenario was still chosen because its budget was the smallest. However, in many cases the Maximum Management scenarios would achieve even greater ecological benefits, particularly in reducing high-risk vegetation classes, if additional management funds were to become available.

12. **TNC's ROI analysis showed that across the ten biophysical settings, the greatest predicted ecological benefits per dollar invested would equally accrue to Aspen-Subalpine Conifer and Limber-Bristlecone Pine-mesic.** All other biophysical settings shared comparable ROIs, although Low Sagebrush Steppe achieved the lowest one.

13. **Maps of recommended burn areas revealed economies of scale for prescribed fire in the subalpine zone.** The Aspen-Subalpine Conifer and Limber-Bristlecone pine-mesic biophysical settings can be recipient of prescribed fire ignited in the adjacent and lower elevation polygons of Aspen-Mixed Conifer biophysical setting.

14. **Maps of recommended treatment areas in the lower elevations revealed that the same areas can be recipient of mutually exclusive treatments.** Many treatments using alone or in combination prescribed fire, mechanical methods, herbicide application, and native species seeding overlapped on the eastern boundary of the Park and were mutually exclusive, such as the application of fire to an area with cheatgrass and late-succession reference classes. Overlap of different recommended treatment areas was caused by the proximity of pixels from very different vegetation classes. Therefore, Park staff would be required to choose a strategy best meeting management objectives and causing the least damaging outcome.

Introduction

In 2009, Great Basin National Park (Park) and The Nature Conservancy (TNC) entered into a Cooperative Agreement to collaborate on fire and vegetation management issues at the Park. The objectives were to (1) map potential and current vegetation, and determine the condition of ecological systems expressed as ecological departure from reference conditions and fire regime condition classes and (2) guide the development of specific, cost-effective fire and vegetation management strategies to maintain, enhance or restore the condition of the Park's ecological systems. In 2010, the Cooperative Agreement was amended to incorporate climate change effects and adaptation strategies into the development of management strategies. A supplemental report addressing climate change will be delivered independently of this report.

TNC applied Landscape Conservation Forecasting—including satellite imagery, remote sensing, predictive ecological models, and cost-benefit assessments (Provencher et al. 2008, 2009a; Low et al. 2010)—to accomplish Agreement's objectives. Several workshops were held during 2010 with the Park's natural resource managers to review and refine ecological models, review findings, and identify and explore potential vegetation management scenarios. Workshops included one session via WebEx conference, one modeling workshop, and two multi-day planning workshops at the Park offices in Baker, Nevada.

Background

The mission of the National Park Service (NPS) is "...to promote and regulate the use of the...national parks...which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (National Park Service Organic Act, 16 U.S.C.1.**)**.

The Park supports a diversity of ecological systems – alpine, forests, woodlands, shrublands, smaller herbaceous meadows, and riparian areas – along the steep elevation gradient of the Snake Range. TNC identified the Snake Range-Spring Valley area as a Great Basin ecoregional priority landscape (Nachlinger et al. 2001), due to the diversity of vegetation types and high occurrence of endemic species. With the exception of NPS roads, buildings, and visitor amenities, the Park is undeveloped and topography is rugged. Prior to the Park's creation in 1896, however, the southern Snake Range experienced U. S. Forest Service multiple land uses, water developments, and fire suppression management. Traditional livestock grazing persisted until 1999 when grazing permits were retired from the Park, except for one sheep allotment on the north western slope. This last allotment was closed in 2006 with the passage of the White Pine County Conservation, Recreation, and Development Act (Public Law 109-432). As a consequence, many ecological systems in the Park have vegetation and fuels that are degraded to various degrees compared to pre-settlement or more natural conditions.

The Park is typical of higher elevations of the Intermountain West where rangelands have undergone unprecedented change over the last 150 years (Blackburn and Tueller 1970; Tausch et al. 1993; National Research Council 1994; Tausch and Nowak 1999; McPherson and Weltzin 2000; Anderson and Inouye 2001; Young and Sparks 2002). Prior to settlement, the grasslands and shrublands of the arid West were structured primarily by fire, precipitation cycles, and insects, with grazing ungulates playing a role whose importance varied regionally. However, these roles have changed; domestic livestock now graze a large majority of both private and public lands in western North America, and wildfire occurs at times, frequencies, and intensities that are outside of pre-settlement ranges (Blackburn and Tueller 1970; Brown and McDonald 1995; Schmidt et al. 2002; West et al. 2002; Beever et al. 2003). Longer fire-free intervals, the long-term historic consumption of fine fuels by livestock, and aggressive policies of fire-suppression starting in the 1920s (Pyne 2004) have favored the expansion of woody species throughout grasslands and shrublands that historically supported few trees, even in areas that have had livestock use removed for decades (Miller and Rose 1999; Tausch and Nowak 1999; Curtin and Brown 2001; Pyne 2004).

While longer fire-free intervals have favored woody species, the regional invasion of cheatgrass (*Bromus tectorum* L.) has shortened fire-free intervals. Cheatgrass, a non-native annual grass, increased dramatically after historic livestock use reduced native bunchgrasses and forbs (Young et al. 1987; Young and Sparks 2002). In the Park, annual grasses are mostly found at the lower elevations and up into the montane zone. Because native plant species do not survive the frequent fires facilitated by cheatgrass (Young et al. 1987), do not compete successfully against cheatgrass for soil moisture (Melgoza et al. 1990), and some do not disperse as effectively, systems can move toward a cheatgrass monoculture nearly devoid of biodiversity, habitat, and economic values. Cheatgrass control, even for the purpose of restoring native species, may face obstacles because it is best achieved by the application of herbicides.

By virtue of being water sources for wildlife and livestock, the Park's riparian habitats have an importance that is proportionally far greater than their small aggregate size. Over the years, many concentrated land uses in these narrow corridors have led to issues such as water diversions, channel down-cutting, lowered water tables, altered understory species composition, invasion by upland conifers (pinyon and juniper), and introduction and spread of aggressive invasive weeds (Chambers and Miller, eds. 2004).

Public agencies responsible for range management have responded to the major ecological changes of the Intermountain West and, accordingly, stakeholders have strongly supported or opposed traditional land management practice and proposed restoration actions (Fleischner 1994; Brown and McDonald 1995; Brussard et al. 1994; Wuerthner and Matteson 2002; Freilich et al. 2003). Stakeholders may disagree with public rangeland management because they share different values about land uses or because there is historic distrust of public land management. Therefore, bringing stakeholders together and in-depth examination of land management values has been described as a first step towards effectively managing and conserving natural resources through community-based conservation (Margoluis and Salafsky 1998; Groves and The Nature Conservancy 2003). Adaptive management theory proposes that stakeholders may quantify and partially resolve their beliefs about land management by comparing the effects of alternative management actions on whole ecosystems using simple, yet robust experimental design procedures (Walters and Holling 1990; Wilhere 2002). Because the space, investment, and time frame required to carry out an experiment can be large, modeling of alternative management actions is often recommended prior to experimentation, if only to discard ineffective actions and document beliefs about system function (Hilborn et al. 1995; Hardesty et al. 2000; Forbis et al. 2006). Managers also may not have the time or funding to wait several years for experimental results, therefore, modeling provides more immediate recommendations. One type of modeling, the state-and-transition models (Horn 1975; Westoby et al. 1989; McIver and Starr 2001; Bestelmeyer et al. 2004) are increasingly popular in natural resource management because their discrete representations of vegetation dynamics simplify ecological complexity and can be developed in cooperation with specialists and lay-people.

Thus, the Park's lands with its legacy of many past decades of meeting multiple-use needs of people, coupled with on-going modified disturbance regimes, now provide opportunities to improve the ecological resilience and reduce detrimental effects of wildfire to human structures and ecological systems with uncharacteristic fuel accumulation. This Landscape Conservation Forecasting project aims to build a good foundation for this to happen.

Project Area

The Park is located on the southern Snake Range in White Pine County close to the Utah Border (Figure 1). The Park is about 77,000 acres mostly found above the 12 inch precipitation zone. Great Basin National Park is a mostly unfragmented landscape that includes a wide diversity of Great Basin ecosystems in the Snake Range and adjoining valleys, ranging from desert upland shrublands, subalpine bristlecone pines, and alpine. A privately owned "T-shaped" parcel intrudes into the central western border of the Park to form the "Keyhole", which was included in the project assessment area thanks to private funding. The northern portion situated north of Mount Washington is generally composed of quartzite, whereas the southern portion is dominated by carbonate rocks 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. The area contains multiple terrestrial and aquatic ecological systems, some uncommon to rare in the Great Basin, 21 limited or endemic plant species, 7 limited or endemic invertebrate species, 3 limited or endemic mollusk species, 3 limited or endemic fish species, 6 tracked bird species, and 7 declining or geographically limited mammal species (Nachlinger et al. 2001).

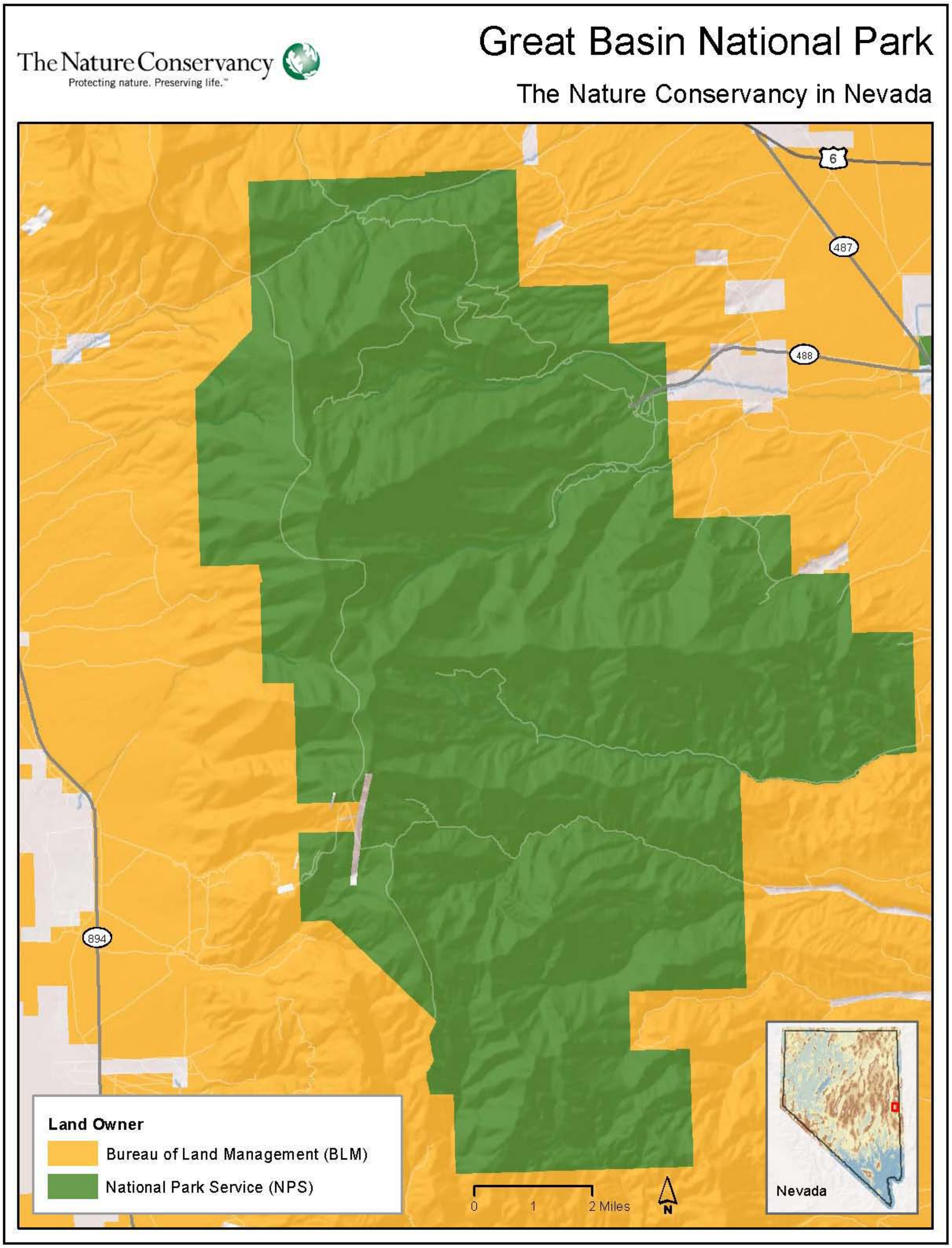


Figure 1. Great Basin National Park. LongNow's "T"-shaped Keyhole property located on the central western slope and surrounded by Park land on three sides was included in the assessment.

Objectives

Key objectives for the Park's Landscape Conservation Forecasting project identified by project participants were as follows:

- Map potential and current vegetation, and ecological condition as expressed by ecological departure from reference condition and FRCC.
- Maintain overall condition and prevent deterioration of the Park's native ecological systems.
- Restore degraded ecological systems to their reference condition or an "acceptable" condition if achieving the reference condition is not feasible.
- Reduce and prevent expansion of non-native species and uncharacteristic vegetation classes that are potentially expensive to restore to more natural classes.
- Treat Wildland-Urban Interface (WUI) areas and reduce fuel loads to help protect human settlements and cultural resources in and around the project area from wildfire.
- Help NPS meet objectives specified in management plans.

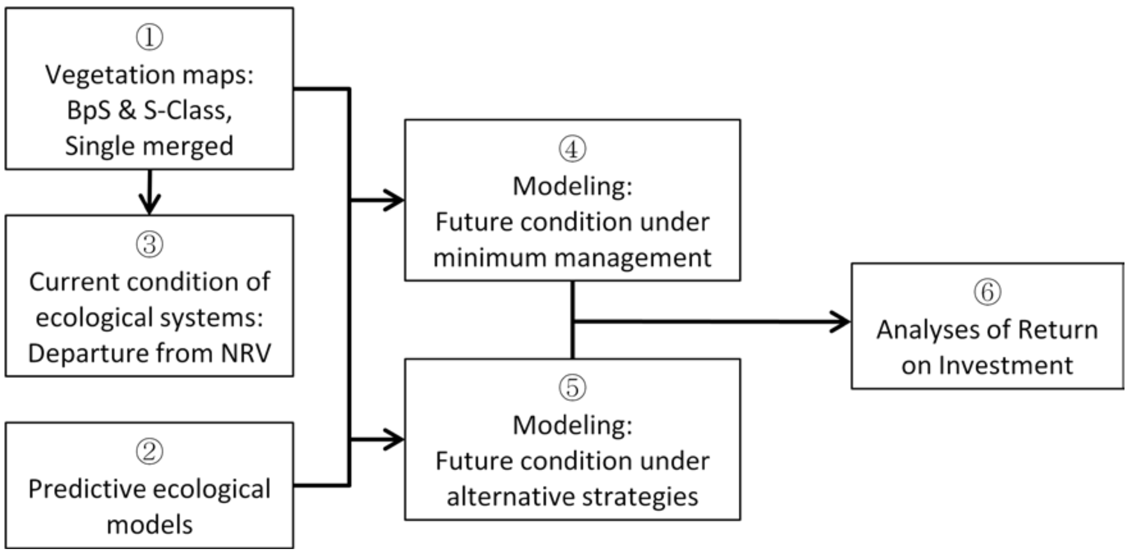
Process and Methods

The Landscape Conservation Forecasting process used for the Park consisted of six primary components or steps, as follows:

1. Develop maps of potential vegetation types, called biophysical settings or synonymously ecological systems, and current vegetation classes within biophysical settings by conducting remote sensing of satellite imagery.
2. Refine computerized predictive state-and-transition ecological models for the ecological systems by updating TNC's Great Basin "library" of models.
3. Determine current condition of all ecological systems (a broad-scale measure of their "health"), using the ecological departure (a.k.a., Fire Regime Condition or FRC) metric and FRCC. Departure was measured by comparing the current condition of vegetation and the Natural Range of Variability (NRV), which represents the reference condition (defined later).
4. Use the computerized ecological models to forecast anticipated future condition of ecological systems under minimum management to quantify future threats.
5. Use the computerized ecological models to forecast anticipated future condition of ecological systems under alternative management strategies.

6. Use Return-on-Investment analysis to assess which strategies for which ecological systems yield the most advantageous results.

A simple schematic diagram that displays the relationship of these components to each other is presented below:



In terms of project chronology, the majority of the remote sensing was conducted during the 2009 growing season and planning started in 2010. On three occasions, late March, early June, and mid-September 2010, workshops were held among TNC, Park staff, and, during the first workshop, Bureau of Land Management staff. A rough timeline of the work done on the project's components is presented in Table 1.

Detailed descriptions of methods used in each of the project's component six steps are presented in the subsections that follow.

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) 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.

Table 1. Chronology of project.

	May-Jul 2009	Jul 2009	Aug-Oct 2009	Oct 2009	Nov 2009-Mar 2010	Workshop 1 Mar 22-24	Apr-Jun 2010	Modeling workshop 3-4 Jun 2010	Jun-Jul 2010	Jul-Sep 2010	Workshop 2 15-16 Sep 2010	Oct 2010	Internet Seminar Nov 2010	Nov 2010	Dec 2010
		2009									2010				
Remote sensing: mapping						Major Review		Observe & Comment			Observe & Comment				
Remote sensing: field work															
Predictive ecological models						Major Review		Major Review			Observe & Comment				
Current condition of ecological systems						Major Review					Observe & Comment				
Modeling: future condition min mgmt						Observe & Comment					Observe & Comment				
Modeling: future condition alt strategies											Major Evaluation				
Return-on-Investment analyses											Observe				
Report preparation															

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 1. 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. 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) (Table 2).

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.

Table 2. Biophysical settings of Great Basin National Park.

Biophysical Setting	Acres	% of project area
Mountain Mahogany	14,053	19.2%
Montane Sagebrush Steppe-upland	12,711	17.3%
Aspen-Subalpine Conifer	11,316	15.4%
Aspen-Mixed Conifer	8,114	11.1%
Pinyon-Juniper Woodland	6,947	9.5%
Spruce	5,768	7.9%
Limber-Bristlecone Pine-mesic	4,502	6.1%
Limber-Bristlecone Pine	1,991	2.7%
Black Sagebrush	1,877	2.6%
Alpine	1,689	2.3%
Montane Sagebrush Steppe-mountain	943	1.3%
Mixed Conifer	594	0.8%
Aspen Woodland	567	0.8%
Montane Riparian	452	0.6%
Low Sagebrush Steppe	422	0.6%
Antelope Bitterbrush	336	0.5%
Montane-Subalpine Grassland	271	0.4%
Basin Wildrye	268	0.4%
Ponderosa Pine	253	0.3%
Riparian Ponderosa Pine	171	0.2%
Wet Meadow	87	0.1%
Mountain Shrub	19	0.0%
Subalpine Riparian	1	0.0%

Group 1: Readily mapped biophysical settings

Biophysical settings that were edaphically controlled and not prone to decadal area change were alpine, low sagebrush (*Artemisia arbuscula*), curl-leaf mountain mahogany (*Cercocarpus ledifolius* var. *intermontanus*), limber-bristlecone pines (dry and mesic), montane-subalpine grassland, and wet meadows.

- Alpine vegetation was treeless and obvious. One mapping difficulty was the separation of the highest elevation of montane sagebrush steppe-mountain sites — essentially dwarf mountain big sagebrush — from alpine shrubs. Both biophysical settings blended into one another. We set a maximum elevation boundary of 10,500 to 11,000 ft depending on location for montane sagebrush steppe-mountain above which the biophysical setting was alpine (assuming no trees).

- Low sagebrush is the only sagebrush that survives on a claypan that perches the water table for extended periods during the spring (USDA-NRCS 2003). Therefore, the presence of sagebrush today was an excellent predictor of this species' dominance during the long process of soil formation. Also, low sagebrush was limited to two general areas in the Park: Horse Heaven and the northern portion of the western slope. This criterion made the separation of low and mountain big sagebrush possible.

- Curl-leaf mountain mahogany woodland is similarly dependent on a few soil types (USDA-NRCS 2003). Because this species is slow-growing and long-lived (>500 years lifespan), it could be reliably mapped as potential vegetation wherever found (Arno and Wilson 1986; Schultz et al. 1996; Ross 1999;

- Limber and bristlecone pines were found in two types: the dry type with ancient trees and the mesic type forming denser forests of old but not ancient trees. The dry type found on rocky substrate exposed to wind at high elevations was open and very distinct. The mesic type blended into the mixed conifer and late-succession aspen-mixed conifer biophysical setting at lower elevation. Although tree crowns were distinct among these types on the imagery, we devoted additional field surveys to the transition zone to confirm our interpretation.

- Montane-subalpine grasslands are localized in the Park, found on distinct geology at subalpine elevation, and appear resistant to tree encroachment. After visiting a major occurrence on the Wheeler Peak Trail, mapping on all other patches became straightforward.

- Wet meadows stood out as very distinct in the infra-red of QuickBird imagery due to the dominance of graminoids on wet soils (i.e., high concentration of chlorophyll). The Park's meadows do not have water diversions and show clear spectral signatures and sharp boundaries.

Group 2: 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, 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.

- We used a 9,400 ft boundary to separate the uplands sites (below 9,400 ft) from the mountain sites (≥9,400 ft) of montane sagebrush steppe based on our experience and soil surveys from Ward Mountain near Ely. With a few rare exceptions, cheatgrass is not found in mountain sites where sufficient moisture favors perennial grasses. Also, mixed and subalpine conifers replace pinyon and juniper as encroaching conifers. USGS Digital Elevation Models were used to draw the boundary, which was adjusted with local observations.

- Black sagebrush, montane sagebrush steppe (mountain and upland), antelope bitterbrush, and mountain shrub *may appear smaller than their potential* because of pinyon and juniper expansion accelerated by fire exclusion. The following delineations were used to describe tree-encroached shrublands: a) trees were conical, therefore less than 150 years old; b) the understory contained several skeletons of dead sagebrush; and c) the herbaceous understory was absent or very reduced. Furthermore, the mountain shrub community was more distinctive in the infra-red spectrum of satellite imagery than purer sagebrush communities and found in localized patches. There was a lot of spectral variation, however, in the types of mountain shrub communities detected. Pinyon and juniper cover were not a problem for detection;

- Basin wildrye was strictly associated with deep fine soils in loamy bottoms, which are dry and level sub-irrigated wash or creek bottoms. Although basin wildrye (*Leymus cinereus*) was frequently absent from valley bottoms, basin big sagebrush (*Artemisia tridentata* spp. *tridentata*), mountain big sagebrush, and rabbitbrush (*Chrysothamnus nauseosus*, *Chrysothamnus viscidiflorus*) dominated these sites with obvious fine soil. Pinyon and juniper encroachment was present in some locations along valley slopes, but the contact point between the slope and the bottom was an adequate boundary to map loamy bottoms;

- Pinyon-juniper woodland *that may appear larger than its potential* due to the same expansion process. True pinyon-juniper woodlands occurred on rocky, thin, clearly unproductive soils, or on slopes >30%. Old trees with large trunk diameters were generally common. An exception to the rule was the occasional case where montane sagebrush steppe was found on slopes between 30-35%. Another exception was the occasional case where old trees were found growing on very rocky soils on <20% slopes;

- Montane-subalpine riparian *may appear smaller than their potential* because of hydrologic changes including entrenchment precipitated by road proximity, water diversion, and historic livestock use. The montane section of Snake Creek is a good example of all of these problems. Montane-subalpine riparian corridors that harbored perennial water where distinct and relatively easy to map. The southern portion of the Park dominated by carbonate rocks contained many dry riparian areas supporting vigorous riparian shrubs and trees. There was no evidence that these areas were more prone to pinyon and juniper encroachment or degradation; and

- Ponderosa pine was found in two forms: riparian and upland. Riparian ponderosa pine was more difficult to detect than anticipated because of heavy encroachment by white fir and Douglas-fir and historic logging of ponderosa pine. The late-succession class of the montane riparian biophysical setting allows for mixed conifer dominance, which is spectrally similar to sparse ponderosa pine encroached with dense mixed conifers. Good examples were found in Shingle Creek (west side) and Pole Creek (east side). Additional field surveys and map assessment by Park staff were devoted to locating riparian ponderosa pine. Once a location was suggested for mapping, the larger crowns of ponderosa pine were identified and short creek sections between scattered ponderosa pine were mapped as riparian ponderosa pine, and not montane-subalpine riparian. Upland ponderosa pine was very patchy and more visible when mixed conifers were few. Mapping could be very difficult in areas that were historically logged and only a few ponderosa pines remained. There is no doubt that we under-estimated the ponderosa pine biophysical setting; however, it is impossible to reconstruct this biophysical setting without a historical land use analysis to reveal locations where ponderosa pine was present but is completely absent today.

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 below in Table 3.

Table 3. The Natural Range of Variability for biophysical settings of Great Basin National Park.

	NRV					
Biophysical Setting	**A[1]**	**B**	**C**	**D**	**E**	**U**
Alpine	1	99				
Antelope Bitterbrush	21	44	21	7	7	0
Aspen Woodland	16	41	33	10		0
Aspen-Mixed Conifer	19	43	24	9	5	0
Aspen-Subalpine Conifer	12	33	47	8		0
Basin Wildrye	18	63	19			0
Black Sagebrush	17	47	24	10	2	0
Limber-Bristlecone Pine	9	12	78			0
Limber-Bristlecone Pine-moist	17	47	36			0
Low Sagebrush Steppe	25	56	19			0
Mixed Conifer	11	19	24	23	23	0
Montane Riparian	21	36	43			0
Montane Sagebrush Steppe-mountain	21	44	22	10	3	0
Montane Sagebrush Steppe-upland	21	44	22	10	3	0
Montane-Subalpine Grassland	4	30	66			0
Mountain Mahogany	8	13	15	23	41	0
Mountain Shrub	7	23	41	29		0
Pinyon-Juniper Woodland	2	6	26	65		0
Ponderosa Pine	11	2	29	57	1	0
Riparian Ponderosa Pine	26	9	47	17	1	0
Spruce	18	36	2	43		0
Subalpine Riparian	13	58	29			0
Wet Meadow	5	38	58			0

[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; and U = uncharacteristic. This terminology was often modified (Appendix 1).

Assessment of Current Ecological Condition – Calculating Ecological Departure

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; Table 3) 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). An example of ecological departure and corresponding FRCC is shown in Table 4.

Table 4. Example of calculation of Ecological Departure and FRCC.

	Current Vegetation Class[1]						
	A	B	C	D	E	U	Total
Natural range of variability (%)	20	50	15	10	5	0	100
Current acres by class in project area	182	7,950	58,718	6,659	264	46,123	119,894
Current presence of classes (%)	0.2	6.6	49.0	5.6	0.2	37.4	
Ecological Departure (%)[2] (a.k.a. Fire Regime Condition)	0.2	6.6	15	5.6	0.2	0	72.4
Ecological Departure Class[3] (a.k.a. Fire Regime Condition Class)							3

1. Legend modified from LANDFIRE: A = early-development; B = mid-development, open; C = mid-development, closed; D = late-development, open; E = late-development, closed; and U = uncharacteristic.
2. Ecological Departure (ED) = $100\% - \sum_{i=1}^{n} \min\{Current_i, NRV_i\}$
3. Ecological Departure Class: 1 for 0% ≤ ED ≤ 33%; 2 for 34% ≤ ED ≤ 66%; 3 for 67% ≤ ED ≤ 100%.

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.

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 (see Table 3). 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 ecological systems are briefly defined in Appendix 1. A complete description of the models (model dynamics) is found in Appendix 2, and model parameter values (probabilistic transitions) are shown in Appendix 3.

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.

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 ARC GIS 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 (Figure 2).

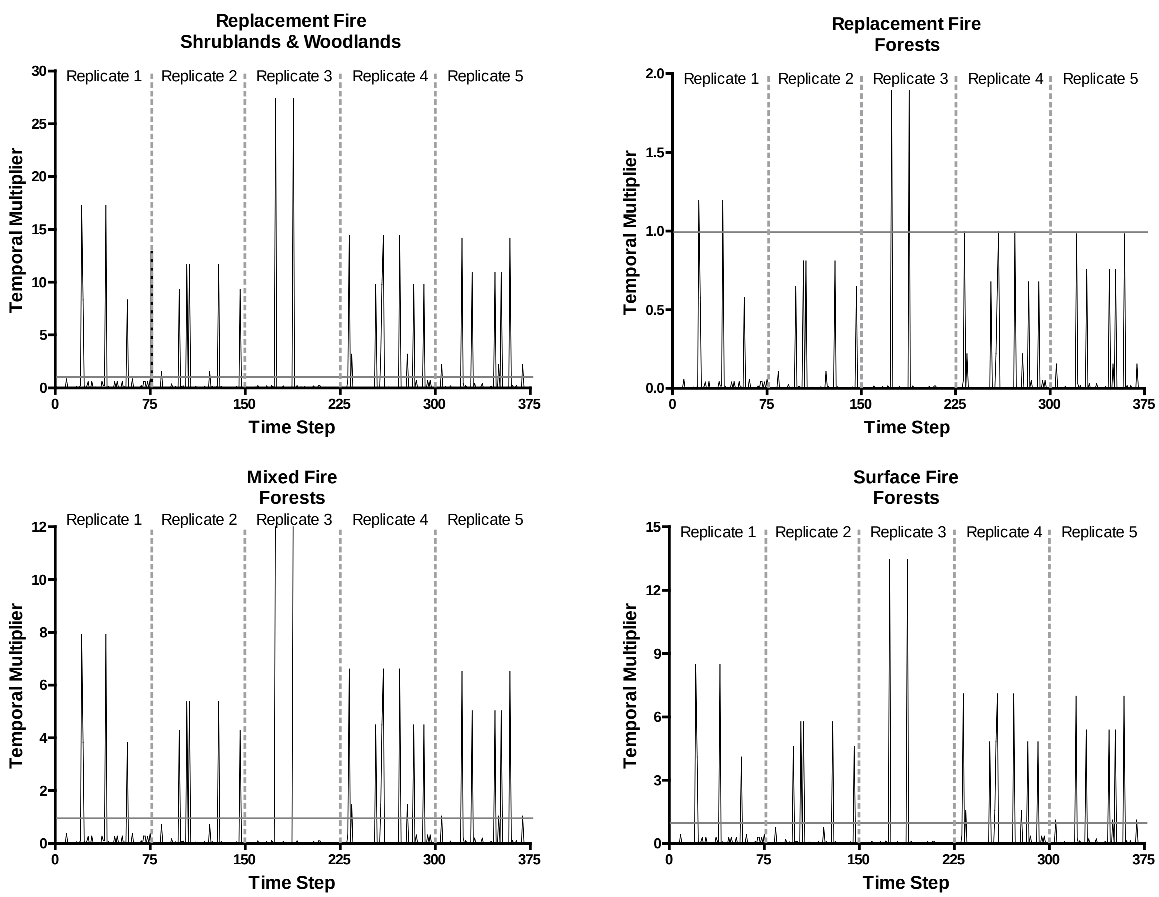


Figure 2. Five replicates of temporal probability multipliers for fire activity. Each replicate is numbered and represented by 75-year period. The horizontal gray line for temporal multiplier = 1 represents the “no-change” or neutral parameter line.

Upland Variability

The additional temporal multipliers in Figure 3 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 (Figure 3). 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:

$$\text{Yearly drought temporal multiplier} = 1/(TM_{SWE} * EXP^{\{-3.46*(MAX\{1, TM_{temp}\}-1)\}}),$$

where TM_{SWE} and TM_{temp} are the temporal multipliers, respectively, for SWE and temperature (Figure 3). As temperature increases, the TM_{SWE} becomes a smaller number, and drought level increases. For years colder than average ($TM_{temp} < 1$), 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.

Riparian Variability

Montane-subalpine riparian systems were strongly dependent on flow variation for flood events. We did not have at our disposal longer term gage data from the Park because time series from different creeks have no data from 1955 to 1993 (the Lehman Creek gage data starts in 1948); however, we used gage data from Lamoille Creek as the USGS had showed that the Lehman and Baker Creeks were very highly correlated to Lamoille Creek (Elliot et al. 2006: http://pubs.usgs.gov/sir/2006/5099/section3.html). We used these temporal multipliers to introduce strong variability to the riparian systems realizing that actual local gage data would provide a different pattern of variability. Variability of the 7-year, 20-year, and 100-year flood events are all based on filtering for increasingly higher values of annual peak flow. The 7-year flood events encompass the full time series of peak flow divided by the temporal average (Figure 4). The temporal multiplier for lateral flow from roads was equated with 25-year flood events (Figure 4).

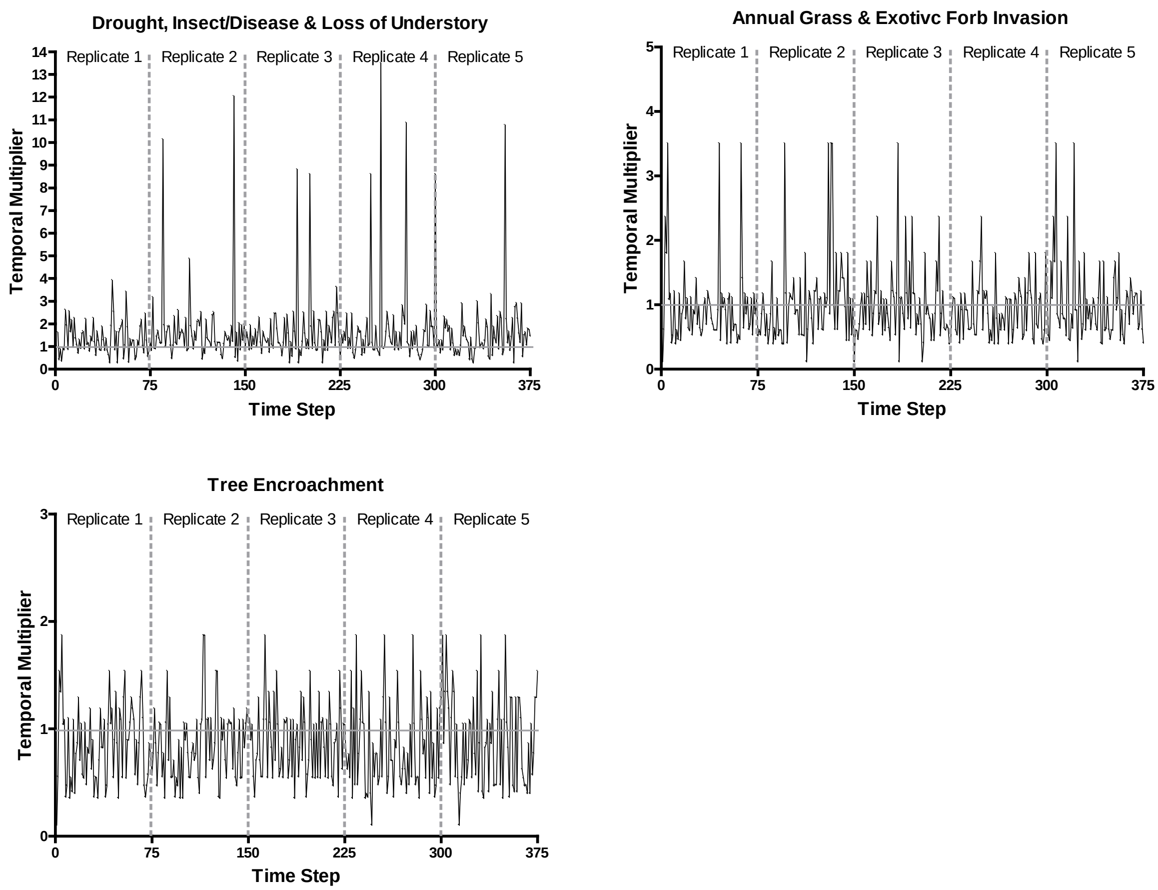


Figure 3. Five replicates of temporal probability multipliers for drought, insect/disease and understory loss; annual grass and exotic forb invasion; and tree encroachment rates. Each replicate is numbered and represented by 75-year period. The horizontal gray line for temporal multiplier = 1 represents the "no-change" or neutral parameter line.

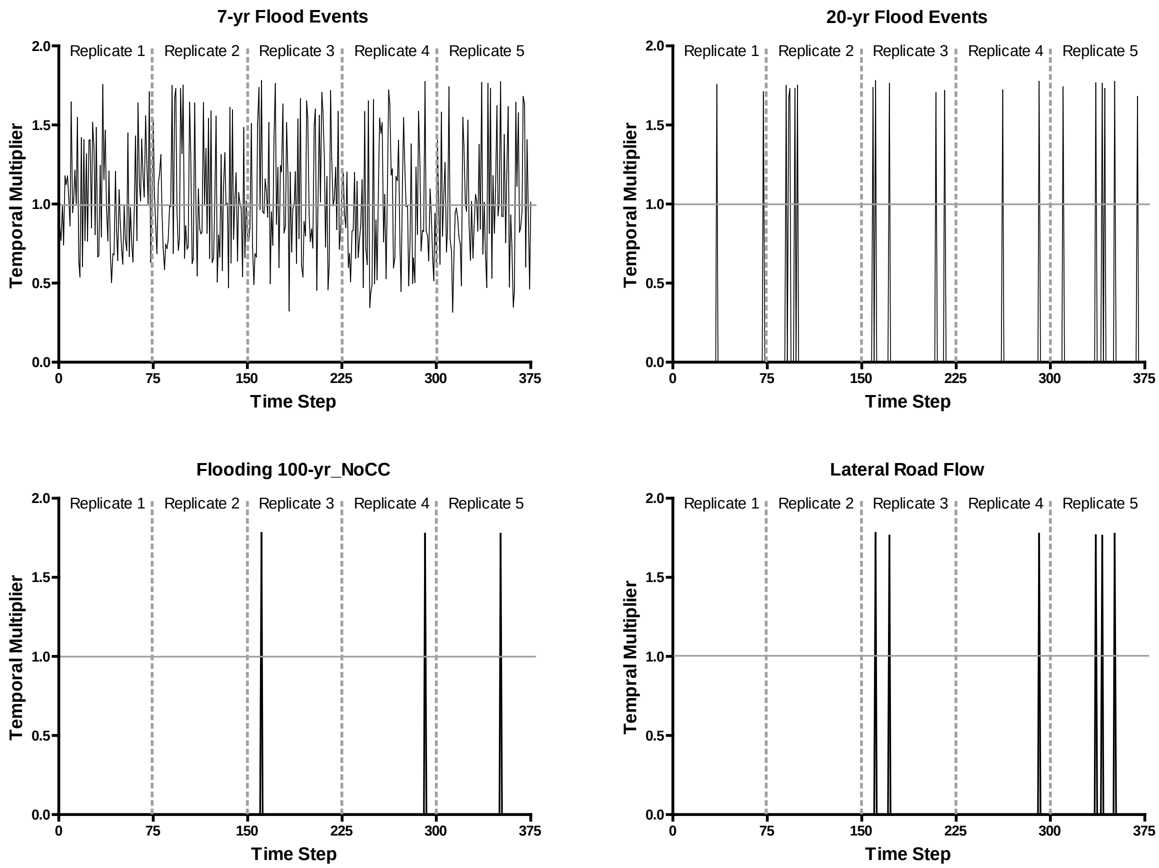


Figure 4. Riparian temporal multipliers for 7-year, 20-year, 100-year flood events, and lateral road flow. For the 20-year and 100-year flood events, and lateral road flow, all values below their threshold are zero. Data obtained from the Lamoille Creek (Ruby Mountains, NV) U.S. Geological Survey gage. The horizontal gray line for temporal multiplier = 1 represents the "no-change" or neutral parameter line.

Assessment of Future Ecological Condition – Minimum Management

Using the computer-based models, TNC simulated the likely future condition of each ecological system after 20 and 50 years, assuming *Minimum Management*. *Minimum Management* essentially represents a custodial level of NPS management with no proactive projects other than the continuation of fire suppression management; it achieves no inventory or treatment of exotic forbs, no prescribed fire, no vegetation treatments, etc. The *Minimum Management* scenario is also required to estimate Return-On-Investment (ROI defined later). Potential sources of future ecosystem-degradation were explicitly modeled, and included increased invasion rates of non-native species (cheatgrass and exotic forbs), increased tree encroachment rates in shrublands, modified mean fire return intervals in shrublands, increased older age classes and fuel loadings in forest systems, and entrenchment of and water diversion in creeks.

The two primary indicators chosen for assessing future condition were the same as current condition: *Ecological Departure* and the percentage of *High-Risk Vegetation Classes* in each system after 20 and 50 years.

Ecological Departure can be categorized into three classes corresponding to LANDFIRE's Fire Regime Condition Classes:

- Class 1 (low departure) contains values for ecological departure from 0% to 33%.
- Class 2 (moderate departure) contains values for ecological departure from 34% to 66%.
- Class 3 (high departure) contains values for ecological departure ≥67%.

The importance of including % High-Risk Vegetation Classes as the second indicator (including vegetation conversion) was amplified when some model simulations showed that an biophysical setting's overall ecological departure score could decrease through targeted restoration strategies (an improvement), whereas its area of high-risk vegetation classes simultaneously increased (a degradation).

Similar to the grouping of Ecological Departure scores into three Ecological Condition Classes, the cover of High-Risk Vegetation Classes was stratified into four categories:

- Low: 0% cover of high-risk vegetation classes, no future risk posed to biophysical setting condition.
- Medium: 1-10% cover of high-risk vegetation classes, acceptable future risk posed to biophysical setting.
- High: 11-30% cover of high-risk vegetation classes, future vegetation classes have the potential to catalyze even greater degradation of a biophysical setting and will require significant resources to contain, let alone restore.
- Very high: >30% cover of high-risk vegetation classes, the system will be highly degraded, perhaps beyond the ability of managers to recover the ecological system.

Assessment of Future Ecological Condition – Alternative Management Strategies

Ten focal biophysical settings were selected for management analyses, based upon their size, high departure from NRV, likelihood of high future departure and/or presence of high-risk vegetation classes. The reasons each of these biophysical settings was chosen for management is presented later in **Findings** under the section ***Management Strategies and Scenarios***:

Biophysical Setting	Area (acres)
Subalpine	
Aspen–Subalpine Conifer	11,320
Limber-Bristlecone Pine-mesic	4,500
Mid-Elevation Woodland	
Aspen–Mixed Conifer	8,110
Shrublands	
Antelope Bitterbrush	340
Basin Wildrye	270
Black Sagebrush	1,880
Low Sagebrush Steppe	420
Montane Sagebrush Steppe-upland	12,710
Riparian & Wet Meadow	
Montane-Subalpine Riparian	450
Wet Meadow	90

As noted previously, the fundamental purpose of this project is to identify specific, cost-effective vegetation management strategies to maintain, enhance or restore biophysical settings to their NRV or some other desired future condition if NRV was impractical. TNC and Park staff worked jointly on three interrelated tasks toward achieving this fundamental purpose: (1) develop a set of more-specific guiding *objectives*; (2) list a comprehensive set of management *strategies* that the Park can implement; and (3) analyze the results (per the three future-condition indicators above) of various alternative management *scenarios*, i.e., combinations of management strategies that have a similar theme.

Management Strategies

Varied management strategies and scenarios were developed as a means of achieving the objectives for the 10 biophysical settings, and the effectiveness of strategies was tested using the predictive ecological models.

Park staff and TNC developed management strategies to achieve the project objectives. All strategies were fundamentally designed to: (1) improve the condition of ecological systems that are currently in an undesirable condition, and/or (2) abate the most serious future threats to ecological systems or human settlements. A cost-per-acre and yearly application rate budget were determined for each management strategy, using various published sources as well as the local experience of managers (Appendix 4). The array of general management strategies included the following (details will be presented later in **Findings** under the section ***Management Strategies and Scenarios***):

- Sagebrush and Antelope bitterbrush — prescribed fire, chainsaw lopping of young pinyon and juniper, chainsaw thinning of older pinyon juniper, mastication of trees, chipping or pile

burning of felled trees, mechanical thinning of shrubs, spot herbicide application, and native plant seeding;
- Aspen-Conifer — prescribed fire and chainsaw thinning of conifers;
- Basin wildrye — prescribed fire, mechanical thinning of shrubs, mastication of pinyon and juniper, spot herbicide application, and native plant seeding, weed inventory and exotic forb control;
- Limber-Bristlecone pine-mesic — prescribed fire; and
- Montane-subalpine riparian and wet meadow — weed inventory, spot application of herbicides to exotic forbs, floodplain restoration.

Initial draft sets of management strategies were developed by TNC and Park staff in the March 2010 workshop. TNC then conducted VDDT computer runs of the state-and-transition models to test and refine a suite of strategies for each of the targeted biophysical settings over a 50-year time horizon. These models also included a "failure rate" for many management strategies to reflect that some management actions only partially succeed at restoring a vegetation class, although cost is incurred for failure. Because the VDDT software that was used does not have an optimization mechanism, this required testing many different combinations of alternative management strategies and levels of treatment. This trial-and-error process created a robust set of strategies that reduced ecological departure and cover of high-risk vegetation classes while minimizing cost.

Management Scenarios

Management scenarios basically represent common "themes" or approaches for grouping individual management strategies, so that the effectiveness of sets-of-strategies can be better compared within and across ecological systems. Scenarios are comparable to alternatives proposed in agency management plans or National Environmental Protection Act (NEPA) documents. Based on past experience in eastern California, Nevada and southwestern Utah, TNC recommended the use of three management scenarios that have become more-or-less standardized in the Landscape Conservation Forecasting process. These three scenarios are thematically described in Table 5. Because scenarios are broad themes to guide modeling during workshops, they become more specific for each biophysical setting, details will be presented later in **Findings** under the section ***Management Strategies and Scenarios***).

Each scenario required budgets for each biophysical setting, which included costs of all management strategies. Budgets were also expressed as area limits, which was the maximum area that could be treated per year for individual actions. If computer simulations reached a given management strategy's annual area limit, that management strategy was subsequently discontinued in the simulation for that year. Cost information for each management strategy for each ecological system, under all scenarios, is listed in Appendix 4.

Table 5. Descriptions of Management Scenarios for Great Basin National Park.

MANAGEMENT SCENARIOS
MINIMUM MANAGEMENT
A control scenario that only included natural disturbances, unmanaged non-native species invasion, and fire suppression management. Fire suppression by agencies was simulated by reducing natural, reference fire return intervals using time series that reflected current fire events from the immediate and nearby areas. Fire event data were obtained from the Federal Fire Occurrence Website. In essence, this scenario can be considered a no-treatment control, but does not represent current management.
MAXIMUM MANAGEMENT
This scenario allocated unlimited management funds with the goal of reducing ecological departure and high-risk vegetation classes to the greatest extent possible. Management strategies were applied in an attempt to reduce ecological departure significantly and/or maintain high-risk vegetation classes below 10% of the area of the biophysical setting. This scenario assumed no financial or other resource constraints on strategy implementation (i.e., annual agency budgets were typically exceeded).
PREFERRED MANAGEMENT
The PREFERRED MANAGEMENT scenario was the result of management strategies identified by Park staff, at and following the workshops. It was usually effective at reducing ecological departure and high-risk vegetation classes while recognizing anticipated agency budgets, management funding availability, and regulatory constraints. Strategies were sought that produced the highest ROI.

Computer Simulations and Reporting Variables

The three scenarios – MINIMUM MANAGEMENT, MAXIMUM MANAGEMENT, and PREFERRED MANAGEMENT – were simulated for each biophysical setting for 50 years using VDDT. Five replicates were run for each scenario to capture extremes in fire activity. The three reporting variables for simulations, i.e. the indicators of future ecological condition, were: (1) ecological departure score, (2) percentage area of high-risk vegetation classes, including the percentage area of ecological-system conversion.

Return-On-Investment Analysis

The final step in the process was the calculation of benefits (magnitude of ecological improvement) as compared to cost of management strategies. TNC developed an ROI metric to determine which of the scenarios (MAXIMUM or PREFERRED) produced the greatest ecological benefits per dollar invested across multiple scenarios *within* each biophysical setting, and *across* the 10 targeted biophysical settings, in relation to MINIMUM MANAGEMENT. The ROI metric was:

> Ecological system-wide ROI. The change of ecological departure, high-risk vegetation classes (if applicable), and vegetation conversion classes (if applicable) between the MINIMUM MANAGEMENT scenario and the MAXIMUM or PREFERRED MANAGEMENT scenario in the last year of the simulation, multiplied by total area of the biophysical setting, divided, respectively, by total cost of each scenario over the duration of the simulation (here 50 years). One uniform correction factor was used to bring all measures to a common order of magnitude.

The ROI values are a useful tool for land managers to decide where to allocate scarce management resources among many possible choices on lands that they administer. Of course, managers may also select final strategies or treatment areas based upon a variety of additional factors, such as availability of financial resources, regulatory constraints, and other multiple-use or societal objectives.

Findings

Biophysical settings

Twenty-four biophysical settings were mapped (Figure 5; Table 2). Curl-leaf mountain mahogany covered most of the Park, closely followed by upland sites of montane sagebrush steppe, and aspen-subalpine conifer. Biophysical settings of intermediate size were Aspen-Mixed Conifer, Pinyon-Juniper Woodland, Spruce, and Limber-Bristlecone Pine-mesic. The smallest biophysical settings (<100 acres) were Wet Meadow, Mountain Shrub, and Subalpine Riparian. Sixteen biophysical settings were <2,000 acres, whereas the remaining were >4,500 acres (Table 2).

Current Ecological Departure

Most biophysical settings were only slightly or moderately departed from their NRV. Nine biophysical settings were slightly departed from NRV, 10 were moderately departed, and only two smaller biophysical settings, Basin Wildrye and Antelope Bitterbrush, were highly departed (Table 6). Accordingly, virtually the entire Park falls within Fire Regime Condition Class 1 (green shading of Table 6 and Figure 6) or 2 (yellow shading).

The primary cause of ecological departure across the landscape is the lack or near absence of the earliest succession classes in Basin Wildrye, Antelope Bitterbrush, Mountain Shrub, Ponderosa Pine, all sagebrush, and Aspen-Conifer biophysical settings (Appendix 5). These same biophysical settings systems showed an over-representation of late succession classes. For example, Montane Sagebrush Steppe-upland below ~9400 feet elevation comprises almost 13,000 acres, approximately 17% of the project area. There is virtually no presence of the early succession classes; moreover, conifer tree species have encroached upon a large portion of the native sagebrush. In the Aspen-Subalpine Conifer biophysical setting, approximately 11,000 acres, over 60% of the system is in the late-closed succession class, as compared to a targeted 8% late-closed under natural disturbance regimes.

Uncharacteristic classes also contributed to ecological departure of some biophysical settings (Appendix 5). The area of Aspen-Conifer biophysical settings already experienced 6-7% loss of clones, which is considered an irreversible conversion. Cheatgrass occupied the understory of shrublands and conifers have encroached Basin Wildrye, Antelope Bitterbrush, and all sagebrush biophysical settings. Uncharacteristic classes occupied large areas of upland sites of Montane Sagebrush Steppe (~30%) more than other biophysical settings. For each biophysical setting, the predicted future percentage of all vegetation classes and resulting future ecological departure score under minimum management are shown in Appendix 5.

Current High-Risk Vegetation Classes

Nearly all uncharacteristic classes were considered high risk by workshop participants (Table 6), except the common shrub-annual-perennial-grasses class (SAP). Therefore, biophysical settings with a greater dominance of high risk vegetation classes are those with the smallest percentage of the shrub-annual-perennial-grasses class. The shrub-annual-perennial-grasses class was proportionally more important in the Antelope Bitterbrush (36%) and Montane Sagebrush Steppe – upland (8%) biophysical settings; therefore, both Aspen-Conifer, Basin Wildrye, Black sagebrush, Low Sagebrush Steppe, Montane Riparian, Montane Sagebrush Steppe – mountain, and Pinyon-Juniper Woodland biophysical settings have a greater proportion of uncharacteristic classes that were high-risk classes.

Table 6. Ecological departure (%) and percent of high-risk classes of Great Basin National Park's biophysical settings. Ecological departure scores were classed as good (0-33%, Class 1, green); fair (34-66%, Class 2, yellow); and poor (>66%, Class 3, red). Stress (levels of high-risk classes) to ecological systems was ranked as: low (0%, dark green); medium (1-10%, light green); high (11-30%, yellow), and very high (>30%, red).

Biophysical Setting		Area (acres)	Ecological Departure (%)	High Risk Classes (%)
Alpine-Subalpine				
	Alpine	1,690	0.1	0
	Aspen-Subalpine Conifer	11,320	60	7
	Limber-Bristlecone Pine Woodland	1,990	16	0
	Limber-Bristlecone Pine Woodland- mesic	4,500	48	0
	Montane-Subalpine Grassland	270	16	0
	Spruce	5,770	36	0
Mid-Elevation Forests				
	Aspen Woodland	570	27	16
	Aspen- Mixed Conifer	8,110	66	6
	Mixed Conifer	590	32	0
	Ponderosa Pine	250	54	0
Shrublands				
	Antelope Bitterbrush	340	74	28
	Basin Wildrye	270	68	43
	Black Sagebrush	1,880	60	39
	Low Sagebrush Steppe	420	61	0
	Montane Sagebrush Steppe- mountain	940	30	2
	Montane Sagebrush Steppe- upland	12,710	56	21
	Mountain Mahogany	14,050	23	0
	Pinyon-Juniper	6,950	11	10
Riparian and Wet Meadows				
	Montane Riparian	450	26	3

Riparian Ponderosa Pine	170	34	0
Wet Meadow	90	49	0

Predicted Future Ecological Condition – Minimum Management

Ecological Departure

Ecological departure scores predicted under minimum management after 50 years of simulation are presented in Table 7. Thirteen biophysical settings showed a predicted improvement (i.e. >5% decline) in ecological departure score, some dramatically so, whereas six showed no predicted change (i.e., within 5% of current condition score) and one (montane riparian) showed a predicted decrease in condition (>5% higher departure score). For each biophysical setting, the predicted future percentage of all vegetation classes and resulting future ecological departure score under minimum management are shown in Appendix 6.

The predicted ecological improvement of more than half of the area's biophysical settings in the absence of any active management appeared to be counter-intuitive. Two possible explanations may be advanced for this result: (1) many biophysical settings respond slowly, especially if they are dominated by late succession classes which just become older; and (2) the ecological model's temporal multipliers incorporated the "escape" of fires into the systems, assuming that aggressive suppression efforts would not be effective in every case. Of these two explanations, the second is perhaps the more influential in producing the counter-intuitive results. More specifically, the predictive models included a modest failure rate for traditional fire suppression activities, as well as varied fire cycles based upon historical data. The models ran five 50-year replicates punctuated by large fires (sometimes no fire for 20 years), which actually served to reduce ecological departure for many biophysical settings by "naturally" increasing their early succession classes, which were lacking in the current condition. It is important to note that this future ecological improvement due to escaped fire(s) in the "modeling world" may not actually come to pass in the real world.

High-Risk Vegetation Classes

In contrast to predicted improvements in ecological departure over 50 years of minimum management, seven of the Park's biophysical settings were predicted to have increases – some dramatic – in the percentage of high-risk classes (Table 7): Aspen-Subalpine Conifer, Aspen-Mixed Conifer, Antelope Bitterbrush, Basin Wildrye, Montane Sagebrush Steppe-upland, Montane Riparian, and Wet Meadow. Nine biophysical settings showed no change (i.e., within 5% of current high-risk classes). These predicted increases in high-risk vegetation classes reflect the critical need to continue active management practices aimed specifically at improving ecological condition and reducing high-risk classes.

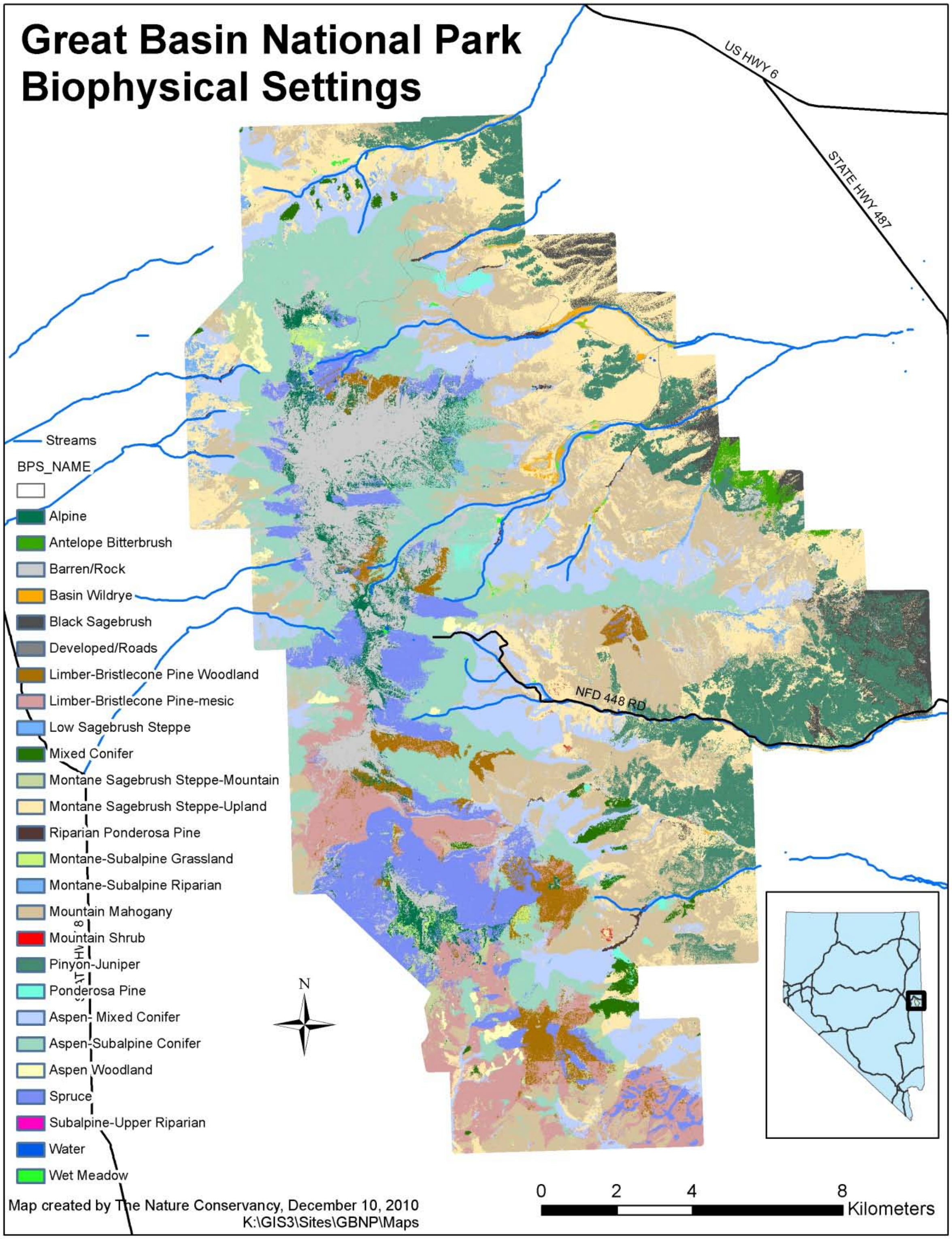


Figure 5. Biophysical settings of Great Basin National Park.

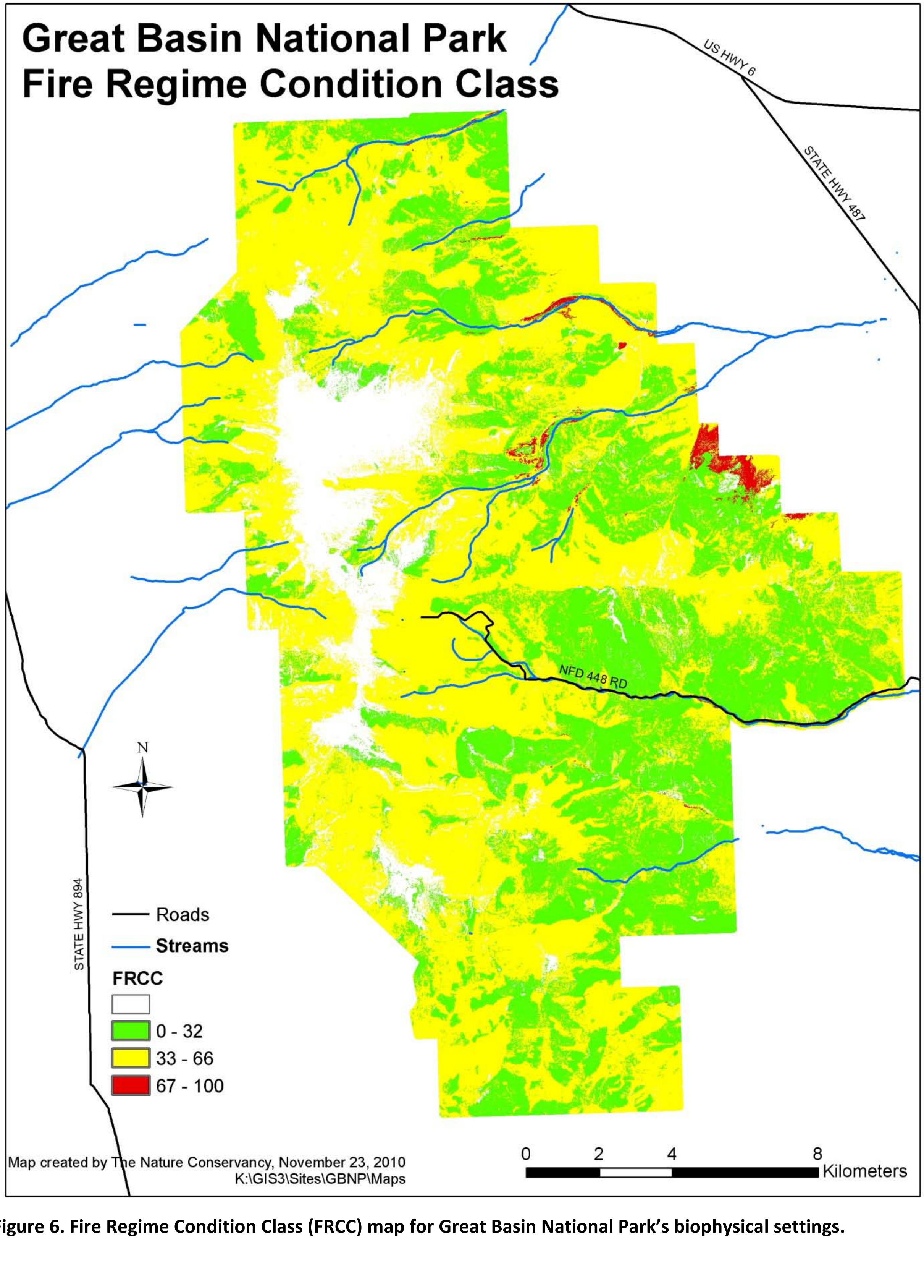


Figure 6. Fire Regime Condition Class (FRCC) map for Great Basin National Park's biophysical settings.

Table 7. Current and predicted future (under minimum management) ecological departure and high-risk vegetation classes of ecological systems of Great Basin National Park; systems in boldface type are the 10 selected for active management analyses. Ecological departure scores were classed as good (0-33%, Class 1, green); fair (34-66%, Class 2, yellow); and poor (>66%, Class 3, red). Stress (levels of high-risk classes) to ecological systems was ranked as: low (0%, dark green); medium (1-10%, light green); high (11-30%, yellow), and very high (>30%, red).

	Ecological Departure		High Risk Classes	
Biophysical Setting	**Current Condition**	**Minimum Mgmt - 50 yrs**	**Current Condition**	**Minimum Mgmt - 50 yrs**
Alpine-Subalpine				
Alpine	0	1	0	0
Aspen-Subalpine Conifer	60	27	7	20
Limber-Bristlecone Pine Woodland	16	17	0	0
Limber-Bristlecone Pine - mesic	48	42	0	0
Montane-Subalpine Grassland	16	4	0	0
Spruce	36	23	0	0
Mid-Elevation Forests				
Aspen Woodland	27	10	16	11
Aspen- Mixed Conifer	66	33	6	12
Mixed Conifer	32	10	0	0
Ponderosa Pine	54	25	0	5
Shrublands				
Antelope Bitterbrush	74	62	28	44
Basin Wildrye	68	70	43	64
Black Sagebrush	60	55	39	40
Low Sagebrush Steppe	61	27	0	1
Montane Sagebrush Steppe- mountain	30	8	2	2
Montane Sagebrush Steppe- upland	56	41	21	30
Mountain Mahogany	23	19	0	4
Pinyon-Juniper	11	16	10	14
Riparian and Wet Meadows				
Montane Riparian	26	40	3	36
Riparian Ponderosa Pine	34	31	0	0
Wet Meadow	49	40	0	36

Management Strategies and Scenarios

Introduction

For the 10 biophysical settings analyzed in greater detail, management strategies were developed under the two primary active-management scenarios: MAXIMUM MANAGEMENT and PREFERRED MANAGEMENT. All strategies were designed to improve the condition of biophysical settings that are currently in an undesirable condition and/or to abate serious future threats to them. Different types of strategies and degrees of application were tested to achieve specific objectives under the two scenarios. Total annual costs for strategy implementation were calculated for each ecological system under each scenario, as well as any one-time costs.

All scenarios for each biophysical setting were then tested via computer simulations using VDDT to determine whether or not they achieved the desired objectives. Outcomes were calculated for ecological departure and high-risk classes or vegetation conversions over 50 years. Area results by vegetation class and biophysical setting for each replicate are shown, respectively, for the MINIMUM MANAGEMENT, PREFERRED MANAGEMENT, and MAXIMUM MANAGEMENT scenarios in Appendices 6, 7, and 8.

Summary descriptions of active-management modeling results are presented for each of the 10 biophysical settings that were selected for such analyses. Each system description includes text, a summary table, and a composite figure that together provide the following information:

1. Brief description of the biophysical setting in Great Basin National Park;

2. Management objectives under the PREFERRED MANAGEMENT scenario because this scenario either had the highest ROI or the lowest cost when MAXIMUM MANAGEMENT and PREFERRED MANAGEMENT had statistically equal ROIs (results shown later);

3. Bulleted description of management strategies, including acres treated and cost, under the PREFERRED MANAGEMENT scenario (Appendix for the MAXIMUM MANAGEMENT scenario);

4. Summary of outcomes (ROI, ecological departure, and high-risk classes or vegetation conversion) expressed as statistical graphs using one-way analysis of variance and two *a priori* contrasts between: MINIMUM MANAGEMENT scenario *versus* PREFERRED MANAGEMENT + MAXIMUM MANAGEMENT scenarios and the PREFERRED MANAGEMENT *versus* MAXIMUM MANAGEMENT scenario (Steel and Torrie 1980); and

Following these individual descriptions of the 10 biophysical settings, a sub-section summarized inter-system ROI results, and a final section on treatments of the PREFERRED MANAGEMENT scenario are mapped by treatment type for all actively managed biophysical setting.

Antelope Bitterbrush Biophysical Setting

The Antelope Bitterbrush biophysical setting occurs in the Park's small Kious Basin with soils dominated by decomposed granite. The biophysical setting is very similar to Montane Sagebrush Steppe-upland, except that antelope bitterbrush is usually dominant to codominant with mountain big sagebrush. At present, this system exhibits high ecological departure at 74%. The high ecological departure is caused by under-represented early and mid-succession classes and by too much uncharacteristic vegetation represented by shrubs with an understory of annual and perennial grasses (36%), tree-encroached shrublands (17%), shrubs with an understory of annual grasses (7%), and depleted shrubs (no herbaceous understory; 6%).

After 50 years in a regime of minimum management, ecological departure improved to 62% from 74%, but high-risk classes increased to 44% from 28% due to sporadic wildfires causing recruitment to earlier succession classes and annual grasslands. These levels of departure and the loss of winter browse to annual grasslands were judged unacceptable.

Park staff focused on a variety of treatment actions (strategies) used alone or in combination including prescribed fire, chainsaw lopping and thinning, mastication, chipping, pile burning, spot herbicide application, and native species seeding.

50-year Preferred Management Scenario Objectives

- Preserve winter browse to the extent possible, which meant maintenance of late-succession classes.
- Improve ecological condition of 340 acres of Antelope Bitterbrush shrubland from 74% departure from NRV to <40% departure (≤Ecological Departure Class 2).
- Contain uncharacteristic classes to <10%.

50-year Preferred Management Strategies and Costs

Strategy	Rate (acres/yr)	Years of Application	Cost ($/acre)
Prescribe burn late-succession classes (C, D, and E)	4	1-5	300
Chainsaw lop in classes late-succession open (D), depleted shrubs (DP), and shrubs with annual and perennial grasses (SAP)	8	1-5	200
Chainsaw thin or masticate[#] trees at 4 acres/year in the late-succession closed wooded class (E)	4	1-5	300
Chainsaw thin trees then conduct spot herbicide application for annual grasses and native species seeding for of tree-encroached shrublands (TE)	8	1-5	750
Spot application of herbicide for annual grasses and seed native species in shrubs with an understory of annual grasses (SA), in depleted shrubs (DP), and new annual grasslands (AG)	5	1-5	300

Herbicide application to control annual grasses in shrublands with an understory of annual and perennial grasses (SAP)	12	1-5	100

#Mastication was not modeled and cost per acre is low for mastication; however this action is compatible and cost could be lowered.

The average annual cost of these treatments was $13,400 per year of implementation, for a total of $71,500 in 5 years.

50-year Outcomes

- The average ROI for the PREFERRED MANAGEMENT scenario (~20) was higher than the average MAXIMUM MANAGEMENT scenario at ~16, but the difference was not significant (P = 0.234; Figure 7 top) with complete overlap in 95% confidence intervals (especially after data transformation for statistical compliance).
- MAXIMUM AND PREFERRED MANAGEMENT SCENARIOS APPROXIMATELY halved ecological departure relative to the MINIMUM MANAGEMENT scenario (62% versus 34% and 35%, respectively; P< 0.001; Figure 7 middle); however, the MAXIMUM AND PREFERRED MANAGEMENT scenarios were statistically equal for ecological departure (see letter comparison in Figure 7 middle).
- MAXIMUM AND PREFERRED MANAGEMENT SCENARIOS reduced high-risk classes compared to the MINIMUM MANAGEMENT scenario (43% versus 1.7% and 9.6%, respectively; P< 0.001; Figure 7 bottom); however, the MAXIMUM MANAGEMENT scenario was significantly better at reducing the high-risk classes than PREFERRED MANAGEMENT scenario (see letter comparison in Figure 7 bottom).
- Both active scenarios met management objectives. The PREFERRED MANAGEMENT scenario was the preferred choice, but given statistically equal ROIs and results above, the lower cost of the PREFERRED MANAGEMENT scenario ($71,500) compared to the MAXIMUM MANAGEMENT scenario ($138,300) alone justified this choice.

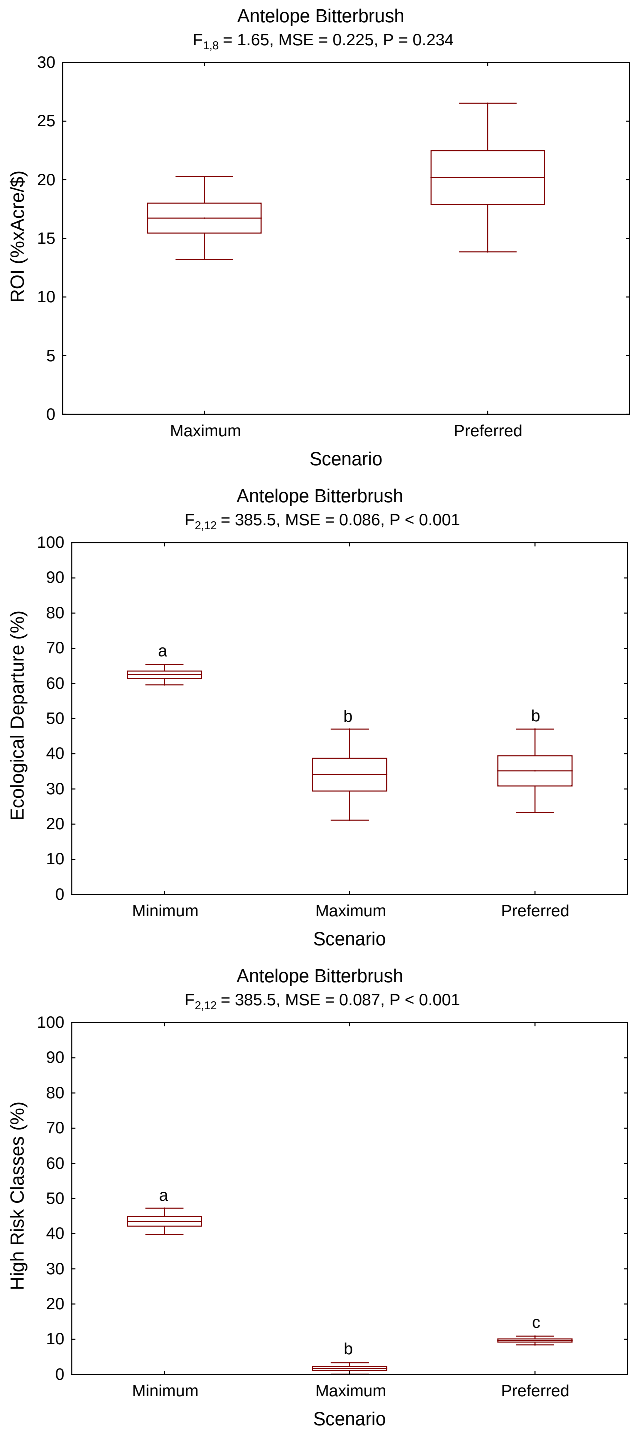


Figure 7. Return-on-Investment, ecological departure, and high-risk classes for the Antelope Bitterbrush biophysical setting with MINIMUM, MAXIMUM, and PREFERRED MANAGEMENT scenarios for Great Basin National Park. The MINIMUM MANAGEMENT scenario is not shown in the ROI graph because this scenario is 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. Data transformations were: and (1 + high-risk class).

Aspen-Mixed Conifer Biophysical Setting

Aspen–mixed conifer forests occur at middle and upper elevations of the Park. The main conifers in this system are white fir and occasionally Douglas-fir. Understories are diverse, with various amounts of low shrubs, forbs and grasses. At present, this system exhibits moderate ecological departure at 66% and already 6% of the potential area has converted to mixed conifers. Moderate ecological departure at present is caused by a large over-abundance of the late succession class, i.e., closed-canopy of dominant mixed conifers and sub-dominant aspen, and corresponding under-representation of early and mid-succession classes.

Although ecological departure improves from 66% to 33% (Ecological Departure Class 1) over 50 years due to sporadic wildfires in a regime of minimum management, the predicted doubling of permanent conversion of aspen to mixed conifers (i.e., loss of clones) without active management (to 12% from the 6% baseline) was considered unacceptable and requiring management.

Park staff focused on prescribed fire to prevent the loss of aspen clones because the Aspen-Mixed Conifer biophysical setting is often found at middle to high elevations on steep and remote terrain preventing easy use of wheeled mechanical methods, which would not comply with normal Park policies. Prescribed fire would be applied at a large scale by management of natural ignitions, helicopter ignitions and ground ignitions where road and foot access are feasible.

50-YEAR PREFERRED MANAGEMENT Scenario Objectives

- Improve ecological condition of 8,110 acres of Aspen-Mixed Conifer forest from 66% departure from NRV to ≤25% departure (Ecological Departure Class 1).
- Contain loss of aspen to <10% (counting the already converted 6%).

50-YEAR PREFERRED MANAGEMENT Strategies and Costs

Strategy	Rate (acres/yr)	Years of Application	Cost ($/acre)
Prescribe burn late-succession classes D and E	325	1-10	250

The average annual cost of this strategy was $81,250/year for years of implementation, for a total of $812,500 in 10 years.

50-year Outcomes

- The ROI for the PREFERRED MANAGEMENT scenario was marginally significantly higher (~15) than the MAXIMUM MANAGEMENT scenario at ~6 (P < 0.063; Figure 8 top) with overlap in 95% confidence intervals. The PREFERRED MANAGEMENT scenario was the preferred choice based strictly on the average only, but not in terms of the ROI's statistical properties. The large variation is ROI was primarily due to the variation in budgets among replicates, and secondarily ecological departure and vegetation conversions.

- MAXIMUM AND PREFERRED MANAGEMENT SCENARIOS resulted in an improved ecological departure score relative to MINIMUM MANAGEMENT (33% versus 19% and 22%, respectively; P< 0.001; Figure 8 middle); however, the MAXIMUM AND PREFERRED MANAGEMENT scenarios were statistically equal for ecological departure (see letter comparison in Figure 8 middle).

- MAXIMUM AND PREFERRED MANAGEMENT SCENARIOS resulted in significantly reduced loss of aspen clones or reduced conversion to mixed conifers relative to MINIMUM MANAGEMENT (12% versus 8% and 8%, respectively; P< 0.001; Figure 8 bottom); however, the both scenarios achieved statistically equal vegetation conversions (see letter comparison in Figure 8 bottom).

- Although both active scenarios met management objectives about equally, the PREFERRED MANAGEMENT scenario had the higher ROI because it was four times less expensive to implement (~$812,500) over 10 years than the MAXIMUM MANAGEMENT scenario (~$3,825,000).

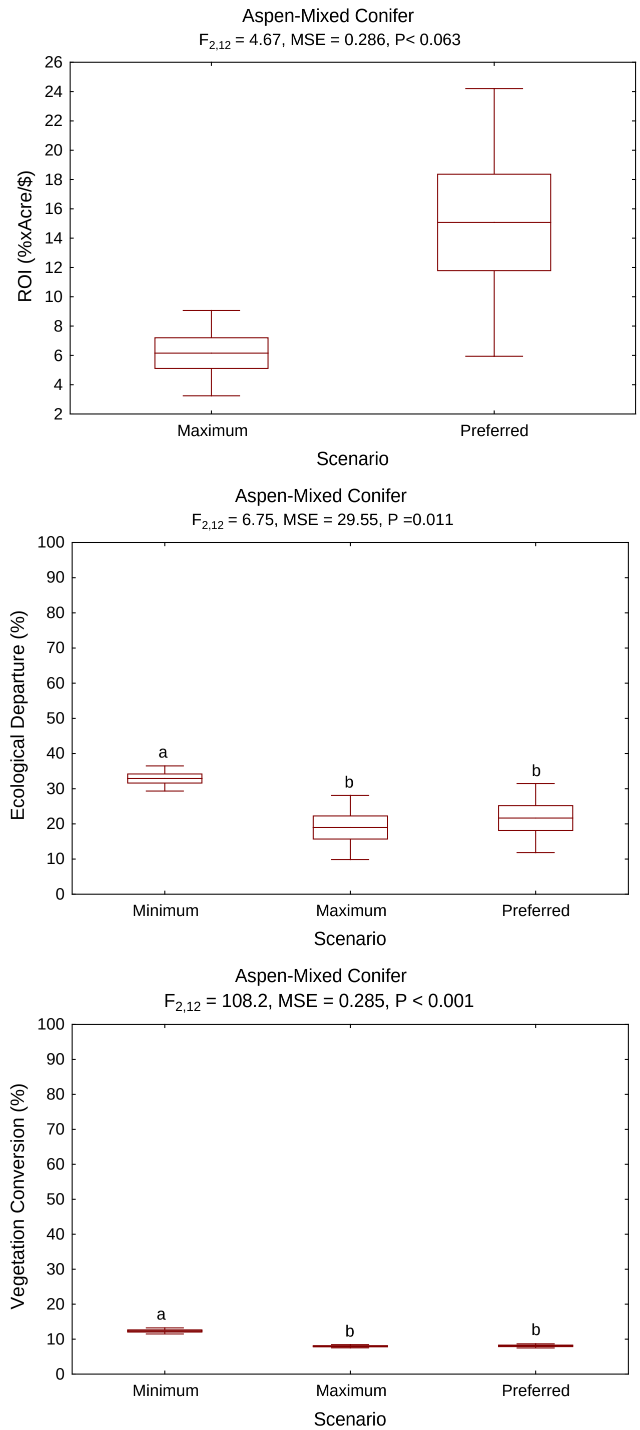


Figure 8. Return-on-Investment, ecological departure, and vegetation conversion for the Aspen-Mixed Conifer biophysical setting with Minimum, Maximum, and Preferred Management scenarios for Great Basin National Park. The Minimum Management scenario is not shown in the ROI graph because this scenario 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: .

Aspen–Subalpine Conifer Biophysical Setting

Aspen–subalpine conifer forests occur at upper elevations of the Park. The main conifer in this system is Engelmann spruce, although limber pine can be important. Understories are diverse, with various amounts of low shrubs, forbs and grasses. At present, this system exhibits moderate ecological departure at 60% and already 7% of the potential area has converted to subalpine conifers. The main basis for heightened ecological departure at present is a large over-abundance of the late succession class, i.e., closed-canopy of dominant subalpine conifers and sub-dominant aspen, and under-representation of two mid-succession classes.

Although ecological departure dramatically improves over 50 years due to sporadic wildfires with minimum management, the predicted large increase of permanent conversion of aspen to subalpine conifers (i.e., loss of clones) without active management (to 20% from the 7% baseline) was considered unacceptable and requiring management.

Park staff focused on prescribed fire to prevent the loss of aspen clones because the Aspen-Subalpine Conifer biophysical setting is often found at middle to high elevations on steep and remote terrain preventing easy use of wheeled mechanical methods, which would not comply with normal Park policies. Prescribed fire would be applied at a large scale by management of natural ignitions, helicopter ignitions and ground ignitions where road and foot access are feasible.

50-YEAR PREFERRED MANAGEMENT Scenario Objectives

- Improve ecological condition of 11,320 acres of Aspen-Subalpine Conifer forest from 60% departure from NRV to ≤33% departure (Ecological Departure Class 1).
- Contain loss of aspen to <10% (counting the already converting 7%).

50-YEAR PREFERRED MANAGEMENT Strategies and Costs

Strategy	Rate (acres/yr)	Years of Application	Cost ($/acre)
Prescribe burn by helicopter or ground ignition late-succession classes D and E	2,950	1-3	50
“Free prescribed fire” as a benefit of prescribed fires conducted in immediately lower elevation or adjacent biophysical settings, such as Aspen-Mixed Conifer (see later Figure 19)	910	1-3	0

The average annual cost of these treatments was $129,500 for years of implementation, for a total of $388,500 in 3 years.

50-year Outcomes

- The ROI for the PREFERRED MANAGEMENT scenario was significantly higher (~93) than the MAXIMUM MANAGEMENT scenario at ~72 ($P < 0.001$; Figure 9 top) with no overlap in 95% confidence intervals. Clearly, the PREFERRED MANAGEMENT scenario was the preferred choice.

- MAXIMUM AND PREFERRED MANAGEMENT SCENARIOS resulted in an improved ecological departure score relative to MINIMUM MANAGEMENT (27% versus 11% and 11%, respectively; $P< 0.001$; Figure 9 middle); however, the MAXIMUM AND PREFERRED MANAGEMENT scenarios were statistically equal for ecological departure (see letter comparison in Figure 9 middle).

- MAXIMUM AND PREFERRED MANAGEMENT SCENARIOS resulted in reduced loss of aspen clones or reduced conversion to subalpine conifers relative to MINIMUM MANAGEMENT (20% versus 7% and 9.6%, respectively; $P< 0.001$; Figure 9 bottom); however, the MAXIMUM MANAGEMENT scenario achieved statistically less conversion than the PREFERRED MANAGEMENT scenario for conversion (see letter comparison in Figure 9 bottom).

- Although both active scenarios met management objectives, the PREFERRED MANAGEMENT scenario had the higher ROI because it was less expensive to implement (~$388,500) than the MAXIMUM MANAGEMENT scenario (~$500,000), which actually demonstrated a somewhat greater ecological improvement of the two scenarios.

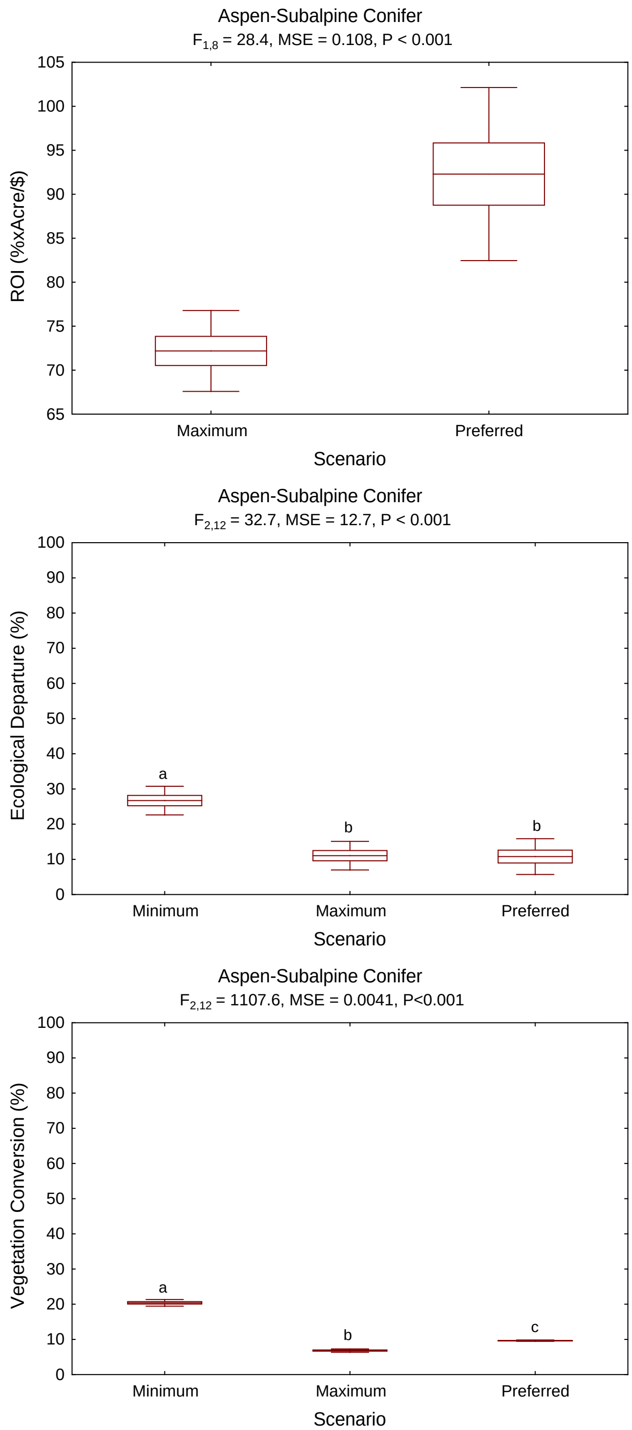


Figure 9. Return-on-Investment, ecological departure, and vegetation conversion for the Aspen-Subalpine Conifer biophysical setting with Minimum, Maximum, and Preferred Management scenarios for Great Basin National Park. The Minimum Management scenario is not shown in the ROI graph because this scenario 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).

Basin Wildrye Biophysical Setting

The Basin Wildrye biophysical setting is scattered along eastern creeks and canyons of the Park on deep silty and loamy soils. Basin wildrye strongly dominates this grassland under natural disturbance regimes, such as fire. At present, this system exhibits high ecological departure at 68% caused by under-represented early and mid-succession classes relative to over-represented late-succession classes and by too much uncharacteristic vegetation represented by depleted shrubs (23%), tree-encroached shrublands (13%), and shrubs with an understory of annual grasses (7%).

After 50 years in a regime of minimum management, scores for ecological departure (68% to 70%) and high-risk classes (43% to 64%) increased, although the change in ecological departure was minor. The increase in high-risk classes was primarily caused by a predicted invasion by exotic forbs and was judged especially unacceptable.

Park staff focused on six treatment actions (strategies) used alone or in combination including prescribed fire, chainsaw thinning, brush thinning, mastication, chipping of felled trees, spot herbicide application, native species seeding, weed inventory, and weed control.

50-YEAR PREFERRED MANAGEMENT Scenario Objectives

- Improve ecological condition of 270 acres of basin wildrye grassland from 68% departure from NRV to ≤33% departure (Ecological Departure Class 1).
- Contain uncharacteristic classes to <20%.

50-YEAR PREFERRED MANAGEMENT Strategies and Costs

Strategy	Rate (acres/yr)	Years of Application	Cost ($/acre)
Prescribe burn late-succession class (C)	3	1-3	500
Thin shrubs then conduct spot herbicide application for annual grasses and native species seeding of shrubs with annual grasses (SA)	2	1-3	600
Masticate trees then spot application of herbicide for annual grasses and seed native species in tree-encroached shrublands (TE) and in tree-encroached shrublands invaded in annual grasslands (TA)	8	1-3	600
Thin shrubs then conduct native species seeding in depleted shrubs (DP)	11	1-3	340
Inventory exotic forbs in all locations of the biophysical settings	10	50	50
Control exotic forbs with herbicides when detected	3 max	50	360

The average annual and total costs of these treatments, respectively, were:

- $12,370/year for the first 3 years and $37,113 in the first 3 years; and

- $1,190/year for the remaining 47 years and $56,050 for the last 47 years.

50-year Outcomes

- The average ROI for the PREFERRED MANAGEMENT scenario (~22) was significantly higher than the average MAXIMUM MANAGEMENT scenario at ~16 (P = 0.003; Figure 10 top) with no overlap in 95% confidence intervals.

- MAXIMUM AND PREFERRED MANAGEMENT scenarios more than halved ecological departure relative to the MINIMUM MANAGEMENT scenario (70% versus 30% and 34%, respectively; P< 0.001; Figure 10 middle). Moreover, the MAXIMUM MANAGEMENT scenario reduced significantly more ecological departure than the PREFERRED MANAGEMENT scenario (see letter comparison in Figure 10 middle).

- MAXIMUM AND PREFERRED MANAGEMENT scenarios dramatically reduced high-risk classes compared to the MINIMUM MANAGEMENT scenario (64% versus 7% and 19.8%, respectively; P< 0.001; Figure 10 bottom); moreover, the MAXIMUM MANAGEMENT scenario was significantly better at reducing the high-risk classes than PREFERRED MANAGEMENT scenario (see letter comparison in Figure 10 bottom).

- The MAXIMUM MANAGEMENT scenario met management objectives, whereas the PREFERRED MANAGEMENT scenario was successful for high-risk classes but failed by 1% on ecological departure. The PREFERRED MANAGEMENT scenario was the preferred choice by ROI calculation because it was nearly half as expensive ($93,160) compared to the MAXIMUM MANAGEMENT scenario ($169,500). Ecologically, the MAXIMUM MANAGEMENT scenario was better.

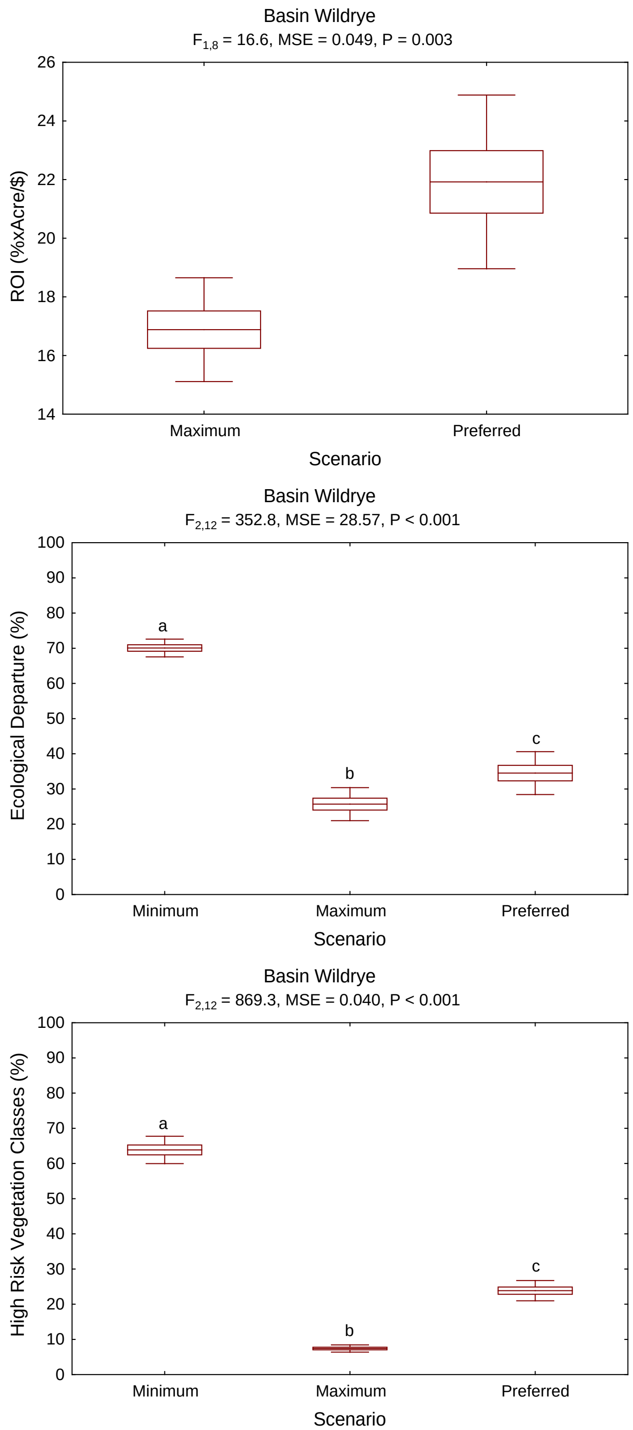


Figure 10. Return-on-Investment, ecological departure, and high-risk classes for the Basin Wildrye biophysical setting with MINIMUM, MAXIMUM, and PREFERRED MANAGEMENT scenarios for Great Basin National Park. The MINIMUM MANAGEMENT scenario is not shown in the ROI graph because this scenario is used in 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. Data transformations were: and (high-risk class).

Black Sagebrush Biophysical Setting

The Black Sagebrush biophysical setting occurs on the northwestern boundary of the Park. Soils typically have a calcite root-restricting layer. At present, this system exhibits moderate ecological departure at 60%. The high ecological departure is caused by under-represented early and mid-succession classes relative to over-represented late-succession classes and by too much uncharacteristic vegetation represented by shrubs with an understory of annual grasses (20%), tree-encroached shrublands (16%), and depleted shrubs (63%).

After 50 years in a regime of minimum management, scores for ecological departure (60% to 55%) and high-risk classes (40%) barely changed, although the percentage of annual grasslands increased to 14% from 0%. These levels of departure and increase in annual grasslands were judged unacceptable.

Park staff focused on a variety of treatment actions (strategies) used alone or in combination including prescribed fire, chainsaw lopping and thinning, brush thinning (including mastication), chipping of felled trees, spot herbicide application, and native species seeding.

50-YEAR PREFERRED MANAGEMENT Scenario Objectives

- Improve ecological condition of 1,880 acres of black sagebrush shrubland from 60% departure from NRV to ≤33% departure (Ecological Departure Class 1).
- Contain uncharacteristic classes to <20%.

50-YEAR PREFERRED MANAGEMENT Strategies and Costs

Strategy	Rate (acres/yr)	Years of Application	Cost ($/acre)
Prescribe burn late-succession classes (C and D)	175	1-3	250
Chainsaw lop young trees in classes late-succession open (C), depleted shrubs (DP), and shrubs with annual grasses (SA)	10	1-3	70
Thin shrubs then conduct spot herbicide application for annual grasses and native species seeding of shrubs with annual grasses (SA)	100	1-3	325
Chainsaw thin or masticate# trees then spot application of herbicide for annual grasses and seed native species in tree-encroached shrublands(TE) and in tree-encroached shrublands invaded in annual grasslands (TA)	100	1-3	500
Direct seeding in depleted shrublands (DP)	10	1-3	200

#Mastication was not modeled and cost per acre is low for mastication; however this action is compatible and cost could be lowered.

The average annual cost of these treatments was $128,967 for year of implementation, for a total of $386,900 in 3 years.

50-year Outcomes

- The average ROI for the PREFERRED MANAGEMENT scenario (~23) was higher than the average MAXIMUM MANAGEMENT scenario at ~20, but the difference was not significant (P = 0.106; Figure 11 top) with overlap in 95% confidence intervals.

- MAXIMUM AND PREFERRED MANAGEMENT scenarios nearly halved ecological departure relative to the MINIMUM MANAGEMENT scenario (55% versus 30% and 34%, respectively; P< 0.001; Figure 11 middle); however, the MAXIMUM AND PREFERRED MANAGEMENT scenarios were statistically equal for ecological departure (see letter comparison in Figure 11 middle).

- MAXIMUM AND PREFERRED MANAGEMENT scenarios reduced high-risk classes compared to the MINIMUM MANAGEMENT scenario (40% versus 10% and 15%, respectively; P< 0.001; Figure 11 bottom); however, the MAXIMUM MANAGEMENT scenario was significantly better at reducing the high-risk classes than PREFERRED MANAGEMENT scenario (see letter comparison in Figure 11 bottom).

- The MAXIMUM MANAGEMENT scenario met management objectives, whereas the PREFERRED MANAGEMENT scenario was successful for high-risk classes but failed by 1% on ecological departure. The PREFERRED MANAGEMENT scenario was the preferred choice only because of the lower cost of the PREFERRED MANAGEMENT scenario ($386,900) compared to the MAXIMUM MANAGEMENT scenario ($613,400). Ecologically, the MAXIMUM MANAGEMENT scenario was better.

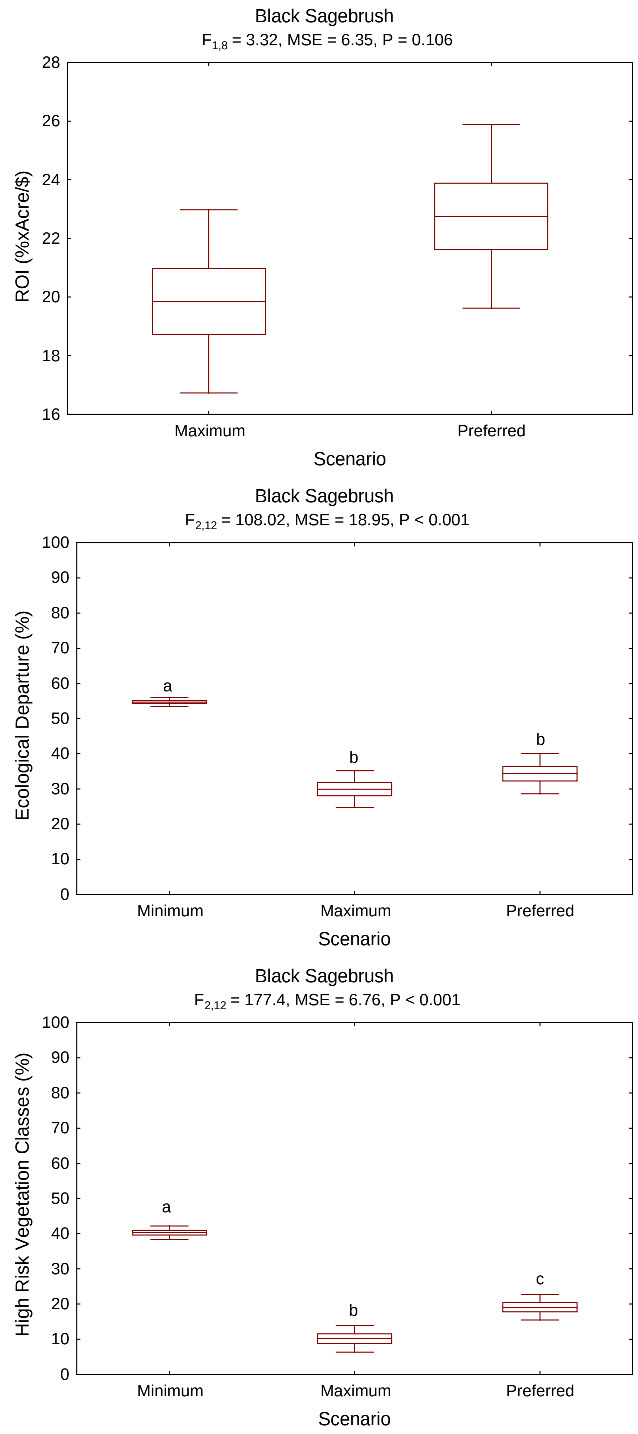


Figure 11. Return-on-Investment, ecological departure, and high-risk classes for the Black Sagebrush biophysical setting with MINIMUM, MAXIMUM, and PREFERRED MANAGEMENT scenarios for Great Basin National Park. The MINIMUM MANAGEMENT scenario is not shown in the ROI graph because this scenario is used 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: .

Limber-Bristlecone Pine-mesic Biophysical Setting

Limber-Bristlecone Pine-mesic forests occur at subalpine elevations in the southern half of the Park. The main conifers in this system are limber pine and bristlecone pine that grow as closed canopy forests, which are very different from the ancient bristlecone and limber pines woodlands in production, cover, and structure. Late-succession understories are often dominated by litter and mineral soil. At present, this system exhibits moderate ecological departure at 48% caused by a large over-abundance of the late succession class and corresponding under-representation of the mid-succession class.

Although ecological departure improved slightly to 42% from 48% over 50 years due to sporadic wildfires in a regime of minimum management, the distribution of classes did not change appreciably. Given the biophysical setting's great inertia to change, Park staff decided that additional management was required, especially to increase the forage base and visibility of bighorn sheep.

Park staff focused on prescribed fire because the Limber-Bristlecone Pine-mesic biophysical setting is generally found at high elevations on steep and remote terrain preventing easy use of wheeled mechanical methods, which would not comply with normal Park policies. Prescribed fire would be applied at a large scale by management of natural ignitions, helicopter ignitions and ground ignitions where road and foot access are feasible.

50-year Preferred Management Scenario Objectives

- Improve ecological condition of 4,500 acres of limber-bristlecone pine-mesic forests from 48% departure from NRV to ≤33% departure (Ecological Departure Class 1).

50-year Preferred Management Strategies and Costs

Strategy	Rate (acres/yr)	Years of Application	Cost ($/acre)
Prescribe burn by helicopter or ground ignition the late-succession class C	555	1-3	50
"Free prescribed fire" as a benefit of prescribed fires conducted in immediately lower elevation or adjacent biophysical settings, such as Aspen-Mixed Conifer or Aspen-Subalpine Conifer (see later Figure 19).	195	1-3	0

The average annual cost of these treatments was $55,500 during years of implementation, for a total of $166,500 in 3 years.

50-year Outcomes

- The ROI for the PREFERRED MANAGEMENT scenario was significantly higher (~87) than the MAXIMUM MANAGEMENT scenario at ~66 (P = 0.003; Figure 12 top) with no overlap in 95% confidence intervals. Clearly, the PREFERRED MANAGEMENT scenario was the preferred choice.

- MAXIMUM AND PREFERRED MANAGEMENT scenarios resulted in an improved ecological departure score relative to MINIMUM MANAGEMENT (42% versus 24% and 24%, respectively; P< 0.001; Figure 12 middle); however, the MAXIMUM AND PREFERRED MANAGEMENT scenarios were statistically equal for ecological departure (see letter comparison in Figure 12 middle).

- Although both active scenarios met management objectives, the PREFERRED MANAGEMENT scenario had the higher ROI because it was designed to be less expensive to implement by the use of "free fire" (~$166,500) than the MAXIMUM MANAGEMENT scenario (~$225,000); otherwise both scenarios achieved the same burning.

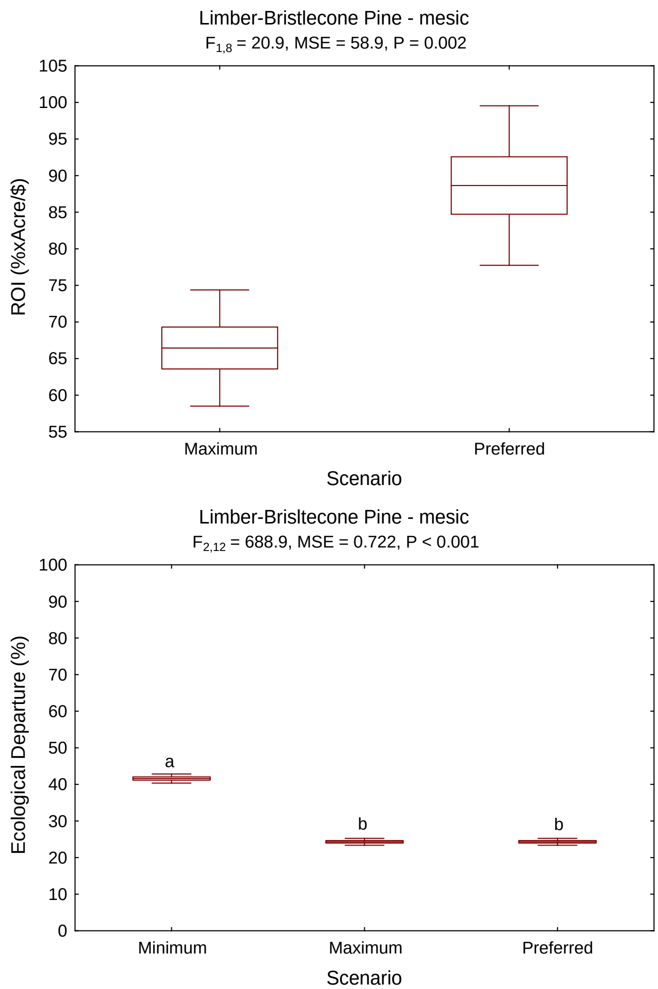


Figure 12. Return-on-Investment, ecological departure, and high-risk classes for the Limber-Bristlecone Pine-mesic biophysical setting with MINIMUM, MAXIMUM, and PREFERRED MANAGEMENT scenarios for Great Basin National Park. The MINIMUM MANAGEMENT scenario is not shown in the ROI graph because this scenario is used in the ROI calculation. Center of box is the mean, edges of box bars ± 1 SE, and bars are 95% confidence interval limits. N = 5 replicates. Different letters above two different boxes indicate significantly different means.

Low Sagebrush Steppe Biophysical Setting

The Low Sagebrush Steppe biophysical setting is found at high elevation on Horseheaven north of Snake Creek and around the northwestern corner of the Park. Low sagebrush is the dominant shrub and, unlike semi-desert low sagebrush shrublands, perennial grass cover is frequently high. At present, this system exhibits moderate ecological departure at 66% caused by under-represented early and mid-succession classes relative to over-represented late-succession classes.

After 50 years in a regime of minimum management, ecological departure (68% to 70%) decreased to 27% from 66% and high-risk classes (tree-encroached shrubland) barely increased from 0% to 1%. Given the importance of low sagebrush steppe for wildlife foraging, Park staff proposed minor management to further reduce to area in late-succession and increase mid-succession classes.

Park staff focused only on prescribed fire as a strategy.

50-YEAR PREFERRED MANAGEMENT Scenario Objectives

- Improve ecological condition of 420 acres of low sagebrush steppe from 66% departure from NRV to ≤17% departure (Ecological Departure Class 1).
- Contain uncharacteristic classes to <2%.

50-YEAR PREFERRED MANAGEMENT Strategies and Costs

Strategy	Rate (acres/yr)	Years of Application	Cost ($/acre)
Prescribe burn 40 acres/year of late-succession class (C)	40	1-3	250

The average annual cost of these treatments was $10,000 for the first 3 years, for a total of $30,000.

50-year Outcomes

- The MAXIMUM AND PREFERRED MANAGEMENT scenarios were identical, therefore their average ROI were equal at about 13.8 (P = 0.84; Figure 13 top; slight differences due to differences in random number sequences).

- MAXIMUM AND PREFERRED MANAGEMENT scenarios decreased ecological departure relative to the MINIMUM MANAGEMENT scenario (27% versus 16%; P< 0.001; Figure 13 middle). As explained above, ecological departures were the same for the MAXIMUM and PREFERRED MANAGEMENT scenarios reduced (see letter comparison in Figure 13 middle).

- MINIMUM, MAXIMUM AND PREFERRED MANAGEMENT scenarios maintained high-risk classes <2% (Figure 13 bottom).

- The MAXIMUM or PREFERRED MANAGEMENT scenarios met management objectives.

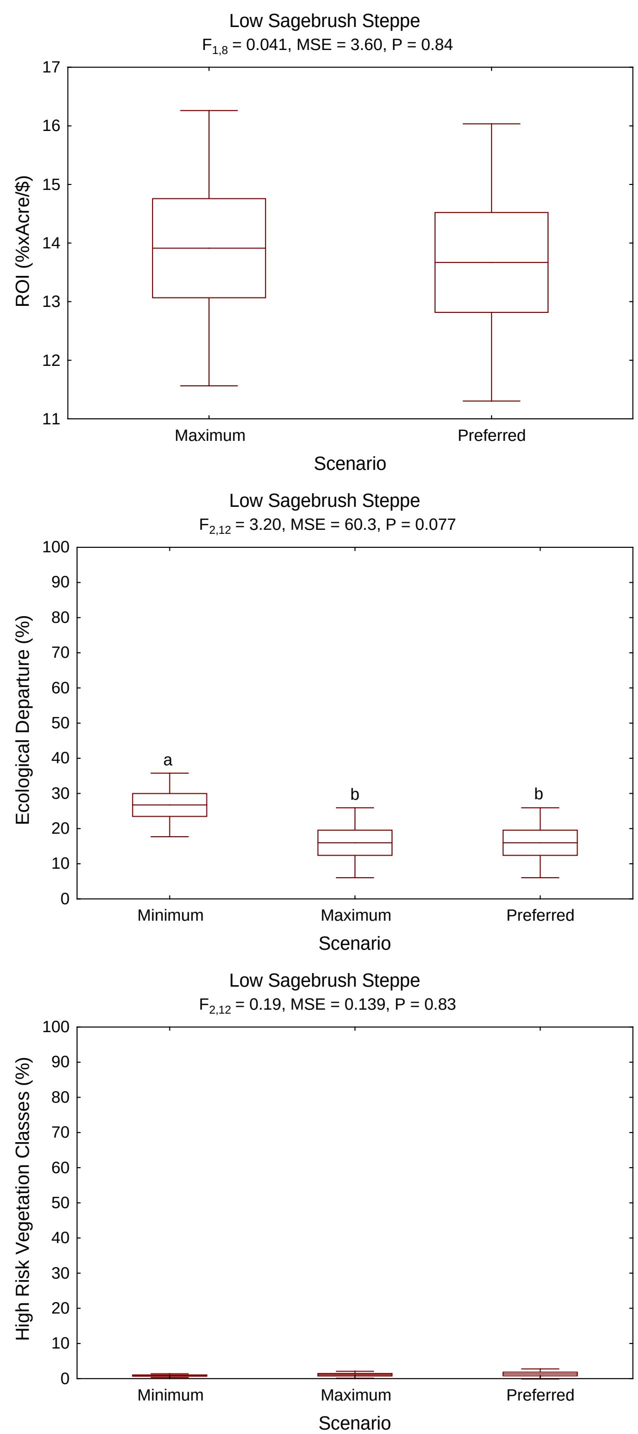


Figure 13. Return-on-Investment, ecological departure, and high-risk classes for the Low Sagebrush Steppe biophysical setting with MINIMUM, MAXIMUM, and PREFERRED MANAGEMENT scenarios for Great Basin National Park. The MINIMUM MANAGEMENT scenario is not shown in the ROI graph because this scenario is used in the ROI calculation. Center of box is the mean, edges of box bars ± 1 SE, and bars are 95% confidence interval limits. N = 5 replicates. Different letters above two different boxes indicate significantly different means. High-risk class data required transformation: log(1 + high-risk class).

Montane Riparian Biophysical Setting

The Montane Riparian biophysical setting occurs in the Park's drainages. The biophysical setting is very heterogeneous in geology, geomorphology, flow (sometimes intermittent), and plant species. Plant and animal species diversity are high. Typical dominant woody species are narrowleaf cottonwood, willows (several species), white fir, Douglas-fir, and Wood's rose. At present, this system exhibits low ecological departure at 26%. Although many creeks are in good condition, Snake Creek and Strawberry Creek have condition issues due to roads and past management. The low ecological departure is caused by under-represented early and mid-succession classes relative to too much late-succession classes. Minor areas of uncharacteristic vegetation represented by entrenched reaches with "desertified" vegetation (DE; 2%) and floodplain encroached by unpalatable shrubs and forbs (mainly *Rosa woodsia* and *Rhus trilobata* [SFE; 1%]) affect the condition of Snake and Strawberry Creeks.

After 50 years in a regime of minimum management, ecological departure increased to 40% from 26% and high-risk classes increased to 36% from 3% due to exotic forb invasion and an modest areas of other uncharacteristic classes. These levels of departure and exotic forb invasion were judged unacceptable.

Park staff focused on weed inventory and exotic species control. Workshop participants discussed the need and merit of floodplain restoration on Snake Creek, although this action was only modeled in the MAXIMUM MANAGEMENT scenario (not shown here). The goal is to reconnect the creek to its southern floodplain. Currently, the creek is entrenched where it flows along the road situated on the north side. Floodplain restoration was not retained in the PREFERRED MANAGEMENT scenario because of the very high $2,000/acre cost; however, if cost can be lowered through evaluation with low-technology rock weirs directing flow to the southern floodplain, managers should reconsider this action that could rehydrate the floodplain and naturally restore species composition towards "wetter" species. Floodplain restoration is particularly desirable in light of the potential for groundwater withdrawal, due to the interbasin transport of groundwater to Clark County Nevada and the existing water diversion in Snake Creek.

50-YEAR PREFERRED MANAGEMENT Scenario Objectives

- Improve ecological condition of 450 acres of Montane Riparian from 36% departure from NRV to <20% departure (Ecological Departure Class 1).
- Contain uncharacteristic classes to <11%.

50-YEAR PREFERRED MANAGEMENT Strategies and Costs

Strategy	Rate (acres/yr)	Years of Application	Cost ($/acre)
Inventory exotic forbs in all locations of the biophysical settings	8	50	50
Control exotic forbs with herbicides when detected	6 max	50	260

The average annual cost of these treatments was $785, for a total of $39,200 over 50 years.

50-year Outcomes

- The average ROI for the PREFERRED MANAGEMENT scenario (~25) was higher than the average MAXIMUM MANAGEMENT scenario at ~21, but the difference was marginally significant (P = 0.062; Figure 14 top) with overlap in 95% confidence intervals (especially after data transformation for statistical compliance).

- MAXIMUM AND PREFERRED MANAGEMENT scenarios approximately halved ecological departure relative to the MINIMUM MANAGEMENT scenario (40% versus 18% and 20%, respectively; P< 0.001; Figure 14 middle); however, the MAXIMUM AND PREFERRED MANAGEMENT scenarios were statistically equal for ecological departure (see letter comparison in Figure 14 middle).

- MAXIMUM AND PREFERRED MANAGEMENT scenarios dramatically reduced high-risk classes compared to the MINIMUM MANAGEMENT scenario (36% versus 3% and 5%, respectively; P< 0.001; Figure 14 bottom); however, the MAXIMUM MANAGEMENT scenario was slightly better at reducing the high-risk classes than the PREFERRED MANAGEMENT scenario (see letter comparison in Figure 14 bottom).

- Both active scenarios met management objectives. The PREFERRED MANAGEMENT scenario was the preferred choice, but given marginally equal ROIs and results above, the lower cost of the PREFERRED MANAGEMENT scenario ($39,200) compared to the MAXIMUM MANAGEMENT scenario ($81,600) alone justified this choice.

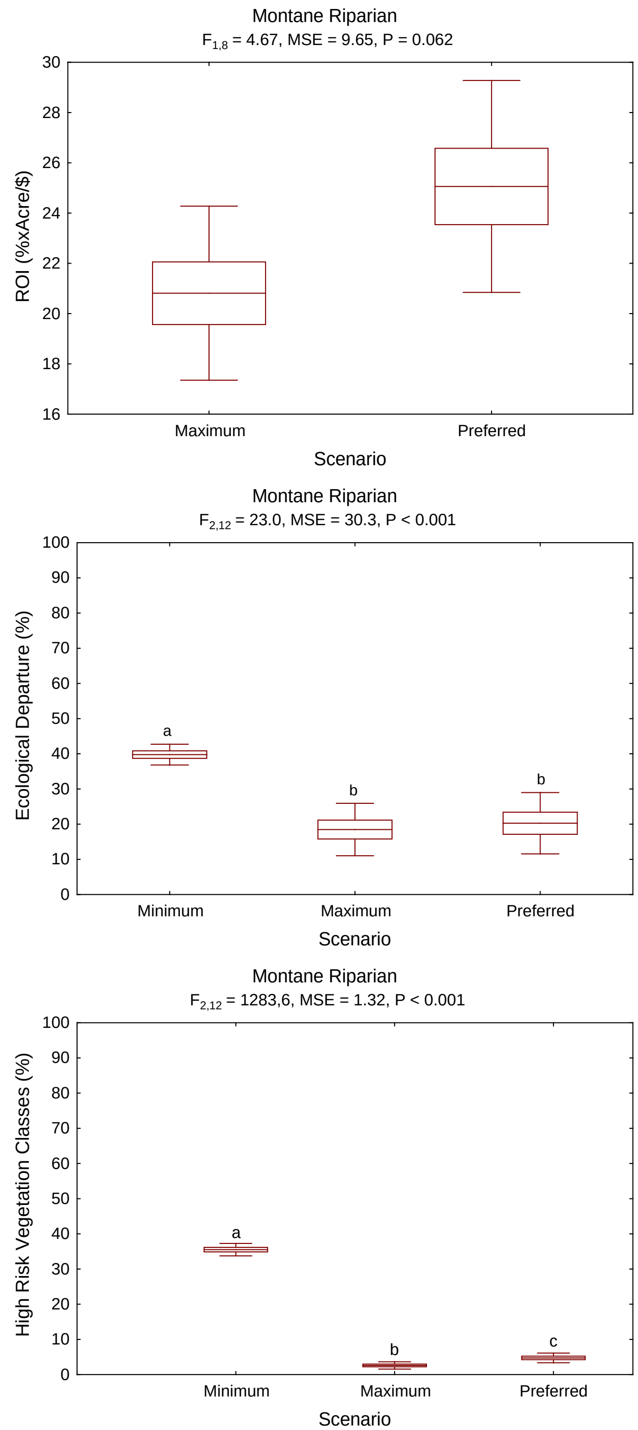


Figure 14. Return-on-Investment, ecological departure, and high-risk classes for the Low Sagebrush Steppe biophysical setting with MINIMUM, MAXIMUM, and PREFERRED MANAGEMENT scenarios for Great Basin National Park. The MINIMUM MANAGEMENT scenario is not shown in the ROI graph because this scenario is used in the ROI calculation. Center of box is the mean, edges of box bars ± 1 SE, and bars are 95% confidence interval limits. N = 5 replicates. Different letters above two different boxes indicate significantly different means.

Montane Sagebrush Steppe-upland Biophysical Setting

The Montane Sagebrush Steppe-upland biophysical setting occurs in the Park's 12 to 14-inch precipitation zone. Mountain big sagebrush is the dominant shrubs, although antelope bitterbrush can be abundant. Other shrubs and herbaceous species are usually abundant and diverse. At present, this system exhibits moderate ecological departure at 56%. The moderate ecological departure is caused by under-represented mid-succession classes (B and C), and by too much uncharacteristic vegetation represented by tree-encroached shrublands (TE; 21%) and shrubs with an understory of annual and perennial grasses (SAP; 8%).

After 50 years in a regime of minimum management, ecological departure improved to 41% from 56%, but high-risk classes increased to 30% from 21% due to sporadic wildfires causing recruitment to earlier succession classes and annual grasslands. These levels of departure and the loss of browse to annual grasslands were judged unacceptable.

Park staff focused on a variety of treatment actions (strategies) used alone or in combination chainsaw lopping and thinning, mastication, spot herbicide application, and native species seeding.

50-YEAR PREFERRED MANAGEMENT Scenario Objectives

- Improve ecological condition of 12,710 acres of Montane Sagebrush Steppe-upland from 56% departure from NRV to ≤33% departure (Ecological Departure Class 1).
- Contain all uncharacteristic classes to <17%.

50-YEAR PREFERRED MANAGEMENT Strategies and Costs

Strategy	Rate (acres/yr)	Years of Application	Cost ($/acre)
Chainsaw lop trees in classes late-succession open (D), depleted shrubs (DP), and shrubs with annual and perennial grasses (SAP)	50	50	70
Chainsaw thin or masticate[#] trees, pile or chip them, then conduct spot herbicide application for annual grasses and native species seeding of tree-encroached shrublands (TE)	50	50	450
Herbicide application to control annual grasses in shrublands with an understory of annual and perennial grasses (SAP)	50	50	100

[#]Mastication was not modeled and cost per acre is low for mastication; however this action is compatible and cost could be lowered.

The average annual cost of these treatments was $31,000, for a total of $1,550,000 in 50 years.

50-year Outcomes

- The average ROI for the PREFERRED MANAGEMENT scenario (~20) was higher than the average MAXIMUM MANAGEMENT scenario at ~16, but the difference was not significant (P = 0.234; Figure 15 top) with complete overlap in 95% confidence intervals.

- MAXIMUM AND PREFERRED MANAGEMENT scenarios approximately halved ecological departure relative to the MINIMUM MANAGEMENT scenario (62% versus 34% and 35%, respectively; P< 0.001; Figure 15 middle); however, the MAXIMUM AND PREFERRED MANAGEMENT scenarios were statistically equal for ecological departure (see letter comparison in Figure 15 middle).

- MAXIMUM AND PREFERRED MANAGEMENT scenarios reduced high-risk classes compared to the MINIMUM MANAGEMENT scenario (43% versus 1.7% and 9.6%, respectively; P< 0.001; Figure 15 bottom); however, the MAXIMUM MANAGEMENT scenario was significantly better at reducing the high-risk classes than PREFERRED MANAGEMENT scenario (see letter comparison in Figure 15 bottom).

- Both active scenarios met management objectives. The PREFERRED MANAGEMENT scenario was the preferred choice, but given statistically equal ROIs and results above, the lower cost of the PREFERRED MANAGEMENT scenario ($71,500) compared to the MAXIMUM MANAGEMENT scenario ($138,300) alone justified this choice.

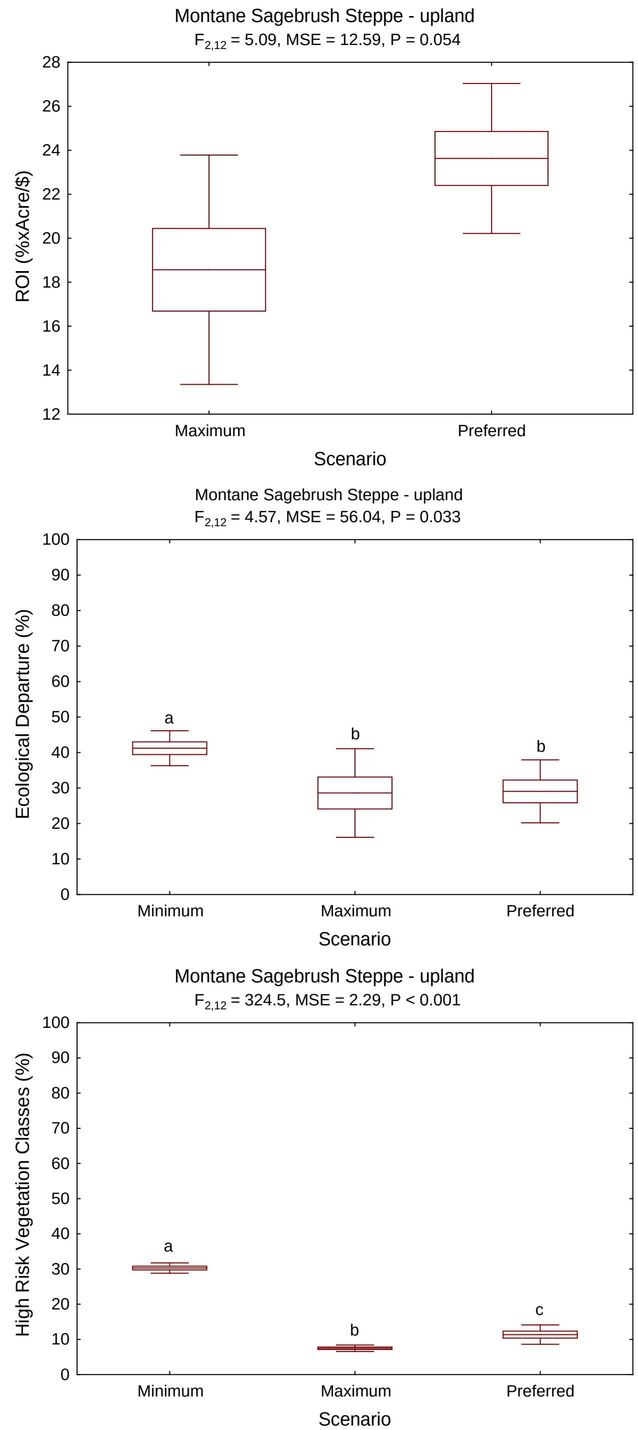


Figure 15. Return-on-Investment, ecological departure, and high-risk classes for the Low Sagebrush Steppe biophysical setting with MINIMUM, MAXIMUM, and PREFERRED MANAGEMENT scenarios for Great Basin National Park. The MINIMUM MANAGEMENT scenario is not shown in the ROI graph because this scenario is used in the ROI calculation. Center of box is the mean, edges of box bars ± 1 SE, and bars are 95% confidence interval limits. N = 5 replicates. Different letters above two different boxes indicate significantly different means.

Wet Meadow Biophysical Setting

The Wet Meadow biophysical setting is scattered in small patches mostly on the eastern side of the Park. Graminoids dominate this biophysical setting. At present, this system exhibits moderate ecological departure at 49% caused by an over-represented mid-succession class. Uncharacteristic classes were not detected.

After 50 years in a regime of minimum management, ecological departure increased to 49% from 40% and high-risk classes increased to 36% from 3% due to exotic forb invasion. These levels of departure and predicted exotic forb invasion were judged unacceptable.

Park staff focused on weed inventory and exotic species control.

50-YEAR PREFERRED MANAGEMENT Scenario Objectives

- Improve ecological condition of 90 acres of Wet Meadow from 49% departure from NRV to ≤33% departure (Ecological Departure Class 1).
- Contain uncharacteristic classes to <11%.

50-YEAR PREFERRED MANAGEMENT Strategies and Costs

Strategy	Rate (acres/yr)	Years of Application	Cost ($/acre)
Inventory exotic forbs in all locations of the biophysical settings	4	50	50
Control exotic forbs with herbicides when detected	1 max	50	260

The average annual cost of these treatments was $460, for a total of $23,000 over 50 years.

50-year Outcomes

- The average ROI for the PREFERRED MANAGEMENT scenario (~18) was higher than the average MAXIMUM MANAGEMENT scenario at ~16, but the difference was not significant (P = 0.41; Figure 16 top) with total overlap of 95% confidence intervals.

- MAXIMUM AND PREFERRED MANAGEMENT scenarios approximately decreased ecological departure relative to the MINIMUM MANAGEMENT scenario (40% versus 20% and 28%, respectively; P< 0.012; Figure 16 middle); however, the MAXIMUM AND PREFERRED MANAGEMENT scenarios were statistically equal for ecological departure (see letter comparison in Figure 16 middle).

- MAXIMUM AND PREFERRED MANAGEMENT scenarios dramatically reduced high-risk classes compared to the MINIMUM MANAGEMENT scenario (36% versus 2% and 9%, respectively; P< 0.001; Figure 16 bottom); however, the MAXIMUM MANAGEMENT scenario was slightly better at reducing the high-risk classes than PREFERRED MANAGEMENT scenario (see letter comparison in Figure 16 bottom).

- Both active scenarios met management objectives. The PREFERRED MANAGEMENT scenario was the preferred choice, but given marginally equal ROIs and results above, the lower cost of the PREFERRED MANAGEMENT scenario ($23,000) compared to the MAXIMUM MANAGEMENT scenario ($72,000) alone justified this choice.

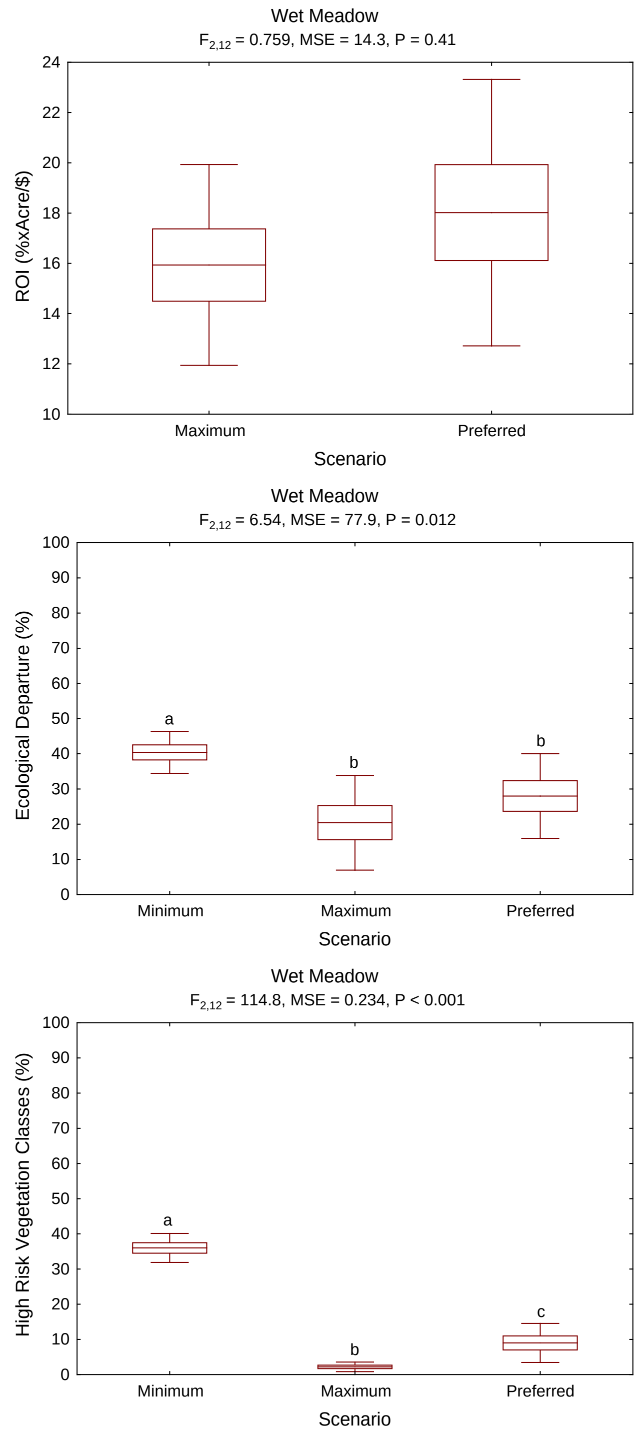


Figure 16. Return-on-Investment, ecological departure, and high-risk classes for the Low Sagebrush Steppe biophysical setting with MINIMUM, MAXIMUM, and PREFERRED MANAGEMENT scenarios for Great Basin National Park. The MINIMUM MANAGEMENT scenario is not shown in the ROI graph because this scenario is used in the ROI calculation. Center of box is the mean, edges of box bars ± 1 SE, and bars are 95% confidence interval limits. N = 5 replicates. Different letters above two different boxes indicate significantly different means. High-risk class data required transformation: .

Prioritizing Actions among Biophysical Settings: Return-on-Investment

Although ROI was used to choose between MAXIMUM MANAGEMENT and PREFERRED MANAGEMENT scenarios within a biophysical setting, ROI is also used to prioritize implementation of scenarios among biophysical settings.

The PREFERRED MANAGEMENT scenario was chosen in all 10 biophysical settings, mainly because of the scenario's lower implementation costs. The Aspen-Subalpine Conifer and Limber-Bristlecone Pine-mesic biophysical settings showed distinctively higher ROIs (expressed as a median) than all others (Figure 18). All other biophysical settings had comparable ROIs with, perhaps, consistently lower ROI for the Low Sagebrush Steppe biophysical setting.

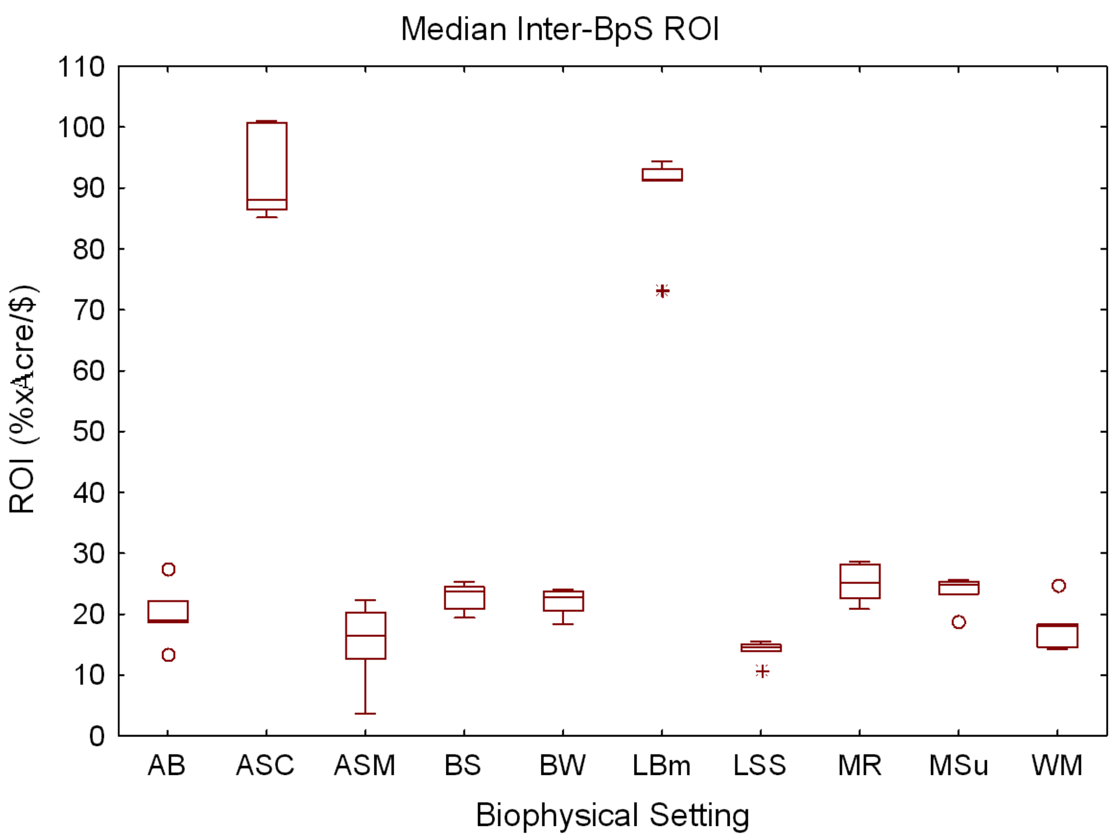


Figure 18. Median ecological system-wide return on investment (ROI) for the 10 ecological systems of Great Basin National Park selected for active management analyses. The line in the box is the median, edges of the box are the 25% and 75% quartile, bars are non-outlier range, circles are outliers, and * is extreme values. We chose the median's statistics because it conveyed more information than graphs based on the mean, which are shown in previous figures. Legend: AB = Antelope Bitterbrush, ASC = Aspen-Subalpine Conifer, ASM = Aspen-Mixed Conifer, BS = Black Sagebrush, BW = Basin Wildrye, LBm = Limber-Bristlecone Pine-mesic, LSS = Low Sagebrush Steppe, MR = Montane Riparian, MSu = Montane Sagebrush Steppe-upland, and WM = Wet Meadow.

In summary, these various ROI values are useful tools for land managers to decide where to allocate scarce management resources among many possible choices on lands that they administer. As a rule of thumb, the higher ROI indicates a higher priority for implementation; therefore, managers should pay special attention to the Aspen-Subalpine Conifer and Limber-Bristlecone Pine-mesic biophysical settings (Table 7). Of course, managers may also select final strategies or treatment areas based upon a variety of additional factors, such as availability of financial resources, policy constraints, and other uses or societal objectives.

Table 8. Summary of ecological forecasts for management scenarios in 10 biophysical setting of Great Basin National Park Ecological departure scores were classed as good (0-33%, Class 1, green); fair (34-66%, Class 2, yellow); and poor (>66%, Class 3, red). Stress (levels of high-risk classes) to ecological systems was ranked as: low (0%, dark green); medium (1-10%, light green); high (11-30%, yellow), and very high (>30%, red).

	Ecological Departure (%)			High-Risk Classes						
Biophysical setting	Current Condition	Minimum Mgmt - 50 yrs	Preferred Mgmt 50 yrs	Current Condition	Minimum Mgmt - 50 yrs	Preferred Mgmt 50 yrs	Area (acres)	Preferred Mgmt Avg. annual cost over years of implementation[&]	mean ROI	Preferred Mgmt Avg. total cost over 50 yrs
Alpine-Subalpine										
Aspen-Subalpine Conifer	60	27	11	7	20	10	11,320	$108,918	92	$326,755
Limber-Bristlecone Pine - mesic	48	42	24	n/a	n/a	n/a	4,500	$29,284	89	$87,854
Mid-Elevation Forests										
Aspen- Mixed Conifer	66	33	22	6	12	8	8,110	$82,834	15	$828,340
Shrublands										
Antelope Bitterbrush	74	62	35	28	44	10	340	$20,866	20	$104,330
Basin Wildrye	68	70	35	43	64	24	270	$12,371 first 3 yrs / $1,192 last 47 yrs	22	$93,159
Black Sagebrush	60	55	34	39	40	19	1,880	$113,877	23	$341,633
Low Sagebrush Steppe	61	27	16	0	1	1	420	$10,616	14	$31,850
Montane Sagebrush Steppe - upland	56	41	29	21	30	11	12,710	$33,422	24	$1,671,115
Riparian and Wet Meadows										
Montane Riparian	26	40	20	3	36	5	450	$1,806	25	$90,301
Wet Meadow	49	40	28	0	36	9	90	$399	18	$19,930
Total										$3,595,268

[&] Simulations were 50 years; however management actions were frequently implemented for much shorter duration. The Montane Riparian and Wet Meadow biophysical settings received treatments consistently every year for 50 years, whereas others biophysical settings had treatments concentrated in the beginning of simulations.

Recommended Treatment Areas

To this point, the analysis has been non-spatial. This section maps the recommended treatment areas to inform implementation decisions by Park managers. The recommended treatment areas show all possibilities, of which managers only need to select a subset. These maps might also be useful to gain economies of scale because different biophysical settings share the same treatments in proximity to one another. One such economy of scale was "free fire" proposed in the previous section for the Aspen-Subalpine Conifer and Limber-Bristlecone Pine-mesic biophysical settings, which also had the highest ROI.

Prescribed Fire

The prescribed fire map was clearly the busiest because this action was proposed for many biophysical settings, including the largest ones, and at a high rate of implementation in the subalpine zone (Figure 19). Park staff assumed at the workshop that many of the proposed burns would require helicopter ignition. The most distinctive spatial features for implementation were the clumping of candidate areas and large number of contact zones among biophysical settings. These features suggest the flexibility to define prescribed fire polygons such that ignitions are conducted in montane biophysical settings and then fire is allowed to move uphill in the subalpine vegetation without ignitions in this later zone. The Aspen-Subalpine Conifer biophysical setting has the greatest adjacency to the Aspen-Mixed Conifer biophysical setting in a lower to higher elevation configuration (Figure 19); therefore the greatest potential for "free fire" will be achieved in the subalpine aspen forests. To a lesser extent, the Limber-Bristlecone Pine-mesic and the Low Sagebrush Steppe biophysical settings could also be recipient of "free fire" ignited from the Aspen-Mixed Conifer biophysical setting; however, fire management staff might also need to consider the riskier option of including horizontal fire spread in the prescribed fire polygons. Horizontal fire spread is considered riskier because fire normally climbs uphill; therefore lateral spread implies that wind is sufficiently strong to overcome the natural movement of fire.

Figure 19 presents a cautionary note for prescribed fire conducted at the Park's eastern boundary. Large areas not considered appropriate for burning are shown between the Park's eastern boundary and the upper montane-subalpine zone. The vegetation in these parts is dominated by curl-leaf mountain mahogany and pinyon-juniper woodlands with high levels of woody biomass. The pathway for prescribed fire escapes from ignitions in Black Sagebrush, Antelope Bitterbrush, and Basin Wildrye biophysical settings would be through these woodlands where large crown fires can spread rapidly. In other words, greater planning should be made for the lowest elevation prescribed fires than the ones in the upper montane-subalpine zone.

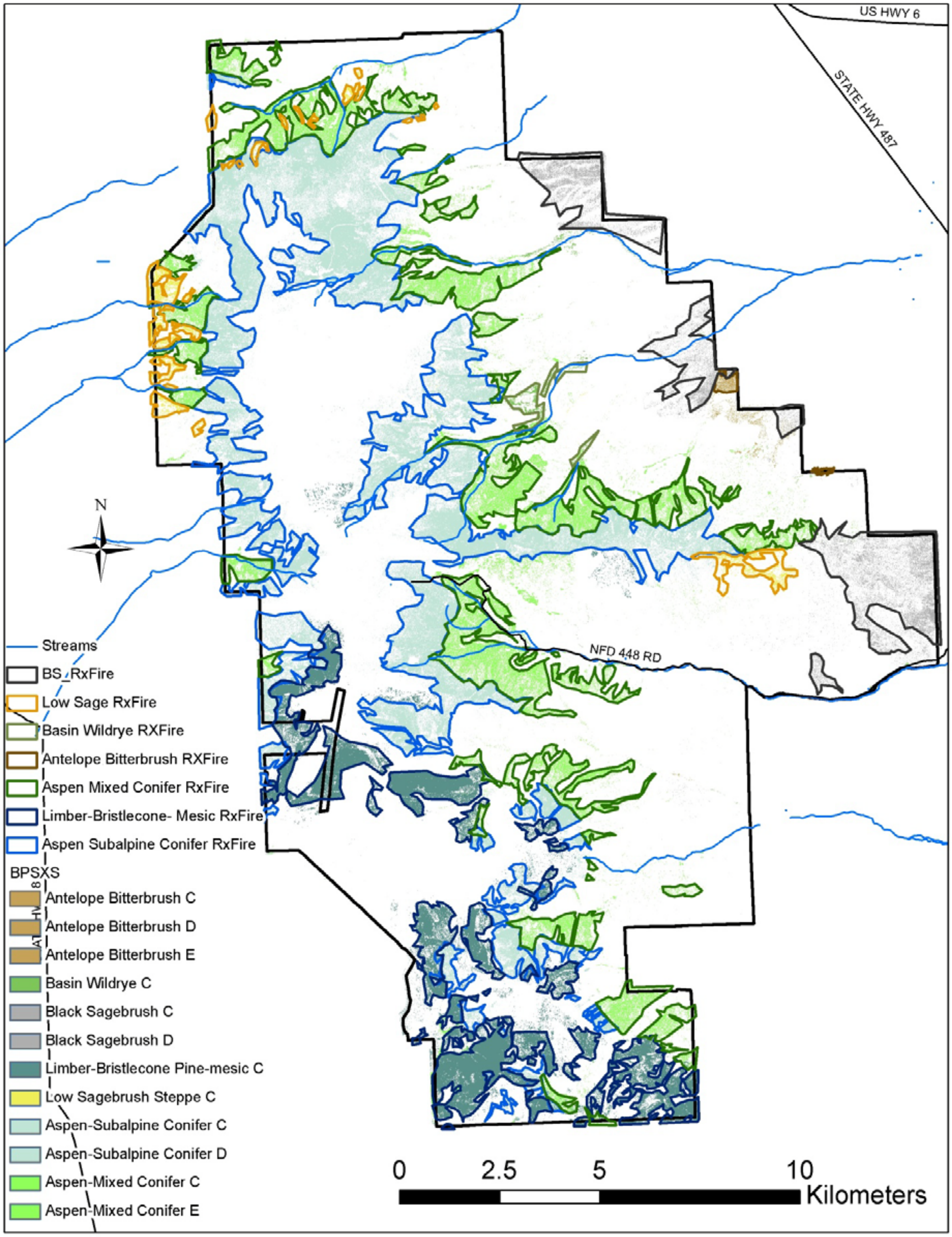


Figure 19. Recommended areas for implementation of prescribed fire. Map shows both the combinations of biophysical setting and vegetation classes were prescribed fire applied and the areas of implementation by biophysical setting.

Chainsaw lopping

Prescribed fire was only applied to reference classes. The next treatment group, chainsaw lopping of young pinyon and juniper trees to slow down their encroachment of shrublands, was applied to both late-succession open classes of the reference condition and uncharacteristic classes (depleted sagebrush [DP], shrub with annual grasses [SA], shrub with annual and perennial grasses [SA]) that are or will become encroached with trees. Lopping was proposed for the Antelope Bitterbrush, Black Sagebrush, and Montane Sagebrush Steppe-upland biophysical settings on a range of shallow (preferred) to steep slopes (Figure 20). Candidate areas were from the upper part of Strawberry Creek, along the eastern boundary, and in the Big Wash drainage.

Comparison of Figures 19 and 20 reveal a large overlap between prescribed burning and chainsaw lopping in black sagebrush. These treatments are mutually exclusive and would need to be spatially segregated to prevent waste of funds. As will be seen for all maps, areas of overlap are common along the eastern boundary and the most worrisome cases involve the presence of vegetation classes with cheatgrass adjacent to reference classes within prescribed fire perimeters.

Chainsaw thinning

Chainsaws were also proposed for more intense removal of older pinyon and juniper in the late-succession closed class (E) of the Antelope Bitterbrush biophysical setting (Figure 21). The principal goal of this action is to preserve winter browse (i.e., antelope bitterbrush and other shrubs) while removing trees, something prescribed fire would not be able to accomplish without a long period of species recovery. The northern most of the three alternative areas of chainsaw thinning was also proposed for prescribed fire (Figure 19 *versus* Figure 21). Prescribed fire was meant to target three late-succession classes C, D, and E of this biophysical setting that are intermingled. Whether fire or chainsaw are used will be decided by the Park's staff; however, we recommend chainsaw thinning for three reasons: preservation of winter browse as per Park objectives, lower risk of fire escaping prescribed burn perimeter, and lower likelihood of stimulating hidden cheatgrass seed banks.

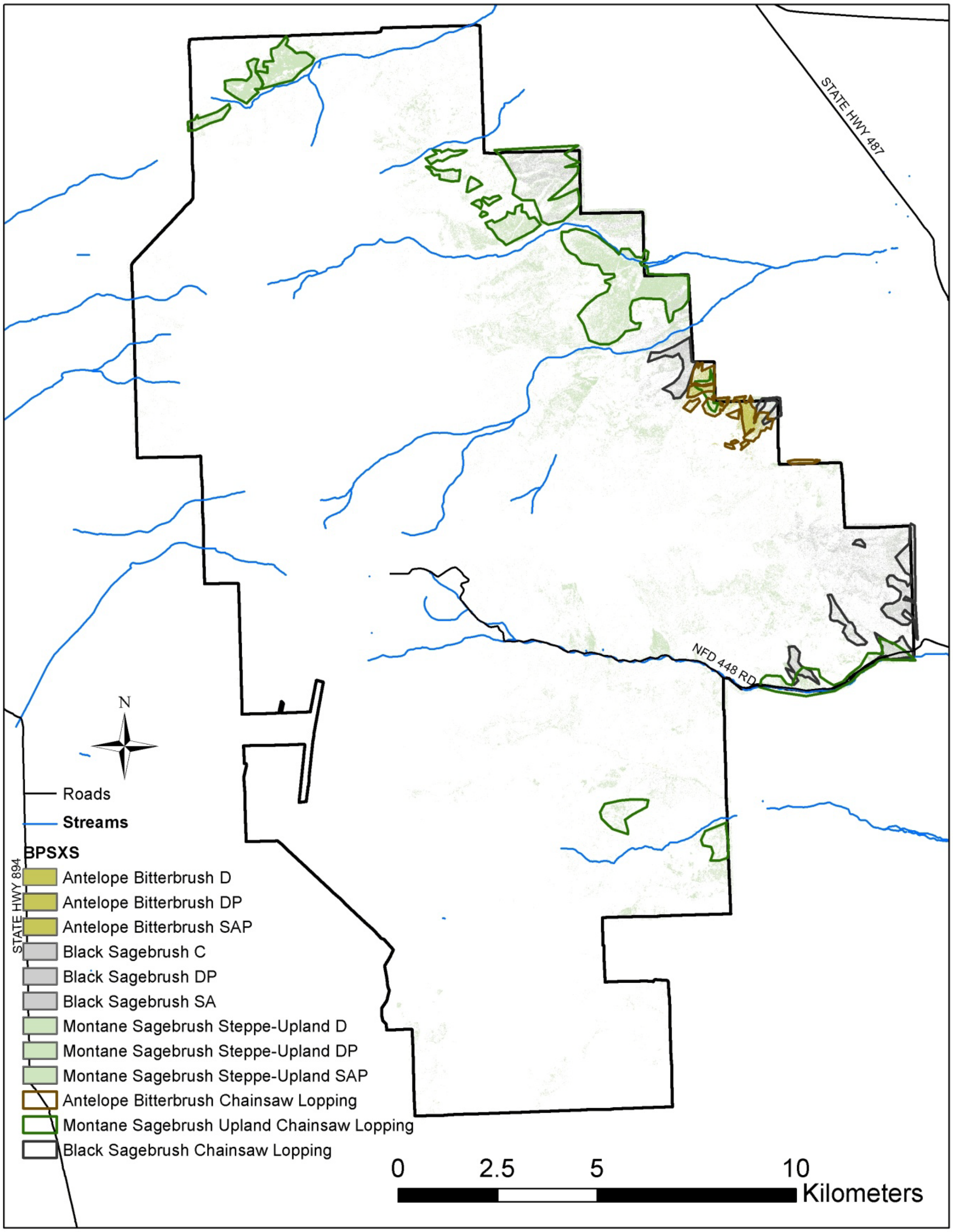


Figure 20. Recommended areas for implementation of chainsaw lopping. Map shows both the combinations of biophysical setting and vegetation classes were chainsaw lopping applied and the areas of implementation by biophysical setting.

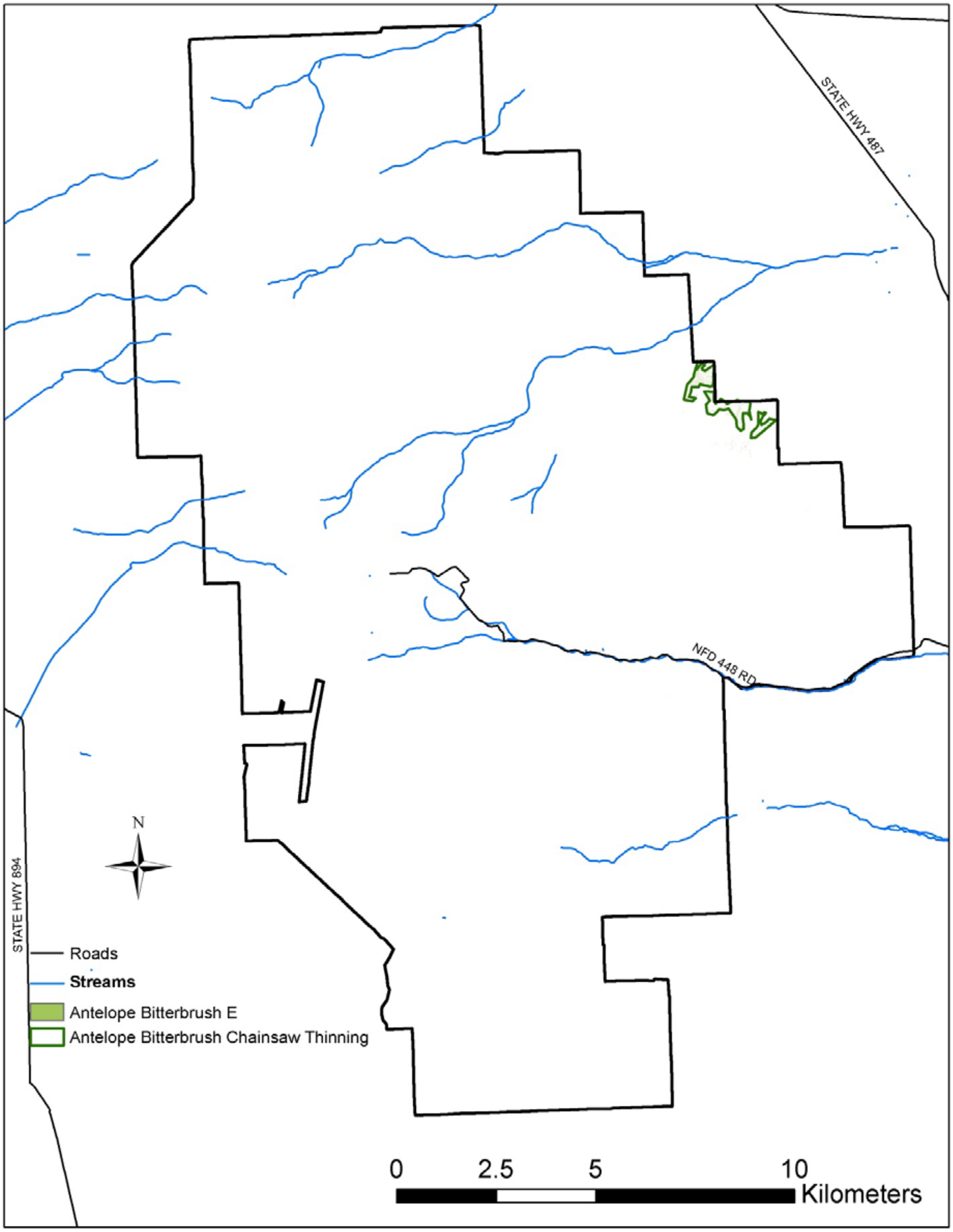


Figure 21. Recommended areas for implementation of chainsaw thinning in the late-succession closed class of Antelope Bitterbrush biophysical setting.

Treatment combinations with seeding

Many proposed restoration strategies require native species seeding because target uncharacteristic classes lacked a native herbaceous understory. These restoration strategies were frequently combinations of actions, including seeding, and, as a result, were the most expensive to implement. Figures 22 and 23 shows all the types of restoration strategies proposed for implementation in depleted (DP) Antelope Bitterbrush, Basin Wildrye, and Black Sagebrush biophysical settings, shrubs with an annual grass understory (SA) in Basin Wildrye and Black Sagebrush biophysical settings, and in tree-encroached (TE) Antelope Bitterbrush, Basin Wildrye, Black sagebrush, and Montane Sagebrush Steppe-upland biophysical settings. Actions were generally limited to slopes <15% to permit the use of thinning and chipping equipment. One exception was the helicopter application of prescribed fire used in combination with herbicide (for annual grasses) and seeding on steeper slopes (>15%) for the Montane Sagebrush Steppe-upland biophysical setting, which was also proposed to receive the *Chainsaw thinning + Chip + Herbicide + Seed* strategy on shallower slopes.

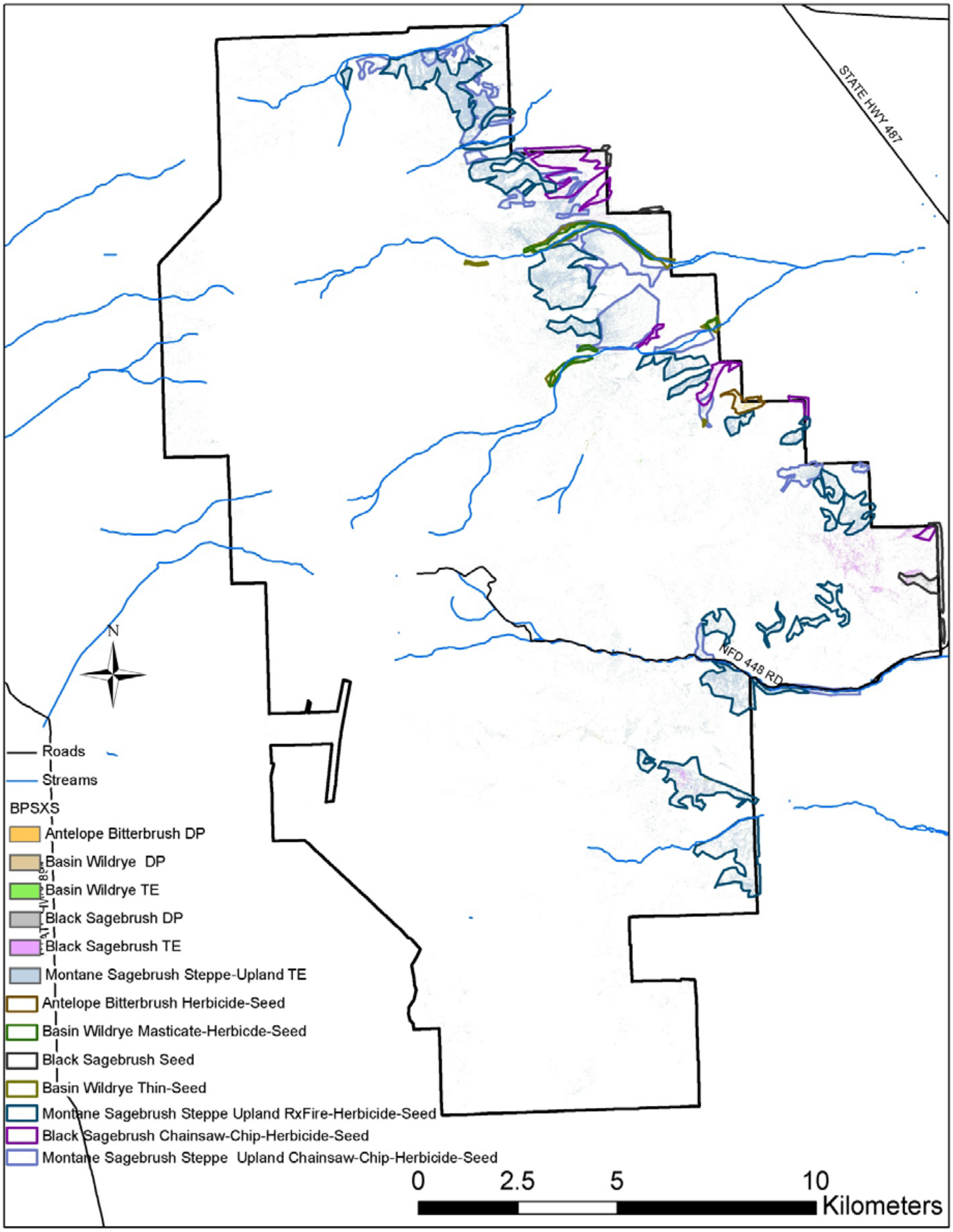


Figure 22. Recommended areas for implementation of various treatments requiring native species seeding. Map shows both the combinations of biophysical setting and vegetation classes were treatments applied and the areas of implementation by biophysical setting.

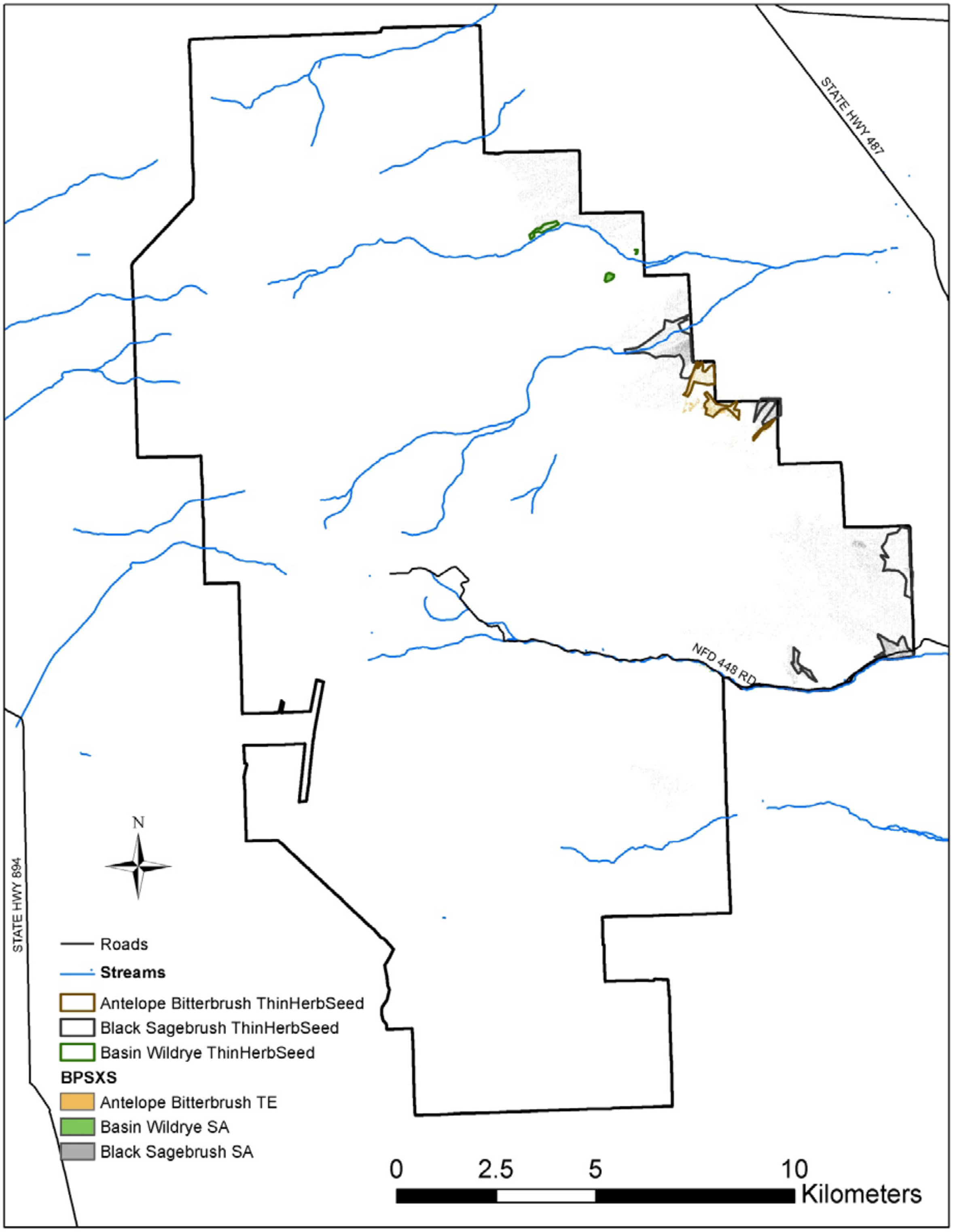


Figure 23. Recommended areas for implementation of various treatments requiring native species seeding. Map shows both the combinations of biophysical setting and vegetation classes were treatments applied and the areas of implementation by biophysical setting.

Annual grass herbicides

A few uncharacteristic vegetation classes were not considered high-risk because they can be restored at a lower cost, even with cheatgrass. The class of shrubs with a mixed understory of annual and perennial grasses (SAP) was not considered high-risk because it “only” requires an application of herbicide specific to annual grasses. The Antelope Bitterbrush and Montane Sagebrush Steppe-upland biophysical settings contained a few areas with this class where spot herbicide application can be conducted (Figure 24). Helicopter application might be more justified in the Kious Basin for bitterbrush and upper Strawberry Creek for the Montane Sagebrush Steppe-upland biophysical setting where pixels are densely located over large enough areas to make application by backpack impractical (Figure 24).

Weed inventory

The last treatment strategy proposed was weed inventory of the Basin Wildrye, Montane Riparian, and Wet Meadow biophysical settings (Figure 25). Weed inventory, and subsequent exotic forb control if exotic species are detected, were the most important actions to preventing future degradation to these biophysical settings (Table 7). Although we mapped the entirety of the biophysical settings, Park staff should prioritize drainages where traffic and recreational uses are greatest as people and their vehicles are perhaps the greatest vectors of weeds. Strawberry Creek, Lehman Creek, Baker Creek, and Snake Creek are perfect candidates for weed invasion.

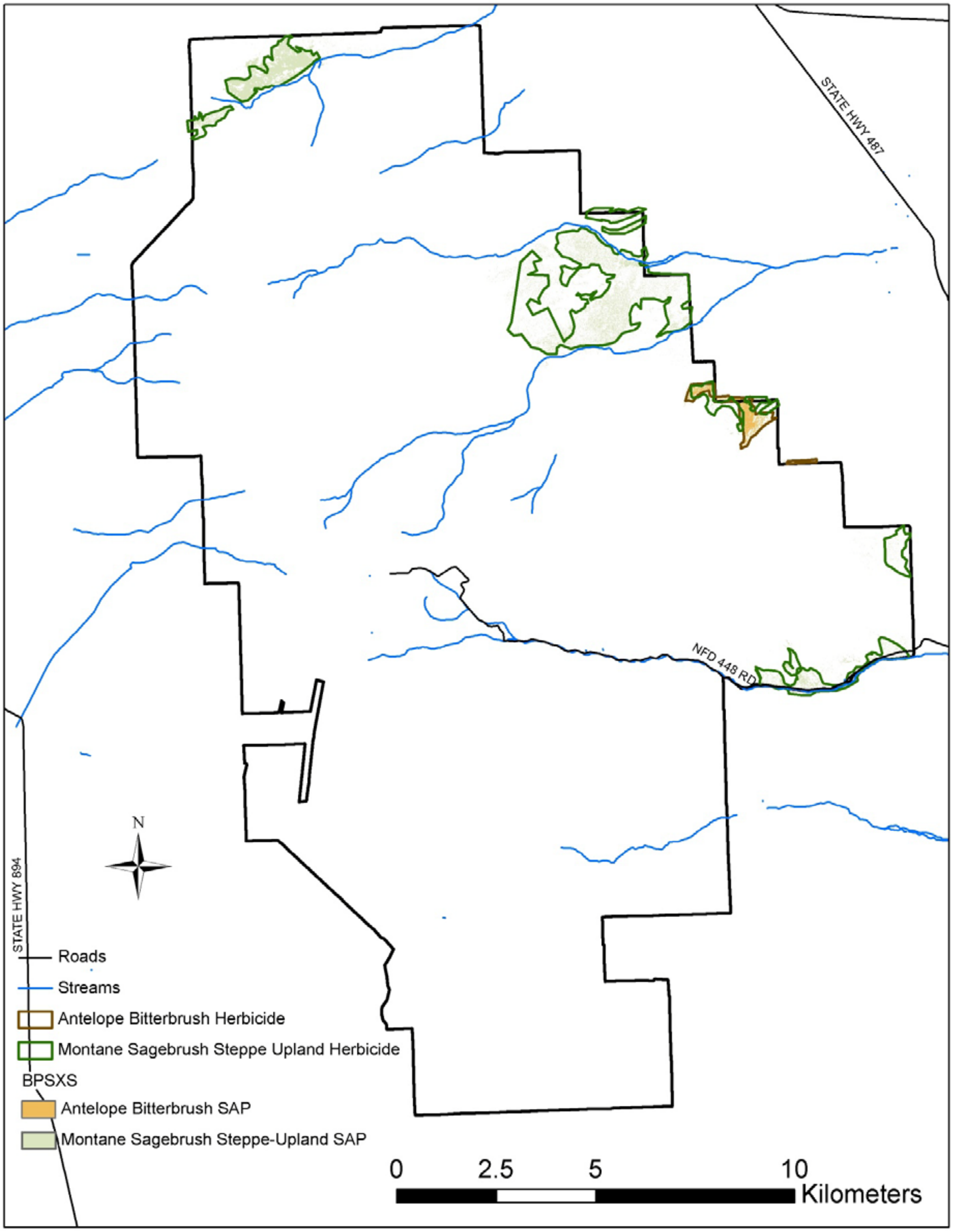


Figure 24. Alternative areas for herbicide application to control annual grasses in the Antelope Bitterbrush and Montane Sagebrush Steppe-upland biophysical settings in the shrub with a mixed understory of annual and perennial grasses.

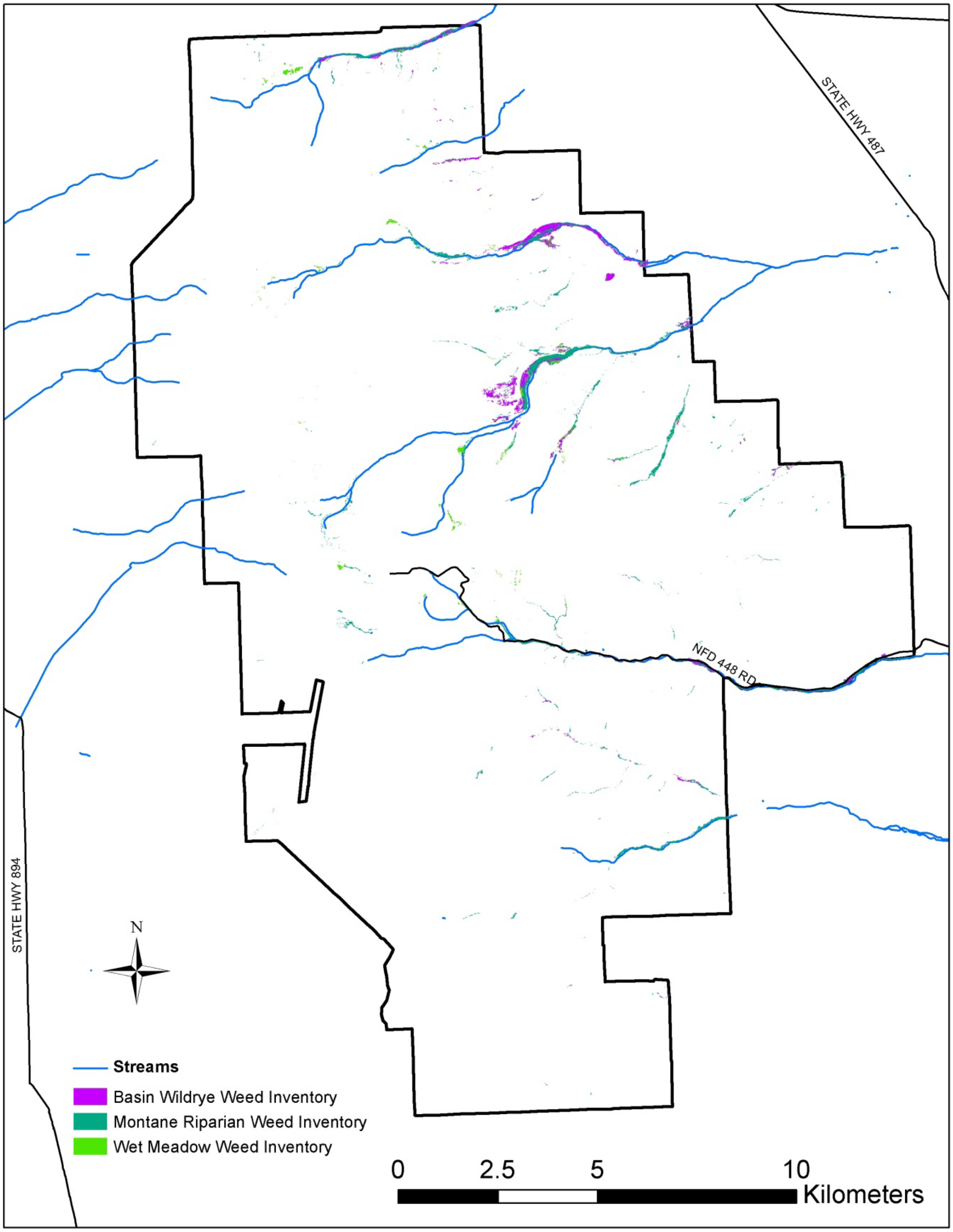


Figure 25. Alternative areas for exotic forb inventory in the Basin Wildrye, Montane Riparian, and Wet Meadow biophysical settings. Currently, the whole biophysical settings were proposed for inventory.

Conclusions

The primary findings of Landscape Conservation Forecasting for Great Basin National Park are summarized below:

1. **The current condition of the Park's ecological systems varies in terms of departure from their NRV, Most biophysical settings are only slightly or moderately departed from their natural range of variability.** Of the area's 21 biophysical settings that were measured, nine are slightly departed from NRV, ten are moderately departed, and only two smaller systems are highly departed. Accordingly, virtually the entire Park falls within Ecological Departure Class (a.k.a., Fire Regime Condition Class) 1 or 2.
2. **The primary cause of ecological departure across the landscape is due to sagebrush systems which lack the earliest succession classes and aspen-conifer systems which are over-represented by late succession classes.** The most likely cause of dominance by older vegetation is fire exclusion, caused by fire-suppression management and past consumption of fine fuels by livestock. For example, montane sagebrush steppe below ~9500 feet elevation comprises almost 13,000 acres, approximately 17% of the project area. There is virtually no presence of the early succession classes; moreover, conifer tree species have encroached upon a large portion of the native sagebrush. In the aspen-subalpine conifer, approximately 11,000 acres, over 60% of the system is in the late-closed succession class, as compared to a targeted 8% late-closed under natural conditions.
3. **Two small systems (antelope bitterbrush and basin wildrye) are highly departed from NRV, primarily due to the presence of cheatgrass and conifer encroachment.**
4. **High-risk vegetation classes are projected to increase substantially in several systems without active management.** Computer simulations show the two aspen-conifer systems are both projected to lose aspen clones in their current late-closed vegetation classes; exotic forbs will invade basin wildrye, riparian, and wet meadow systems; and annual grasses will increase in most shrubland systems.
5. **Ten biophysical settings were chosen for specific management.** The key ecological management issues include:
    a. ***Sagebrush systems (montane sagebrush-upland, black sagebrush, low sagebrush steppe, antelope bitterbrush, basin wildrye)*** – lack of early succession classes, pinyon-juniper encroachment, and increasing cover of cheatgrass.
    b. ***Aspen-conifer systems (aspen-subalpine conifer and aspen-mixed conifer)*** -- high percentage of conversion to conifers and permanent loss of aspen clones.
    c. ***Mesic limber-bristlecone pine*** – high percentage of late-succession classes at the expense of mostly mid-succession forests.
    d. ***Riparian, wet meadow, and basin wildrye systems*** – invasion by exotic forbs.

6. **A variety of strategies were modeled for each biophysical setting targeted for management. Multiple strategies are required for most ecosystems;**
    - **a.** ***Sagebrush*** management strategies include: prescribed fire to restore early succession classes; chainsaw lopping of encroached conifer trees; chainsaw thinning of late succession classes or tree-encroached sagebrush, variously combined with chipping, mastication, pile burning, herbicide and/or seeding of native species; and varied applications of herbicide and/or native seeding to uncharacteristic vegetation classes.
    - **b.** ***Aspen-conifer*** management strategies include prescribed fire to prevent transition to conifers and loss of aspen clone.
    - c. ***The mesic limber-bristlecone pine*** forest management strategy includes prescribed fire to reduce the area of late-succession classes and increase those of early and mid-succession classes.
    - **d.** ***Riparian and wet meadow*** management strategies include cyclic weed inventory and spot application of herbicides.
7. **Eleven biophysical settings were not targeted for active management in the Park because they are projected to benefit from periodic wildfires: curl-leaf mountain mahogany, pinyon-juniper woodland, spruce, limber-bristlecone pine, montane sagebrush steppe-mountain sites, mixed conifer, aspen woodland, montane-subalpine grassland, ponderosa pine, riparian ponderosa pine, mountain shrub, and subalpine riparian.** With the exception of alpine, fire is present to different degrees in all biophysical settings of the Snake Range. The 11 biophysical settings with no or few uncharacteristic classes benefitted enough from simulated fire as to not require further management to achieve low ecological departure. Simulated fire, although beneficial to ecological condition, was not enough for the remaining 10 biophysical settings with high levels of ecological departure or uncharacteristic classes.
8. **The computer simulations captured five different wildfire patterns over a 50 year period, with varying outcomes; however, in all cases the introduction of prescribed fire in early years additionally had beneficial ecological effect for the targeted biophysical settings.** For an aspen-subalpine conifer simulation, one "replicate" created a total of 4,500 acres of wildfire over 50 years in the 11,300 acre system, based on two years where very large fires occurred after decades of fire suppression. Another replicate had about half as much total wildfire, only 2,300 acres. One replicate had more frequent fire years. Two replicates had large fires in later years (Year 47), thereby producing a larger percentage of the early succession class. However, with prescribed fire introduced in the first three years, all replicates had more wildfire in subsequent years and generated low ecological departure (FRCC 1) after 50 years.
9. **The PREFERRED MANAGEMENT scenarios achieved lower ecological departure (seven in FRCC 1 and three at the lower end of FRCC 2) for all ten focal biophysical settings -- as compared to current condition and/or minimum management scenarios. Moreover, the preferred management strategies reduced or contained high-risk vegetation classes for all 10 biophysical settings.**

10. **Most preferred management strategies were implemented over a three-year up-front period, but achieved long term (50 year) results.** The time horizon for implementing strategies varied by biophysical setting and treatment, but the large majority of preferred treatments were for three years, with a few for a period of five or ten years. Only weed inventory and exotic species control treatments required ongoing implementation over a 50 year time horizon.

11. **The PREFERRED MANAGEMENT scenario significantly accrued the highest return-on-investment (ROI) for five biophysical settings, as compared to the MAXIMUM MANAGEMENT scenario.** For the five other biophysical settings, the average ROI of the PREFERRED MANAGEMENT scenario was higher but not statistically different from the ROI of the MAXIMUM MANAGEMENT scenario. The PREFERRED MANAGEMENT scenario was still chosen because its budget was the smallest. However, in many cases the MAXIMUM MANAGEMENT scenarios would achieve even greater ecological benefits, particularly in reducing high-risk vegetation classes, if additional management funds were to become available.

12. **TNC's ROI analysis showed that across the ten biophysical settings, the greatest predicted ecological benefits per dollar invested would equally accrue to Aspen-Subalpine Conifer and Limber-Bristlecone Pine-mesic.** All other biophysical settings shared comparable ROIs, although Low Sagebrush Steppe achieved the lowest one.

13. **Maps of recommended burn areas revealed economies of scale for prescribed fire in the subalpine zone.** The Aspen-Subalpine Conifer and Limber-Bristlecone pine-mesic biophysical settings can be recipient of prescribed fire ignited in the adjacent and lower elevation polygons of Aspen-Mixed Conifer biophysical setting.

14. **Maps of recommended treatment areas in the lower elevations revealed that the same areas can be recipient of mutually exclusive treatments.** Many treatments using alone or in combination prescribed fire, mechanical methods, herbicide application, and native species seeding overlapped on the eastern boundary of the Park and were mutually exclusive, such as the application of fire to an area with cheatgrass and late-succession reference classes. Overlap of different recommended treatment areas was caused by the proximity of pixels from different vegetation classes. Therefore, Park staff would be required to choose a strategy best meeting management objectives and causing the least damaging outcome.

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Appendix 1. Descriptions of vegetation classes within biophysical settings for Great Basin National Park.

Class Code[&]	Class abbreviation[&] and brief description
	Alpine (ALP) 1144
A	*Early*: 0-10% cover of graminoids; <90% soil cover; 0-2 yrs
B	*Late-closed:* >11% cover of graminoids and forbs; <10% cover of low shrubs; >2 yrs
U	Na
	Antelope Bitterbrush (AB) 1126ab
A	*Early*: 0-10% canopy of antelope bitterbrush/mountain sage; 10-80% grass/forb cover; 0-12 yrs
B	*Mid--open*: 11-30% cover of antelope bitterbrush; >50% herbaceous cover; 13-38 yrs
C	*Mid--closed*: 31-50% cover of antelope bitterbrush/mountain sage; 25-50% herbaceous cover, <10% conifer sapling cover; 38+ yrs
D	*Late-open*: 10-20% pinyon cover <5m; 25-40% cover of antelope bitterbrush/mountain sage; <30% herbaceous cover; 80-129 yrs
E	*Late-closed*: 21-40% pinyon cover 10-25m; 6-20% antelope bitterbrush/mountain sage; <20% herbaceous cover; 130+ yrs
U	*ES*: *Early*-Shrub; 20-50% cover rabbitbrush species
U	*TE*: Tree-Encroached; >21% pinyon cover 10-25m; <5% shrub cover; <5% herbaceous cover
U	*DP*: Depleted; 20-50% cover of antelope bitterbrush/mountain sage; <5% herbaceous cover; <10% pinyon sapling cover
U	*SAP*: Shrub-Annual-Grass-Perennial-Grass; 21-50% cover of antelope bitterbrush/mountain sage; >5% cover of native grass; 5-10% cheatgrass cover; <10% pinyon sapling cover
U	*AG:* Annual-Grass; 10-30% cover of cheatgrass
	Aspen Woodland (ASP) 1011
A	*Early*; 0-100% cover of aspen <5m tall; 0-9 yrs
B	*Mid*1-*closed*; 40-99% cover of aspen <5-10m; dense herbaceous and non-sagebrush shrub understory and midstory; 10-39 yrs
C	*Late*1-*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	*Late*1-*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.
	Aspen-Mixed Conifer (AMC) 1061
A	*Early*; 0-100% cover aspen <5m; mountain snowberry and *ribes* common; 0-19 yrs
B	*Mid*1-*closed*: 40-99% cover aspen <5-10m; mountain snowberry and *ribes* common; 11-39 yrs
C	*Mid*2-*closed*: 40-99% cover aspen 10-24m; conifer saplings visible in mid-story; mountain snowberry and *ribes* common; 40-79 yrs

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Class Code[&]	Class abbreviation[&] and brief description
D	*Late*1-*open*: 10-39% cover aspen 10-25 m; 0-25% mixed conifer cover 5-10 m; mountain snowberry and *ribes* common; >80 yrs
E	*Late*1-*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
	Aspen-Subalpine Conifer (ASC) 1061s
A	*Early*: 50-100% cover aspen <2m; mountain snowberry and *ribes* common; 0-9 yrs
B	*Mid*1-*closed*: 40-99% cover aspen <5-10m; mountain snowberry and *ribes* common; 10-39 yrs
C	*Mid*2-*open*: 10-30% cover aspen 10-24m; 10% cover of white fir and Engelman spruce; mountain snowberry and *ribes* common; 40-169 yrs
D	*Late*1-*closed*: 40-50% cover of white fir and Engelman 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 Engelman spruce 25-49m; >129 yrs
	Basin Wildrye (BW) 1126bw
A	*Early*: 0-20% cover of basin wildrye; 0-10 yrs
B	*Mid--Closed*: 21-80% cover of basin wildrye; <11% shrub cover; 11-75 yrs
C	*Late-Open*: 11-20% cover of big sagebrush & rabbitbrush; <75% cover of basin wildrye; >75 yrs
U	*DP*; Depleted; >20% cover of native shrubs; <5% basin wildrye; >20% mineral soil and litter cover
U	*SA*; Shrub-Annual-Grass; >10% cover of native shrubs; 0-30% basin wildrye; 5-30% cover of cheatgrass
U	*AG*: Annual-Grass; 5-40% cover of cheatgrass
U	*TE*: Tree-Encroached; 10-40% cover of conifers; <10% herbaceous cover
U	*TA*: Tree-Annual-Grass; 10-40% cover of conifers; 5-20% cover annual grasses
U	*EF*: Exotic-Forbs; 5-100% exotic forbs (knapweed, tall whitetop, purple loosetrife)
U	*ES*: *Early*-Shrub; >20% cover of rabbitbrush species; native grasses present
	Black Sagebrush (BS) 1079an
A	*Early*: <10% cover rabbitbrush; 10-40% cover of grass; <50% cover mineral soil; 0-25 yrs
B	*Mid*1-*open*: 10-20% cover of black sagebrush and rabbitbrush; 10-30% grass cover; <40% cover of mineral soil; 25-119 yrs
C	*Late1-Open*: 1-10% pinyon-juniper sapling cover; 20-30% cover of black sagebrush; 10-30% cover of grasses; 120-194 yrs
D	*Late*1-*Closed*: 10-40% cover of pinyon or juniper 5-10m high; <10% black sagebrush cover; <10% grass cover; >195 yrs
E	*Mid-Open*: animal burrow; 20-80% cover of mineral soil and rocks; <20% cover of winterfat, Indian ricegrass, spiny hopsage, and salt bushes; 0-999yrs
U	*ES*: *Early*-Shrub;10-40% cover rabbitbrush species
U	*TE*: Tree-Encroached; >40% pinyon or juniper cover 5-10m; <5% shrub cover; <5% herbaceous cover

Appendix 1. Descriptions of vegetation classes within biophysical settings for Great Basin National Park.

Class Code[&]	Class abbreviation[&] and brief description
U	*DP*: Depleted; 20-50% cover of black sagebrush; <5% herbaceous cover; <10% pinyon or juniper sapling cover
U	*SAP*: Shrub-Annual-Grass-Perennial-Grass; 20-50% cover of black sagebrush; >5% cover of native grass; 5-20% cheatgrass cover; <10% pinyon or juniper sapling cover
U	*SA*: Shrub-Annual-Grass; 20-50% cover of black sagebrush; <5% cover of native grass; 5-20% cheatgrass cover; <10% pinyon or juniper sapling cover
U	*AG:* Annual-Grass; 10-30% cover of cheatgrass
	Limber-Bristlecone Pine Woodland (LB) 1020
A	*Early*: 0-10% limber and bristlecone pine cover 0-5m high, abundant mineral soil or talus cover; sparse ground cover; 0-99 yrs
B	*Mid1-Open*: 11-30% limber and bristlecone pine cover 5-10m high, abundant mineral soil or talus cover; sparse ground cover; 100-249 yrs
C	*Late1-Open*; very old trees; 11-30% limber and bristlecone pine cover 5-25m high, abundant mineral soil or talus cover; sparse ground cover; >250 yrs
U	Na
	Limber-Bristlecone Pine Woodland – mesic (LBm) 1020
A	*Early*: 0-10% limber and bristlecone pine cover 0-5m high, abundant soil or talus; *Ribes* and *P*oa present; 0-49 yrs
B	*Mid1-Open*: 11-20% limber and bristlecone pine cover 5-10m high; *Ribes* and *P*oa present; 50-199 yrs
C	*Late1-Closed*; old trees but not ancient; 20-40% limber and bristlecone pine cover 5-25m high; *Ribes* and *P*oa present; >200 yrs
U	Na
	Low Sagebrush Steppe (LSS) 1124
A	*Early*: 15-25% herbaceous cover (bluebunch wheatgrass, Thurber's needlegrass); 0-10% cover of rabbitbrush; 0-25 yrs
B	*Mid*1-*open*: 11-20% cover of low sagebrush and mountain snowberry; 15-25% herbaceous cover (bluebunch wheatgrass, Thurber's needlegrass); 25-99 yrs
C	*Late1-Closed*: 21-30% cover of low sagebrush and Utah serviceberry; 10-15% herbaceous cover (bluebunch wheatgrass); >100 yrs
U	*TE:* 6-30% cover of trees; <5% herbaceous cover
U	*DP*: 5-20% cover of low sagebrush <0.5m, <5% herbaceous cover
U	*ES: Early*-Shrub;10-30% cover rabbitbrush species
	Mixed Conifer (MC)
A	*Early*; 0-29yrs; 0-15% cover of tree/shrub/grass; <5m; 0-29 yrs
B	*Mid*1-*closed*; 30-99yrs; 35-100% cover of conifers <24m; 30-99 yrs
C	*Mid*1-*open*; 31-99yrs; 0-35% cover of conifers <24m; 30-99 yrs
D	*Late*1-*open*; 100-999yrs; 0-35% cover of conifers 25-49m; >100 yrs
E	*Late*1-*closed*; 100-999yrs; 35-100% cover of conifers 25-49m; >100 yrs
U	*TA*; 10-100% cover of young and older conifers; >5% cheatgrass cover
U	*AG*: >10% cheatgrass cover; trees largely absent; charred logs or standing dead trees often

Appendix 1. Descriptions of vegetation classes within biophysical settings for Great Basin National Park.

Class Code[&]	Class abbreviation[&] and brief description
	present; native grasses and forbs may be present
	Montane Riparian (MR) 1154
A	*Early*: 0-50% cover of cottonwood, willow, Wood's rose <3m; carex present; 0-5 yrs
B	*Mid*1-*open*: 31-100% cover of cottonwood, aspen, willow, Wood's rose <10m; 5-20 yrs;
C	*Late*1-*closed*; 31-100% cover of cottonwood, alder, aspen, willow 10-24m; >20 yrs
U	*SFE*: Shrub-Forb-Encroached; 10-50% cover of Wood's rose in open areas or under tree canopy
U	*EF*: Exotic-Forbs; 10-100% cover of exotic forbs (knapweed, tall whitetop, purple loosetrife), salt cedar, or Russian olive
U	*DE*: Desertification; Entrenched river/creek with 10-50% cover of upland shrubs (e.g., big sage); >5% native grass cover
U	*AG*: Annual-Grass; 10-30% cover of cheatgrass on dry incised banks; < 10% shrub cover
U	*SAP: Shrub-Annual-Grass-Perennial Grass*: Entrenched river/creek with 10-50% cover of upland shrubs (e.g., big sage); >5% cheatgrass cover; >5% native grass cover
U	*SD: Seeded*; Entrenched river/creek with >20% crested wheatgrass cover
U	*SDA: Seeded-Annual-Grass*; Entrenched river/creek with >20% crested wheatgrass cover; >5% cheatgrass cover
U	*TE: Tree-Encroached*; Entrenched river/creek with >20% pinyon or juniper cover 5-10m; <5% shrub cover; <5% herbaceous cover
U	*DW: Dewatered*; Riparian floodplain with dry channel due entirely to water withdrawal; vegetation dominated by riparian and sub-xeric shrubs and trees; frequent evidence of branch pruning or dead cottonwoods or willows in what would have been *Late1-Closed* class.
U	*PD: Partially-Dewatered*; Riparian floodplain with partially dewatered channel due entirely to water withdrawal; vegetation as described for *Early*, *Mid1-Open, and Late1-Closed* classes; water level substantially below bankfull; evidence of branch pruning or dead cottonwoods or willows in *Late1-Closed* class.
U	*EFD: Exotic-Forb-Dewatered*; 10-100% cover of exotic forbs (knapweed, tall whitetop, purple loosetrife), salt cedar, or Russian olive in either dewatered or partially dewatered channel.
U	*DEP: Desertified-Partially-Dewatered;* Entrenched riparian floodplain with partially dewatered channel due entirely to water withdrawal; vegetation as described in *DE* class.
	Montane Sagebrush Steppe-mountain (>9500') 1126m
A	*Early*: 0-10% canopy of mountain sagebrush/ mountain brush, >50% grass/forb cover; ; 0-12 yrs;
B	*Mid--open*: 11-30% cover of mountain sagebrush / mountain shrub, >50% herbaceous cover; 13-37 yrs;
C	*Mid--closed*; 31-50% cover of mountain sagebrush / mountain brush, 25-50% herbaceous cover, <10% conifer sapling cover; >38 yrs
D	*Late-open*: 10-30% cover conifer <10m, 25-40% cover of mountain sagebrush / mountain brush, <30% herbaceous cover, 80-129 yrs

Appendix 1. Descriptions of vegetation classes within biophysical settings for Great Basin National Park.

Class Code[&]	Class abbreviation[&] and brief description
E	*Late-closed*: 31-80% conifer cover 10-25m, 6-20% shrub cover, <20% herbaceous cover; >129 yrs
U	*ES: Early*-Shrub; 0-40% cover rabbitbrush species
U	*TE*: Tree-Encroached; 31-80% conifer cover 10-25m, <5% shrub cover, <5% herbaceous cover; >130 yrs
U	*DP*: Depleted; 20-50% cover of mountain sage/mountain brush; <5% herbaceous cover; <10% conifer sapling cover
U	*SAP*: Shrub-Annual-Grass-Perennial-Grass; 10-50% cover of mountain sage/mountain brush; >5% cover of native grass; 5-10% cheatgrass cover; <10% conifer sapling cover (this class is uncommon and assumed temporary)
U	*AG:* Annual-Grass; 10-30% cover of cheatgrass (this class is uncommon and assumed temporary)
	Montane Sagebrush Steppe-upland 1126u
A	*Early*: 0-12 yrs; 0-10% canopy of mountain sage/mountain brush; 10-80% grass/forb cover
B	*Mid--open*: 13-38 yrs; 11-30% cover of mountain sage/mountain shrub; >50% herbaceous cover
C	*Mid--closed*; : 38+ yrs; 31-50% cover of mountain sage/mountain brush; 25-50% herbaceous cover, <10% conifer sapling cover
D	*Late-open*: : 80-129 yrs; 10-30% cover conifer <5m for PJ and <10m for mixed conifers; 25-40% cover of mountain sage/mountain brush; <30% herbaceous cover
E	*Late-closed*: 130+ yrs; 31-80% conifer cover (lower for PJ, greater for mixed conifers) 10-25m; 6-20% shrub cover; <20% herbaceous cover
U	*ES*: *Early*-Shrub;20-50% cover rabbitbrush species
U	*TE*: Tree-Encroached; 31-80% conifer cover 10-25m; <5% shrub cover; <5% herbaceous cover
U	*DP*: Depleted; 20-50% cover of mountain sage/mountain brush; <5% herbaceous cover; <10% conifer sapling cover
U	*SAP*: Shrub-Annual-Grass-Perennial-Grass; 21-50% cover of mountain sage/mountain brush; >5% cover of native grass; 5-10% cheatgrass cover; <10% conifer sapling cover
U	*SA*: Shrub-Annual-Grass; 21-50% cover of mountain sage/mountain brush; ≤5% cover of native grass; ≥5% cheatgrass cover; <10% conifer sapling cover
U	*AG:* Annual-Grass; 10-30% cover of cheatgrass
	Montane-Subalpine Grassland (MG) 1146
A	*Early*-open: 0-5 yrs; 0-10% herbaceous cover — graminoids, forbs, and sedges; abundant bare ground and rock cover; 0-4 yrs
B	*Mid*--closed: 5-10 yrs; 11-30% herbaceous cover — graminoids, forbs, and sedges; abundant bare ground and rock cover; 5-9 yrs
C	*Late*-open: >10 yrs; 11-30% herbaceous cover — graminoids, forbs, and sedges ; 9-30% low shrub cover; common bare ground and rock cover; >10 yrs
U	Na
	Mountain Mahogany (MM)

Appendix 1. Descriptions of vegetation classes within biophysical settings for Great Basin National Park.

Class Code&	Class abbreviation& and brief description
	1062
A	*Early*: 10-55% cover mountain mahogany seedlings and saplings, 0-2m; mineral soil abundant; grasses and shrubs present but not abundant; 0-19 yrs
B	*Mid*1- *Open*: 30-45% cover of mountain mahogany, mountain sagebrush, snowberry, and mountain snowberry 2-5m high; 60-59 yrs
C	*Mid*1-*Closed*: 0-30% cover mountain mahogany 2-5m; mineral soil abundant; grasses and mountain sagebrush, snowberry, and mountain snowberry common; 20-59 yrs
D	*Late*1-*Open*: 0-30% cover of mountain mahogany 5-25m; grasses and mountain sagebrush, snowberry, and mountain snowberry common; >60 yrs
E	*Late*1-*Closed*: 30-55% cover of mountain mahogany, 5-25m; >49 yrs;
U	*TA*: Tree-Annual-Grass; 10-55% cover of mountain mahogany; 5-20% cheatgrass cover
U	*AG*: Annual-Grasses; 5-30% cheatgrass cover
	Mountain Shrub (MSb) 1126ms
A	*Early*: 0-10% canopy of Utah serviceberry, squaw apple (*Peraphyllum ramosissimum*, a rare shrub), antelope bitterbrush; 10-80% grass/forb cover; 0-12 yrs
B	*Mid*--*open*: 11-30% cover of Utah serviceberry/squaw apple/antelope bitterbrush; >50% herbaceous cover; 13-38 yrs
C	*Mid*--*closed*: 31-50% cover of Utah serviceberry/squaw apple/antelope bitterbrush/mountain big sagebrush; 25-50% herbaceous cover, <10% conifer sapling cover; 38+ yrs
D	*Late*-*open*: 10-20% pinyon pine-white fir cover <5m; 25-40% cover of Utah serviceberry/squaw apple/antelope bitterbrush/mountain big sagebrush; <30% herbaceous cover; 80-129 yrs
U	*ES*: *Early*-Shrub; 20-50% cover rabbitbrush species
U	*TE*: Tree-Encroached; >21% pinyon pine-white fir cover 10-25m; <5% shrub cover; <5% herbaceous cover
	Pinyon-Juniper Woodland (PJ) 1019
A	*Early*-*open*: 5-20% herbaceous cover; 0-9 yrs
B	*Mid*1-*open*: 11-20% cover big sage or black sage <1.0m; 10-40% herbaceous cover; 10-29 yrs
C	*Mid*2-*open*; 11-30% cover of pinyon and/or juniper <5m; 10-40% shrub cover; <20% herbaceous cover; 30-99 yrs
D	*Late*1-*open*: old growth, 31-50% cover of pinyon and/or juniper <5m-9m; 10-40% shrub cover; <20% herbaceous cover; >99 yrs
U	*TA*: Tree-Annual-Grass; 31-50% cover of pinyon and/or juniper <5m-9m; 10-40% shrub cover; <20% cheatgrass cover
U	*AG*: Annual-Grasses; 5-30% cheatgrass cover
	Ponderosa Pine 1054
A	*Early*: 0-60% cover of shrub/grass; conifer seedlings can be abundant <5m; 0-39yrs;
B	*Mid*1-*closed*: 31-60% cover of ponderosa pine, Douglass-Fir, and white fir 5-10m; dense shrub cover possible; 40-159yrs

Appendix 1. Descriptions of vegetation classes within biophysical settings for Great Basin National Park.

Class Code[&]	Class abbreviation[&] and brief description
C	*Mid*1-*open*: 10-30% cover of ponderosa pine (dominant), Douglass-Fir, and limber pine 5-10m; abundant shrub and grass cover; 40-159yrs
D	*Late*1-*open*: 10-30% cover of ponderosa pine (dominant), Douglass-Fir, and limber pine 11--50m; abundant shrub and grass cover; >160 yrs
E	*Late*1-*closed*: 31-80% cover of ponderosa pine, Douglass-Fir, and limber pine 11-50m; mountain snowberry common; ; >160 yrs
U	*TA*; 10-80% cover of young and older ponderosa pine and other conifer; >5% cheatgrass cover ; native grass and shrubs present to abundant
U	*AG*: >10% cheatgrass cover; trees largely absent; charred logs or standing dead trees often present; native grasses and forbs present to abundant
	Riparian Ponderosa Pine 1155pp
A	*Early*: 0-60% cover of cottonwood, willow (early in succession) and ponderosa pine (later in succession) saplings <5m high; carex may be abundant; 0-20yrs
B	*Mid*1-*closed*: 41-60% cover of ponderosa pine (dominant), white fir 5-10m; dense willow cover possible; 20-60 yrs
C	*Mid*1-*open*: 11-40% cover of ponderosa pine 5-10m; abundant willow and carex cover; 20-60 yrs
D	*Late*1-*open*: 11-40% cover of ponderosa pine 11--25m; abundant willow and carex cover; 60-999yrs
E	*Late*1-*closed*: 41-60% cover of ponderosa pine and white fir 11-25m; willow and carex common; 60-999yrs
U	Na
	Spruce (SP) 1056
A	*Early*: 0-100% cover of Engelman spruce seedling/shrub/grass <5m; 0-39 yrs
B	*Mid*1-*closed*: 40-100% cover of Engelman spruce and aspen 5-24m; 40-129yrs
C	*Mid*1-*open*: 0-40% cover of Engelman spruce 5-24m pole size; ; 40-129yrs
D	*Late*1-*closed*: 40-100% cover of Engelman spruce 25-49m; >129 yrs
U	Na
	Subalpine-Upper Riparian (SR) 1160
A	*Early*: 0-50% cover of willow, <3m; large patches of basin wildrye, sedges, and tufted grasses; 0-2 yrs
B	*Mid*1-*open*: 10-30% cover of mixed conifers 0-5m; aspen and willow abundant; large patches of basin wildrye, sedges, and tufted grasses; 3-22 yrs
C	*Late*1-*closed*: 31-50% cover of mixed conifers 5-10m; aspen and willow abundant; >22 yrs
U	*Na*
	Wet Meadow (WM) 1145wm
A	*Early*-open: 0-60% herbaceous cover — mostly graminoids; 0-2 yrs
B	*Mid*--closed: 61-100% herbaceous cover — mostly graminoids; 3-22 yrs
C	*Late*-open: 0-10% tree-shrub (aspen, willow, Wood's rose, sagebrush), cover; 60-80% herbaceous cover — mostly graminoids; >22 yrs

Appendix 1. Descriptions of vegetation classes within biophysical settings for Great Basin National Park.

Class Code[&]	Class abbreviation[&] and brief description
U	*SFE-All*: Shrub-Forb-Encroached; >10%% cover of less palatable grasses and forbs (e.g., *Iris missouriensis*); OR >10% shrub cover; bare ground cover 10-30% cover
U	*EF*: Exotic-Forbs; 20-100% exotic forbs (knapweed, tall whitetop, purple loosetrife)
U	*DE*: Desertification; Entrenched water table with 10-50% cover of sagebrush
U	*SA*; Shrub-Annual-Grass; >10% cover of native shrubs; <5% native grass cover; 5-30% cover of cheatgrass
U	*AG*: Annual-Grass; 10-30% cover of cheatgrass; < 10% shrub cover
U	*TE*: Tree-Encroached; 31-80% conifer cover 10-25m; <5% shrub cover; <5% herbaceous cover

[&]: *See codes and abbreviations in Table 1. The code is used in the computer modeling software.*
na: not applicable to ecological system

Appendix 2. Description of ecological model dynamics for Great Basin National Park.

Introduction

Non-spatial state-and-transition models of ecological systems were created with the software Vegetation Dynamics Development Tool (VDDT from ESSA Technologies, Ltd.; Barrett 2001; Beukema et al. 2003). In VDDT, succession and disturbance are simulated in a semi-Markovian framework. Each vegetation state has one possible deterministic transition based on time in the state (usually succession) and several possible probabilistic transitions (natural and management). Each of these transitions has a new destination state and probability associated with it. Based on the timing of the deterministic transition and the probabilities of the stochastic transitions, at each time step a polygon may remain the same, undergo a deterministic transition based on elapsed time in the current state or undergo a probabilistic transition based on a random draw (for example, replacement fire). Model parameters (succession duration and disturbance rates) are presented in Appendix 3.

We created 23 state-and-transition models for each of the biophysical settings in Table (2). Appendix 1 presents the different states, phases, and their abbreviations for each biophysical setting. Although each model represented a distinct biophysical setting, some models were grouped on the same VDDT project page (i.e., Uber model) to allow for seamless system conversions (for example, loss of aspen to mixed conifer) and future climate change effect modeling:

- Forest and shrubland Uber VDDT project contained 15 biophysical settings: Alpine, Limber-Bristlecone Pine (dry), Limber-Bristlecone Pine-mesic, Spruce, Aspen-Subalpine Conifer, Mixed conifer, Montane Sagebrush Steppe-mountain, Aspen-Mixed Conifer, Aspen Woodland, Ponderosa Pine, Curl-leaf Mountain Mahogany, Pinyon-Juniper, Montane Sagebrush Steppe-upland, Mountain Shrub, and Black Sagebrush;
- Riparian Uber VDDT project contained two biophysical settings: Subalpine Riparian and Montane Riparian;
- Wet Meadow and Basin Wildrye biophysical setting Uber VDDT project;
- The remaining VDDT projects contained only one biophysical setting:
    - Montane-Subalpine Grassland
    - Low sagebrush Steppe
    - Riparian Ponderosa Pine
    - Antelope Bitterbrush.

All models had at their core the LANDFIRE reference condition represented by some variation around the A-B-C-D-E classes (Table 2; Appendix 1). Essentially, this meant that models had an early development class and mid-development and/or late-development classes. Mid- and late-development classes may be expressed as open or closed canopy. Several models contained <5 boxes that did not follow the classic nomenclature. The A-E class models simply represented succession from usually herbaceous vegetation to increasing woody species dominance where the dominant woody vegetation might be shrubs or trees. Aspen (three types) and curl-leaf mountain mahogany started as woody dominated early-development vegetation, not herbaceous vegetation. For the models to also reflect the effects of management, we added uncharacteristic vegetation classes that represented different states that only exist because of direct or indirect human activity (Appendix 1).

In all models, any disturbance was quantified by a rate expressed as a probability per year. This rate is the inverse of the return interval of a disturbance or a frequency of spatial events. For example, a mean fire return interval of 100 years is equal to a rate of 0.01/year (0.01 = 1/100). The probability/year rate is used in VDDT because it has the very convenient property of being additive, whereas return intervals are not additive. This rate was further multiplied by a proportion that partitioned the main rate in terms of success and failure outcomes, allocation of resources to realize different management objectives, or extent of application (for example, 5% of the biophysical setting was grazed at a rate of 1.0/year – livestock grazed every year [not a current practice in the Park], thus the return interval is 1 year). The rate that was ultimately used was the probability/year multiplied by proportions of allocation. Any rate, which is generally based on return intervals, is converted to a spatial draw per year as a necessary time for space substitution. Although VDDT is a non-spatial simulation software, the underlying process imitates temporal rates with virtual pixel draws. To pursue the fire return interval example, a probability/year of 0.01 means that 1 out of every 100 pixels on average receives fire within a year. Temporal multipliers described in the main text can be used to modify how many pixels are selected per year while maintaining a temporally average rate of 0.01/year.

Models contained more management activities than were actually employed in final simulations to explore possibilities with workshop participants. The rate of application of each management action was set by the area limit function of VDDT that was reflective of management budgets and minimum treatments required to achieve objectives. Because area limits overrule rates, we generally used a default rate of 0.01 for all actions –another arbitrary rate could have been chosen; however, the proportional allocation of the area limit to different outcomes of the same management action was controlled by VDDT entries (Appendix 3). Some outcomes represented failure rates for an action, such as when a plant seeding failed and was replaced by cheatgrass.

The format of model descriptions that follow will consist of a standard template of entries by biophysical setting (alphabetical order). Some entries will be repetitive among biophysical settings and with Appendix 1. Each biophysical setting's model is intended to be self contained.

Alpine (ALP) 1144

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Date created: December 2010**

Vegetation classes:

- *A-Early*: 0-10% cover of graminoids; <90% soil cover; 0-2 yrs
- *B-Late-closed:* >11% cover of graminoids and forbs; <10% cover of low shrubs; >2 yrs
- U-*None*

Reference Condition:

- **Natural Range of Variability**
  - 1%: *A-Early*
  - 99%: *B-Late-closed*
  - 0%: U-*None*
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Alpine (ALP) 1144

Succession:

Succession is simple in this two-box model:
- Early to late-succession closed: 2 years

Natural Disturbances:

Three natural disturbances apply to the Alpine biophysical setting:
- *Snow-deposition* slows succession only in the early-succession class (*ALP-A*) under the assumption that a thicker than normal and slowly melting snow bank kills or severely thins vegetation. A rate of 0.01/year is arbitrarily assumed.
- *Drought* thinned the late-succession class (*ALP-B*) under the assumption than alpine vegetation is not normally water limited. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), kills naturally drought resistant species.
- *Replacement fire* is caused by and limited to the area of lightning strikes. Because fire is very

rare in the alpine, a small arbitrary rate of 0.0001/year or 1 pixel hit out of 10,000 was chosen.

Management Actions:

None.

Literature from LANDFIRE Model Tracker:

Baker, W. L. 1980. Alpine vegetation of the Sangre De Cristo Mountains, New Mexico: Gradient analysis and classification. Unpublished thesis, University of North Carolina, Chapel Hill. 55 pp.

Bamberg, S. A. 1961. Plant ecology of alpine tundra area in Montana and adjacent Wyoming. Unpublished dissertation, University of Colorado, Boulder. 163 pp.

Bamberg, S. A., and J. Major. 1968. Ecology of the vegetation and soils associated with calcareous parent materials in three alpine regions of Montana. Ecological Monographs 38(2):127-167.

Biondi, F., Kozubowski. T.J., Panorska, A.K., and L. Saito. 2007. A new stochastic model of episode peak and duration for eco-hydro-climatic applications. Ecological Modelling 211:383-395.

Cooper, S. V., P. Lesica, and D. Page-Dumroese. 1997. Plant community classification for alpine vegetation on Beaverhead National Forest, Montana. USDA Forest Service, Intermountain Research Station, Report INT-GTR-362. Ogden, UT. 61 pp.

Komarkova, V. 1976. Alpine vegetation of the Indian Peaks Area, Front Range, Colorado Rocky Mountains. Unpublished dissertation, University of Colorado, Boulder. 655 pp.

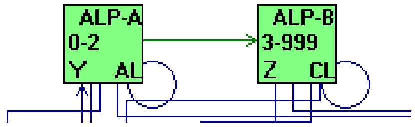
Komarkova, V. 1980. Classification and ordination in the Indian Peaks area, Colorado Rocky Mountains. Vegetatio 42:149-163.

Schwan, H. E., and D. F. Costello. 1951. The Rocky Mountain alpine type: Range conditions, trends and land use (a preliminary report). Unpublished report prepared for USDA Forest Service, Rocky Mountain Region (R2), Denver, CO. 18 pp.

Thilenius, J. F. 1975. Alpine range management in the western United States--principles, practices, and problems: The status of our knowledge. USDA Forest Service Research Paper RM-157. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 32 pp.

Willard, B. E. 1963. Phytosociology of the alpine tundra of Trail Ridge, Rocky Mountain National Park, Colorado. Unpublished dissertation, University of Colorado, Boulder.

State-and-Transition Model (cropped):



Antelope Bitterbrush (AB) 1126ab
Area of Application and Context: • **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.** • **No livestock grazing (since 2006 on northwestern slope).** • **Until recently, full fire suppression management.** • **Date created: December 2010**
Vegetation classes: • A-*Early*: 0-10% canopy of antelope bitterbrush/mountain sage; 10-80% grass/forb cover; 0-12 yrs • B-*Mid--open*: 11-30% cover of antelope bitterbrush/mountain sage; >50% herbaceous cover; 13-38 yrs • C-*Mid--closed*: 31-50% cover of antelope bitterbrush/mountain sage; 25-50% herbaceous cover, <10% conifer sapling cover; 38+ yrs • D-*Late-open*: 10-20% pinyon cover <5m; 25-40% cover of antelope bitterbrush/mountain sage; <30% herbaceous cover; 80-129 yrs • E-*Late-closed*: 21-40% pinyon cover 10-25m; 6-20% antelope bitterbrush/mountain sage; <20% herbaceous cover; 130+ yrs • U-*ES*: *Early*-Shrub; 20-50% cover rabbitbrush species • U-*TE*: Tree-Encroached; >21% pinyon cover 10-25m; <5% shrub cover; <5% herbaceous cover • U-*DP*: Depleted; 20-50% cover of antelope bitterbrush/mountain sage; <5% herbaceous cover; <10% pinyon sapling cover • U-*SAP*: Shrub-Annual-Grass-Perennial-Grass; 21-50% cover of antelope bitterbrush/mountain sage; >5% cover of native grass; 5-10% cheatgrass cover; <10% pinyon sapling cover • U-*AG:* Annual-Grass; 10-30% cover of cheatgrass

Reference Condition:
 	
• **Natural Range of Variability**
  ➢ 21%: A-*Early*
  ➢ 44%: B-*Mid--open*
  ➢ 21%: C-*Mid--closed*
  ➢ 7%: D-*Late-open*
  ➢ 7%: E-*Late-closed*
  ➢ 0%: U
• **Model Tracker Status**
  ➢ Updated Model Tracker December 2010 for biophysical setting Antelope Bitterbrush (AB) 1126ab

Succession:

This biophysical setting is considered a special case of Montane Sagebrush Steppe-upland. Succession follows the 5-box pathway with vegetation starting as predominantly herbaceous and ending with wooded with pinyon and juniper dominance and a viable shrub and herbaceous understory. The succession pathway is not entirely deterministic as we used the *tree-invasion* probabilistic disturbance to cause a transition from the mid-succession open (*AB-B*) and closed (*AB-C*) to the late-succession open (*AB-D*) classes. This rate of transition is 0.01 probability/year pixels starting at age 40 in the mid-succession open class (*AB-B*). This rate is consistent with the transition from Phase 1 to Phase 2 by Miller and Tausch (2001): this rate approximately replicated encroachment levels proceeding in three phases of about 50 years each. Deterministic succession transitions occur at the following ages:

- Early to mid-succession open: 11 years
- Mid-succession open to Late-succession open: 40-49 years (probabilistic)
- Mid-succession open to closed: 49 years
- Mid-succession closed to late-succession open: ≥50 years (probabilistic)
- Late-succession open to closed: 114 years

Natural Disturbances:

The duration of mean fire return interval was ~50 years (therefore, the *replacement fire* disturbance rate is 0.02/year). *Replacement fire* restarted the succession clock to age zero within the reference condition, which was labeled the *early-succession* or *AB-A* class (a phase of the reference condition). *Replacement fire* in vegetation classes that already experienced a threshold transition also caused a threshold transition to less desirable vegetation classes, such as *annual grassland (AG)* if cheatgrass was present in the originating class and, *early shrub* (*ES*) if cheatgrass was absent (Tausch *et al*., 1993; Freilich and Reich, 1998; Tausch and Nowak, 1999; Anderson and Inouye, 2001). One exception was the shrubland with mixed annual and perennial grasses class (*SAP*) where *replacement fire* caused a transition to the early-succession class (*AB-A*) 50% of times and annual grassland (*AG*) for the other 50% of times.

Another widespread natural disturbance in almost all classes was *drought* that cause stand replacing events (generally 10% of times) or stand thinning (90% of times). In most cases *drought* created tree and shrub mortality under the assumption that prolonged and decreased soil moisture weakened plants that might ultimately be killed by insects or disease. Therefore, we did not double-count mortality. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant shrubs and trees. For vegetation classes in the reference condition, drought induced mortality either caused a transition to the early-development class (*AB-A*), or a transition to the previous succession class or a reversal of woody succession within the same vegetation class. In uncharacteristic classes, *drought* caused a transition to early-succession shrub (*ES*) from depleted shrubland (*DP*) and tree-encroached shrubland (*TE*) and to annual grassland (*AG*) from shrub with annual grasses (*SA*) and tree-encroached with annual grasses (*TA*). The shrubland with mixed annual and perennial grasses class (*SAP*) was again an exception where *drought* mostly thinned the shrubs or trees, but also caused a 5% transition to the early-succession class (*AB-A*) and 5% transition to annual grassland (*AG*).

Tree-invasion (i.e., pinyon-juniper encroachment) has been discussed above. Pinyon and juniper encroachment of shrublands was a time-dependent process because seedlings required mature shrubs (we used between 40-100 years of succession), such as sagebrush and bitterbrush, for nurse plants. A standard rate of pinyon-juniper encroachment was 0.01/year (1 of 100 pixels per year) often starting in the late-development or uncharacteristic shrub-dominated vegetation classes of shrublands. For uncharacteristic classes, *tree-invasion* caused a transition to tree-encroached shrub (TE) from depleted shrubs (*DP*) and to tree-encroached with annual grass (*TA*) from shrubland with mixed annual and perennial grasses class (*SAP*) and shrub with annual grass (*SA*).

Cheatgrass invasion (*AG-invasion*) started in the mid-succession closed class (*AB-C*) and continued in the late-succession open class (*AB-D*), was present in nearly all uncharacteristic classes with shrubs, but was absent from the late-succession closed (wooded; *AB-E*) and the tree-encroached class (TE) due to shading. A moderate rate was 0.005/year (1 out of 200 pixels converted to a cheatgrass-invaded class per year) was chosen. A base rate of 0.001/year was estimated from data of northwest Utah collected by the Utah Division of Wildlife Resources in black sagebrush semi-desert. Black sagebrush semi-desert is usually considered more resistant to cheatgrass invasion than Wyoming big sagebrush semi-desert or other big sagebrush dominated biophysical settings. Because NPS, BLM or USFS did not have similar data, we defaulted to five times the rate estimated from the Utah data. The higher rates indicated greater susceptibility to cheatgrass because soils were more productive.

Management Actions:

Modeled management activities included various mechanical treatments, prescribed burning, herbicide, and seeding (Appendix 4). As a rule of thumb, management actions not followed by seeding were applied to reference states where the native perennial understory vegetation was present and was assumed to be releasable.

1. Prescribed fire using hand ignition was proposed in mid-succession closed (*AB-B*) and both late-succession classes (*AB-D* & *AB-E*) to create early-succession vegetation (*AB-A*). An average of 30% of the burn perimeter contained unburned areas (normal mosaic pattern). Cost per unit area increased with smaller burns.

2. Chainsaw thinning of older pinyon and juniper trees was designed to restore shrublands to the mid-succession open class (*AB-B*) because it was assumed (and observed) that trees have already suppressed (reduced cover) the shrub and herbaceous understory in late succession, but not eliminated the understory. Slash created from thinning trees would be chipped on site and chips spread or slash would be pilled and burned.

3. Chainsaw lopping of young pinyon and juniper trees was applied to both the late-succession open (*AB-D*), depleted shrubland (*DP*), and shrubland with mixed annual and perennial grass (*SAP*) classes for the purpose of slowing down tree-encroachment of shrublands and maintaining the openness of Greater Sage-grouse habitat. Slash from tres would be scattered on site and not chipped or burned.

4. Herbicide Plateau® was proposed for control of cheatgrass in the shrubland with mixed annual and perennial native grasses (*SAP*) class. This action caused a 90% transition to the mid-succession closed class (*AB-C*) and no change 10% of times (failure rate).

5. For uncharacteristic classes either dominated by shrubs but with a presence or high potential for cheatgrass invasion (SA, DP) or annual grasslands (*AG)*, spot application of Plateau® followed by native species seeding was recommended. Failures pathways varied among these classes. All starting classes would be converted to the early-succession class (*AB-A*) with a 70% success rate, whereas failure was annual grassland for annual grasslands (*AG*) and shrublands with annual grass class (*SA*) and early-succession shrub (*ES*) for depleted shrubland.

6. For tree-encroached Antelope Bitterbrush, the preferred method for their removal was tree removal by chainsaw (or mastication) followed by spot Plateau® application for cheatgrass control and native species seeding. Successful restoration to the early-succession class (*AB-A*) was assumed at 80%, whereas failure led to early-succession shrubs (*ES*). This method was the most expensive of all.

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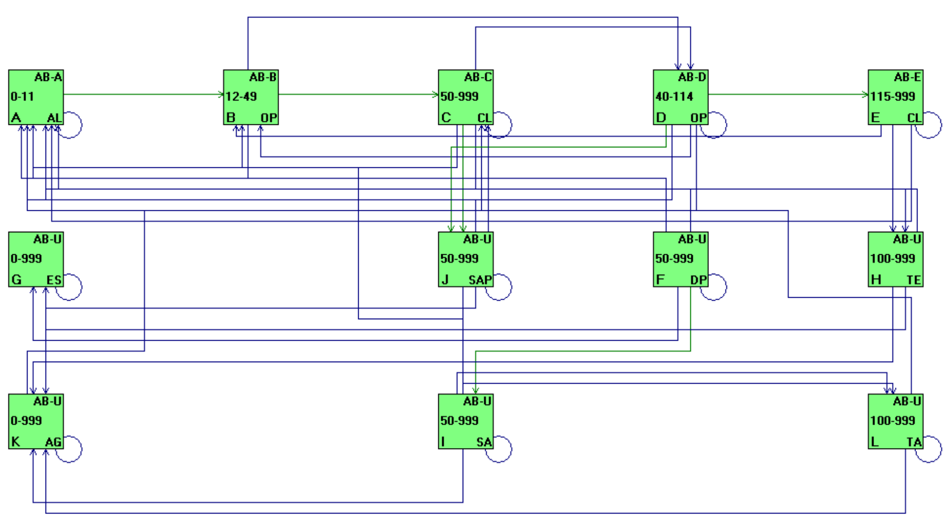
State-and-Transition Model:



Aspen-Mixed Conifer (ASM) 1061

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Date created: December 2010**

Vegetation classes:

A- Early; 0-100% cover aspen <5m; mountain snowberry and *ribes* common; 0-19 yrs
*B-Mid*1-*closed*: 40-99% cover aspen <5-10m; mountain snowberry and *ribes* common; 11-39 yrs
*C-Mid*2-*closed*: 40-99% cover aspen 10-24m; conifer saplings visible in mid-story; mountain snowberry and *ribes* common; 40-79 yrs
*D-Late*1-*open*: 10-39% cover aspen 10-25 m; 0-25% mixed conifer cover 5-10 m; mountain snowberry and *ribes* common; >80 yrs
*E-Late*1-*closed*: 40-80% cover of mixed conifer 10-50m; <40% cover of aspen 10-25m; mountain snowberry and *ribes* present; >100 yrs
MC-E- Conversion to Mixed Conifer; 35-90% cover of mixed conifers 10-49m; mountain snowberry and *ribes* present; conifer litter abundant

Reference Condition:

- **Natural Range of Variability**
  - 19%: A-*Early*
  - 43%: B-*Mid1-closed*
  - 24%: C-*Mid2--closed*
  - 9%: D-*Late-open*
  - 5%: E-*Late-closed*
  - 0%: U
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for the Aspen-Mixed Conifer biophysical setting (ASM) 1061

Succession:

Succession follows the 5-box pathway with vegetation starting as dense resprouting aspen and ending with dominance of white fir or Douglas-fir and co-dominance of aspen. Throughout succession the shrub and herbaceous understory is very diverse. The succession pathway is not entirely deterministic as we used the probabilistic *alternate-succession* disturbance to cause a transition from the late-succession open (*ASM-D*) to the late-succession closed (*ASM-E*) class. This rate of transition is 1/year and starts at age 80 years conditional of the *Time-Since-Disturbance* function that allows transition between these classes only if a pixel has not experience any fire for 100 years. Deterministic succession transitions occur at the following ages:

- Early to mid1-succession closed: 9 years

- Mid1-succession closed to mid2-succession closed: 39 years
- Mid2-succession closed to late-succession open: 79 years
- Late-succession open to late-succession closed: ≥80 years conditional on *Time-Since-Disturbance* = 100 years (probabilistic)

Natural Disturbances:

Fire was the primary stochastic disturbance. *Replacement fire* was set at a mean return interval of 50 years (0.02/year) and restarted the succession clock to age zero within the reference condition, which was labeled the *early development* or *BPS-A* class (a phase of the reference condition). *Replacement fire* affected the following classes: *mid1-succession closed* (*ASM-B*) and 90% of times the *late-succession closed* (*ASM-D*). *Mixed severity fire* was a combination of stand-replacing fire 75% of times and thinning fire 25% of times in the *mid2-succession closed* class (*ASM-C*). Low severity thinning fire was assumed to kill young conifers, several aspen trees, but not change the age of the majority of the trees. *Mixed severity fire* was also present in the *late-succession closed* class (*ASM-D*) as the remaining 10% of the *replacement fire*. This fire was fueled by more conifer fuel and thinned the pixel to the previous succession phase.

The most widespread natural disturbance was *avalanches*, which obliterated every vegetation classes back to the beginning of succession. The rate for *avalanches* was not data supported but inferred from a 7-year El Nino cycle for heavier snow deposition (0.013 = 1/7) multiplied by a proportion of 5% to represent the proportion of this biophysical setting at risk of avalanches in the Park. The total rate, therefore, was 0.13/year × 0.05 = 0.0065/year.

Another widespread natural disturbance was *insect/disease outbreaks* that cause stand replacing events (generally 20% of times) or stand thinning (80% of times). In the case of aspen and mixed conifer, *insect/disease outbreak* was used because it played a distinctive role that was more prominent than *drought* for natural resource managers. The *insect/disease outbreak* return interval rate varied between the two classes where it appeared. Older aspen trees are first affected by the *insect/disease* disturbance in the *mid2-succession closed* class (*ASM-C*) at a rate of 0.005/year (1/200 years) using the proportions above with thinning to the previous succession classes. The nature of the *insect/disease outbreak* disturbance changes for conifers when they get older in the *late-succession closed* class (*ASM-E*), i.e., it makes no difference what happens to aspen trees. The rate in this older class is therefore that of the Mixed Conifer biophysical setting at 0.003/year (1/333 years), a rate obtained from U.S. Forest Service forestry experts at the Dixie National Forest in western Utah.

Native-grazing includes deer foraging (primarily) and elk impacts to aspen systems. This herbivory's effects vary with succession phases. For the *early-succession* class (*ASM-A*) during which aspen resprout are sensitive to intense browse, we assumed a generic rate of 0.01/year of which 5% caused succession to start over (age = 0) because of intense herbivory and 95% when relatively unaffected by n*ative-grazing*. *Native-grazing* was deemed unimportant in the *mid1-succession* class (*ASM-B*) because of full aspen vigor, but becoming significant enough in the *mid2-succession* class (*ASM-C*) to cause a reversal succession to the previous class at a very low rate of 0.001/year. *Native-grazing* persists in the *late-succession* classes (*ASM-D* and *ASM-E*) by accelerating conifer dominance by 10 years when the pixel is selected (in VDDT jargon: RelAge = +10).

Aspen-Mixed Conifer (all aspen biophysical settings) had unique dynamics that led to the loss of clones (*LosingClone*). With lack of fire or other disturbances that removed conifers, or persistent excessive herbivory that killed resprouts, aspen became dominated by mixed conifers. Continued dominance by conifers eventually resulted with death of the clone and a permanent establishment of mixed conifer. The *LosingClone* disturbance, therefore, is a permanent vegetation conversion disturbance to the Mixed Conifer biophysical setting set at a rate of 0.02/year activate from succession age 250 to 300 years. The important assumption was that clones can persist in a suppressed condition for a at least 100 years past the normal age of tree senescence (~125 years); therefore clones were assumed to persist until 250 years, an arbitrary deadline that allowed for ample variation in aspen persistence. After 250 years, clones are loss at a uniform rate of 0.02/year (1 pixel per every 50 pixels per year). This rate insures that all clones are converted to the Mixed Conifer biophysical setting during the last 50 years (from ages 250 to 300).

Management Actions:

Only one management action is contemplated for management in the Park:

- *Prescribed fire* applied to vegetation classes with coniferous fuel: *mid2-succession closed* (*ASM-C*), *late-succession open* (*ASM-D*), and *late-succession closed* (*ASM-E*). The Park staff limited this action to the two oldest classes because the *mid2-succession closed* (*ASM-C*) is under-represented. Because of abundant conifer fuel, the percent of the area charred was 100%.

Chainsaw thinning was also considered by workshop participants , but not retained in the final choice. This action would involve the selective felling of conifers in the classes *mid2-succession closed* (*ASM-C*), *late-succession open* (*ASM-D*), and *late-succession closed* (*ASM-E*). The resulting classes varied among these the originating classes. Removal of conifers in the *mid2-succession closed* (*ASM-C*) simply kept this treatment in that class but at a beginning of the age interval (i.e., pure aspen). When older conifer trees are present in the *late-succession open* class (*ASM-D*), vegetation reverts to the *mid1-succession closed* class (*ASM-B*) if managers also remove a few older aspen trees to encourage resprouting and favor the remaining younger trees. Removal of still older conifers in the *late-succession closed* (*ASM-E*) results in full regeneration (*ASM-A*) 25% of times and in *mid2-succession closed* vegetation (*ASM-C*) in the remaining 75% of cases where a greater number of co-dominant aspen remain.

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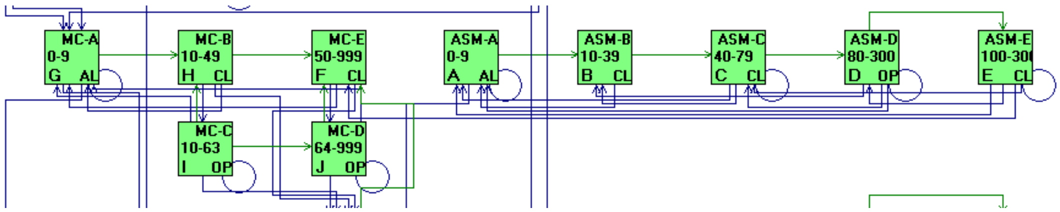
State-and-Transition Model (cropped):



Aspen-Subalpine Conifer (ASC) 1061s
Area of Application and Context: • **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.** • **No livestock grazing (since 2006 on northwestern slope).** • **Until recently, full fire suppression management.** • **Date created: December 2010**
Vegetation classes: • *A-Early*: 50-100% cover aspen <2m; mountain snowberry and *ribes* common; 0-9 yrs • *B-Mid*1-*closed*: 40-99% cover aspen <5-10m; mountain snowberry and *ribes* common; 10-39 yrs • *C-Mid*2-*open*: 10-30% cover aspen 10-24m; 10% cover of white fir and Engelman spruce; mountain snowberry and *ribes* common; 40-169 yrs • *D-Late*1-*closed*: 40-50% cover of white fir and Engelman 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 Engelman spruce 25-49m; >129 yrs

Reference Condition:
 	
• **Natural Range of Variability**
  ➢ 12%: A-*Early*
  ➢ 33%: B-*Mid-closed*
  ➢ 47%: C-*Mid--open*
  ➢ 8%: D-*Late-closed*
  ➢ 0%: U
• **Model Tracker Status**
  ➢ Updated Model Tracker December 2010 for biophysical setting Aspen-Subalpine Conifer (ASC) 1061s

Succession: Succession follows the 4-box pathway with vegetation starting as dense resprouting aspen and ending with dominance of Engelman spruce, with limber pine present to abundant, and co-dominance of aspen. Throughout succession the shrub and herbaceous understory is very diverse. The succession pathway is entirely deterministic with transitions occurring at the following ages: ➢ Early to mid1-succession closed: 9 years ➢ Mid1-succession closed to mid2-succession open: 39 years ➢ Mid2-succession open to late-succession closed: 169 years.
Natural Disturbances:

Fire was the primary stochastic disturbance and restarted the succession clock to age zero within the reference condition. *Replacement fire* was set at a mean return interval of 125 years (0.008/year) for the *mid1-succession closed* (*ASC-B*) to m*id2-succession open* (*ASC-C*) classes and 200 years (0.005/year) for the *late-succession closed* class (*ASC-D*). This last fire return interval is similar to that of the Spruce biophysical setting. *Surface fire* was also present in the *late-succession closed* class (*ASC-D*) with a mean return interval of 700 years (0.0014/year).

The most widespread natural disturbance was *avalanches*, which obliterated every vegetation classes back to the beginning of succession. The rate for *avalanches* was not data supported but inferred from a 7-year El Nino cycle for heavier snow deposition (0.013 = 1/7) multiplied by a proportion of 5% to represent the proportion of this biophysical setting at risk of avalanches in the Park. The total rate, therefore, was 0.13/year × 0.05 = 0.0065/year.

Drought was a stand thinning disturbance limited to the *late-succession closed* class (*ASC-D*) where subalpine conifers dominated forest dynamics. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), are less common and kill naturally drought resistant shrubs and trees.

The disturbance *insect/disease* is limited to the two older classes. In the *mid2-succession open* class (*ASC-C*), the *insect/disease* rate was equal to that of drought (previous paragraph) and partitioned between stand replacing events (10% of times) and stand thinning (90% of times). In the *late-succession closed* class (*ASC-D*) where the forest behaved as subalpine conifers (see Spruce biophysical setting), *insect/disease* was a pure stand replacing event at a lower return interval of 250 years (0.004/year).

Native-grazing includes deer foraging (primarily) and elk impacts to aspen systems. This herbivory's effects vary with succession phases because we assumed that the effects of deer browse would be less in the subalpine than montane zone. *Native-grazing* was deemed unimportant in the *early-succession* (*ASC-A*) and *mid1-succession* class (*ASC-B*) because of full aspen vigor, but becoming significant enough in the *mid2-succession closed* (*ASC-C*) and *late-succession closed* classes (*ASM-D*) to cause small changes to succession. A reversal of succession to the previous class and thinning by an arbitrary of -10 years in the existing class (in VDDT jargon: RelAge = +10) occurs in the *mid2-succession closed* (*ASC-C*) at a very low rate of 0.001/year. *Native-grazing* persists in the *late-succession closed* class (*ASC-D*) by accelerating conifer dominance by 10 years when the pixel is selected.

Aspen-Subalpine Conifer (all aspen biophysical settings) has unique dynamics that led to the loss of clones (*LosingClone*). With lack of fire or other disturbances that removed conifers, or persistent herbivory that killed resprouts, aspen became dominated by subalpine conifers. Continued dominance by conifers eventually resulted with death of the clone and a permanent establishment of subalpine conifers. The *LosingClone* disturbance, therefore, is a permanent vegetation conversion disturbance to the Spruce biophysical setting set at a rate of 0.02/year activate from succession age 250 to 300 years. The important assumption was that clones can persist in a suppressed condition for a at least 100 years past the normal age of tree senescence (~125 years); therefore clones were assumed to persist until 250 years, an arbitrary deadline that allowed for ample variation in aspen persistence. After 250 years, clones are loss at a uniform rate of 0.02/year (1 pixel per every 50 pixels per year). This rate insures that all clones are converted to the Spruce biophysical setting during the last 50 years (from ages 250 to 300).

Management Actions:

Only one management action was contemplated for management in the Park, although mechanical actions are used elsewhere in the western USA:

- *Prescribed fire* can theoretically be applied to vegetation classes with coniferous fuel: *mid2-succession open* (*ASC-C*) and *late-succession closed* (*ASC-D*), The Park staff limited this action to the oldest class because the *mid2-succession open* (*ASC-C*) is under-represented. Because of abundant conifer fuel, the percent of the area charred was 100%.

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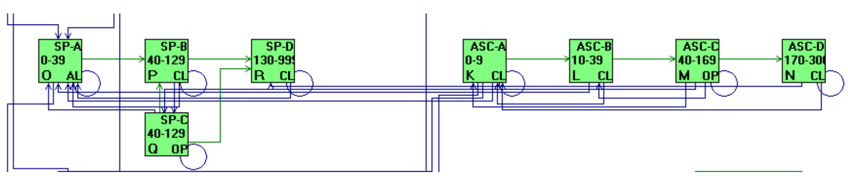
Welsh, S. L, N. D. Atwood, S. l. Goodrich, and L. C. Higgins. 2003. A Utah Flora, Third edition, revised. Print Services, Brigham Young University, Provo, UT. 912 p.

State-and-Transition Model (cropped):



Aspen Woodland (ASP) 1011
Area of Application and Context: • **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.** • **No livestock grazing (since 2006 on northwestern slope).** • **Until recently, full fire suppression management.** • **Date created: December 2010**
Vegetation classes: • *A-Early*; 0-100% cover of aspen <5m tall; 0-9 yrs • *B-Mid*1-*closed*; 40-99% cover of aspen <5-10m; dense herbaceous and non-sagebrush shrub understory and midstory; 10-39 yrs • *C-Late*1-*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-Late*1-*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 Variability**
    ➢ 16%: A-*Early*
    ➢ 41%: B-*Mid-closed*
    ➢ 33%: C-*Late--closed*
    ➢ 10%: D-*Late-open*
    ➢ 0%: U
• **Model Tracker Status**
    ➢ Updated Model Tracker December 2010 for biophysical setting Aspen Woodland (ASP) 1011

Succession: Succession follows the 4-box pathway with vegetation starting as dense resprouting aspen and ending with a woodland of older aspen and an opening canopy. Throughout succession the shrub and herbaceous understory is very diverse. The succession pathway is not entirely deterministic as we used the probabilistic *alternate-succession* disturbance to cause a transition from the *late-succession closed* (*ASM-C*) to the *late-succession open* (*ASM-D*) class. This rate of transition is 0.33/year and starts at age 40 years conditional of the *Time-Since-Disturbance* function that allows transition between these classes

only if a pixel has not experience any fire for 100 years. Deterministic succession transitions occur at the following ages:

- Early to mid1-succession closed: 9 years
- Mid1-succession closed to mid2-succession closed: 39 years
- Mid2-succession closed to late-succession open: >40 years conditional on *Time-Since-Disturbance* = 100 years (probabilistic).

Natural Disturbances:

Fire was the primary stochastic disturbance and restarted the succession clock to age zero within the reference condition, which was labeled the *early development* or *BPS-A* class. *Replacement fire* was set at a mean return interval of 50 years (0.02/year) in all vegetation classes, except for the *late-succession open* class (*ASP-D*) where it is 55 years (0.018/year). It was assumed that fire is all from importation from surrounding montane sagebrush steppe (a mean fire return interval of ~50 years) because most aspen woodlands are patchy and adjacent to sagebrush. In the *depleted* class (*DP*), 80% of the fire causes a transition to the early-succession class (ASP-A) as above, but 20% will cause a permanent vegetation conversion to the *early succession* class of the Montane Sagebrush Steppe-upland biophysical setting (*MSu-A*).

The most widespread natural disturbance was *avalanches*, which obliterated every vegetation classes back to the beginning of succession. The rate for *avalanches* was not data supported but inferred from a 7-year El Nino cycle for heavier snow deposition (0.013 = 1/7) multiplied by a proportion of 1% to represent the proportion of this biophysical setting at risk of avalanches in the Park. The total rate, therefore, was 0.13/year × 0.01 = 0.0013/year.

The disturbance *insect/disease* was limited to the two older succession classes and the *depleted* class (DP). The *insect/disease* rate was 0.005/year (200 years) and nearly equal, but different, equal to that of severe drought with a return interval rate of every 178 years (a rate of 0.0056/year) based on the frequency of severe drought (>7-year drought events with consecutive far-below average soil moisture) intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. In the *late-succession closed* class (*ASP-C*), the *insect/disease* rate was partitioned between stand replacing events (20% of times) and stand thinning (80% of times) within the same class. In the *late-succession open* class (*ASP-D*), *insect/disease* was a pure stand thinning event to the previous succession class. The fate of aspen was more complicated in the *depleted* class (*DP*) where trees and clones are more sensitive to disturbance: 80% of times the disturbance causes a transition to the *early-succession* class (*ASP-A*); 10% of times to the Montane Sagebrush Steppe-upland *mid-succession open* class (*MSu-B*); and 10% of times to the Montane Sagebrush Steppe-upland biophysical setting *mid-succession closed* class (*MSu-C*). The last two transition are permanent biophysical setting conversions.

Native-grazing includes deer foraging (primarily) and elk impacts to aspen systems. This herbivory's effects vary with succession phases. *Native-grazing* was judged more important in the *early-succession* (*ASP-A*) than the other classes and absent in the *mid-succession closed* class (*ASP-B*) due to full aspen vigor. Heavy browse will reset succession to age zero in the *early-succession* class (*ASP-A*) for 95% of the pixels (spatial rates are more important than return intervals for herbivory as wildlife browsing occurs every year), whereas the same browse will cause a rare loss of the clone for 55 of pixels to the Montane Sagebrush Steppe-upland biophysical setting *early-succession* class (*MSu-A*). *Native-grazing* was a *t*hinning disturbance in the *late-closed succession* (*ASP-C*) and *late-succession open* (*ASP-D*) classes at a very low rate of 0.001/year: severe browse caused a transition from the *late-closed succession* (*ASP-C*) to the *mid-succession closed* class (*ASP-B*), and from the *late-succession closed* class (*ASC-D*) to the *mid-succession closed* class (*ASP-B*). This assumed that older trees suffered more from severe browse and barking. *Native-grazing* persisted in the *depleted* class (*DP*) but with negative effect for vegetation conversion: 80% of times the disturbance causes a transition to the *early-succession* class (*ASP-A*); 10% of times to the Montane Sagebrush Steppe-upland *mid-succession open* class (*MSu-B*); and 10% of times to the Montane Sagebrush Steppe-upland biophysical setting *mid-succession closed* class (*MSu-C*).

Aspen Woodland (all aspen biophysical settings) has unique dynamics that led to the loss of clones (*LosingClone*). With lack of fire or other disturbances that cause resprouting, aspen clones in the *late-succession open* class (*ASP-D*) substantially open up and become encroached by mountain big sagebrush and highly vulnerable to permanent loss of the clone. The *LosingClone* disturbance, therefore, is the beginning of permanent vegetation conversion disturbance set at a rate of 0.02/year activate from succession age 250 to 300 years. The important assumption was that clones can persist in a suppressed condition for a hundred of years past the normal age of tree senescence (~125 years), but then clones are loss at a uniform rate of 1/50 or 50 years.

Management Actions:

None needed. Prescribed fire in the late fall or early spring ignited in the surrounding biophysical setting would be the main management action. Fuels in aspen woodlands contain high levels of moisture during the growing season and do not burn well or at all. Seasonal curing of fuels is required.

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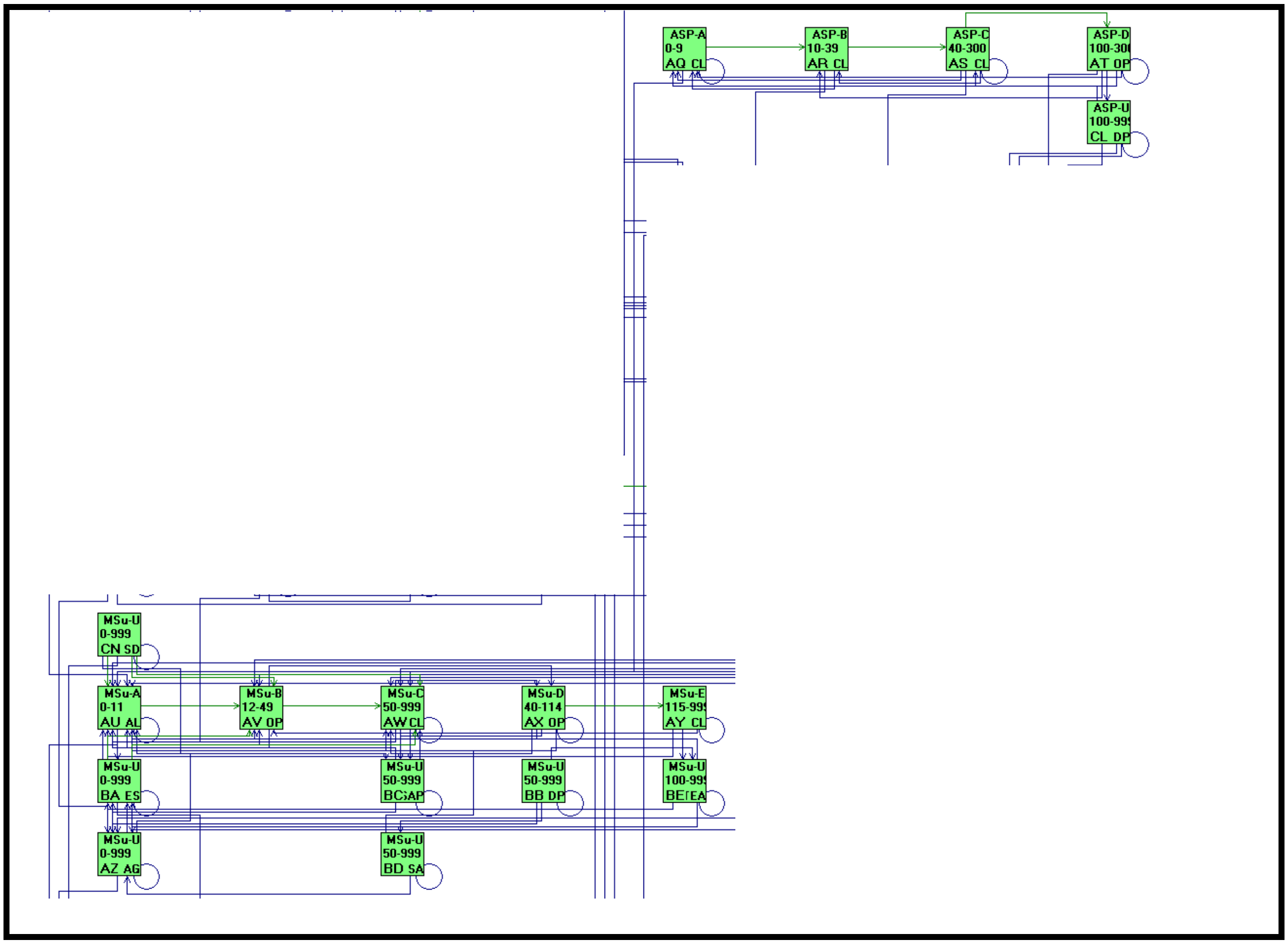
Welsh, S. L, N. D. Atwood, S. l. Goodrich, and L. C. Higgins. 2003. A Utah Flora, Third edition, revised. Print Services, Brigham Young University, Provo, UT. 912 p.

State-and-Transition Model (cropped):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ASP-B
10-39
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AT OP
ASP-U
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0-999
CN SD
MSu-A
0-11
AU AL
MSu-B
12-49
AV OP
MSu-C
50-999
AW CL
MSu-D
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AX OP
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BB DP
MSu-U
MSu-U
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AZ AG
MSu-U
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BD SA

Basin Wildrye (BW) 1126bw

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Date created: December 2010**

Vegetation classes:

- *Early*: 0-20% cover of basin wildrye; 0-10 yrs
- *B-Mid--Closed*: 21-80% cover of basin wildrye; <11% shrub cover; 11-75 yrs
- *C-Late*-*Open*: 11-20% cover of big sagebrush & rabbitbrush; <75% cover of basin wildrye; >75 yrs
- *U-DP*; Depleted; >20% cover of native shrubs; <5% basin wildrye; >20% mineral soil and litter cover
- *U-SA*; Shrub-Annual-Grass; >10% cover of native shrubs; 0-30% basin wildrye; 5-30% cover of cheatgrass
- *U-AG*: Annual-Grass; 5-40% cover of cheatgrass
- *U-TE*: Tree-Encroached; 10-40% cover of conifers; <10% herbaceous cover
- *U-TA*: Tree-Annual-Grass; 10-40% cover of conifers; 5-20% cover annual grasses
- *U-EF*: Exotic-Forbs; 5-100% exotic forbs (knapweed, tall whitetop, purple loosetrife)
- *U-ES*: *Early*-Shrub; >20% cover of rabbitbrush species; native grasses present

Reference Condition:

- **Natural Range of Variability**
  - 18%: A-*Early*
  - 63%: B-*Mid-closed*
  - 19%: C-*Late-open*
  - 0%: U
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Basin Wildrye (BW) 1126bw

Succession:

Succession follows the 3-box pathway with vegetation starting as a basin wildrye grassland and ending as a grassland with <20% of shrubs. Basin wildrye dominates all phases of succession. The succession pathway is entirely deterministic with transitions occurring at the following ages:

- Early to mid-succession closed: 9 years
- Mid-succession closed to late-succession open: 74 years

Natural Disturbances:

Fire was the primary stochastic disturbance and restarted the succession clock to age zero within the reference condition. *Replacement fire* had a mean return interval varying between 40 years (0.025/year) and ~65 years (0.015/year) in reference classes. A 50-year fire return interval (0.02/year) characterized the *early-succession* class (*BW-A*). With the accumulation of fine fuel as the cover of basin wildrye increases, the fire return interval of the mid-succession closed class (BW-B) shortens to 40 years (0.025/year). The return interval Increased to 65 years (0.015/year) with the encroachment of shrubs in the *late-succession open* class (*BW-C*). The same rate for *replacement fire* is also found in the uncharacteristic *shrub with annual grass* class (*SA*). In other uncharacteristic classes, the fire return interval varied from 10 years (0.1/year) in the *annual grassland* class (*AG*), 200 years (0.005/year) in *depleted* shrubs (*DP*), and 50 years in the *exotic forb* class (*EF*). Tree encroachment lengthens the fire return interval to ~165 years (0.0068/year) in the *tree-encroached* class (*TE*), whereas cheatgrass shortens it to 125 years (0.008/year) in the *tree with annual grass* class (*TA*).

Drought causes stand replacing or stand thinning events depending on the vegetation class. In most cases *drought* created tree and shrub mortality under the assumption that prolonged and decreased soil moisture weakened plants that might ultimately be killed by insects or disease. Therefore, we did not double-count mortality. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant shrubs and trees. In the *mid-succession closed* class (*BW-B*), drought thins basin wildrye within the class, whereas *drought* thins shrubs to the previous class 90% of times and causes stand replacement 10% of times in the *late-succession open* class (*BW-C*). In uncharacteristic classes, the pattern caused by *drought* persisted in the following classes:

- *Depleted* shrubland (*DP*) with 90% remaining in this class and 10% transitioning to the *annual grassland* class (*AG*);
- *Shrub with an annual grass understory* class (*SA*) with 90% remaining in this class and 10% transitioning to the *annual grassland* class (*AG*);
- Tree-encroached shrubland (*TE*) thinned within this class and 10% transitioning to the *early shrub* class (ES); and
- Tree-encroached with annual grasses (*TA*) thinned within the class and 10% transitioning to the *annual grassland* (*AG*).

All other disturbances caused transition to or within uncharacteristic classes.

- *Tree invasion* reflects pinyon and juniper encroachment of shrublands or grasslands with shrubs and is a time-dependent process because tree seedlings require mature shrubs for nurse plants (we used between >75 years of succession), such as sagebrush and bitterbrush. A standard rate of pinyon-juniper encroachment was 0.01/year (1 of 100 pixels per year). This rate is consistent with the transition from Phase 1 to Phase 3 by Miller and Tausch (2001): this rate approximately replicated encroachment levels proceeding in three phases of about 50 years each. *Tree invasion* of shrubs without cheatgrass, including in the *late-succession open* class (*BW-C*), causes a transition to the *tree-encroached* class (*TE*). With cheatgrass present in the understory, the transition is to the *tree-encroached with annual grass* class (*TA*).

- *Exotic invasion* occurred in all classes, except the *early shrub* class (*ES*), *tree encroached* class (*TE)*, and *tree with annual grass* class (*TA*), and causes a transition to the *exotic forb* class (*EF*) at a rate of 0.01/year. This aggressive rate was chosen by managers to simulate a worst case scenario.

- Cheatgrass invasion (*AG-invasion*) was tied to a base rate of 0.001/year estimated from data of northwest Utah collected by the Utah Division of Wildlife Resources in black sagebrush semi-desert. Black sagebrush semi-desert is usually considered more resistant to cheatgrass invasion than big sagebrush dominated biophysical settings. Because NPS, BLM or USFS did not have similar data, we defaulted to twice the rate estimated from the Utah data. The higher rates indicated greater susceptibility to cheatgrass because soils were more productive. *AG-invasion* started in the mid-succession closed class (*BW-B*) at a very low rate of 0.0001/year reflecting strong resistance of basin wildrye to invasion and continued in the *late-succession open* class (*BW-C*) with conversions to the *shrub with annual grass* class (*SA;* 0.002/year) if succession was <174 years and to the *tree with annual grass* class (*TA*; 0.002/year) if succession ≥175 years. *AG-invasion* was present in nearly all uncharacteristic classes with shrubs and no cheatgrass, but was absent from the *exotic forb* class (EF). The *depleted* class (*DP*) behaved exactly as the *late-succession open* class (*BW-C*) above. The *early shrub* class (*ES*) was more resistant to cheatgrass invasion than the *depleted* class (*DP*) with a lower rate of 0.001/year. The most susceptible class is the *tree-encroached* (*TE*) because it was assumed that the understory was completely open to invasion due to absence of shrubs and grasses at a rate of 0.005/year.

Management Actions:

A large variety of management actions can be applied to the Basin Wildrye biophysical setting because it shares problems typical of sagebrush systems and wet meadows.

- Basin wildrye thrives with fire. Therefore, prescribe burning can be applied to all reference classes to maintain the grassland character, although management was focused on the *late-succession open* class (*BW-C*). Due to the large biomass of fine fuels, a 70% char rate was assumed.
- Mechanical methods combined with herbicide application and seeding is typically applied to uncharacteristic classes with woody species:
    - ➢ Thin shrubs then conduct spot herbicide application for annual grasses and native species seeding in the *shrub with annual grass* class (*SA*). Failure rate is 20% with a transition to the *annual grassland* class (*AG*);
    - ➢ Thin shrubs then conduct native species seeding for the *depleted* class (*DP*). A 20% failure rate for seeding was assumed with a resulting increase of the *early shrub* class (*ES*); and
    - ➢ Masticate trees then spot application of herbicide for annual grasses and seed native species in the *tree-encroached* class (*TE*) and in the *tree-encroached invaded by annual*

grass class (*TA*). Again a 20% failure rate was assumed, causing an increase in the *annual grassland* class (*AG*).

- To keep exotic forbs out of the Park, persistent tracking and control is required:
  - Inventory exotic forbs in all locations of the biophysical setting; and
  - Control exotic forbs if present with herbicides. The failure rate was 50% (no change), thus requiring respraying in future years.

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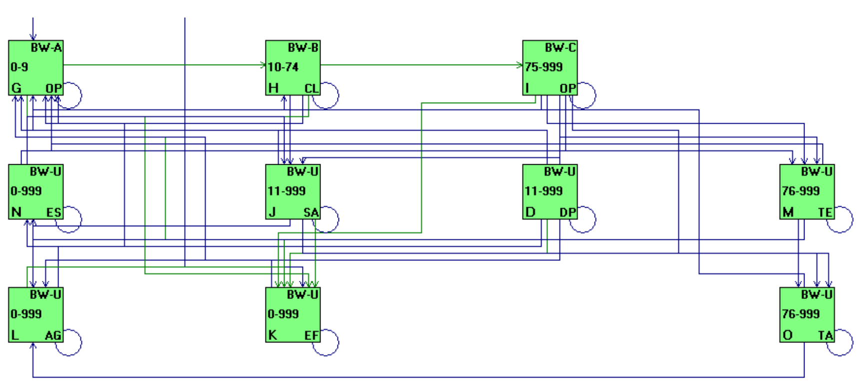
State-and-Transition Model (cropped):



Black Sagebrush (BS) 1079an
Area of Application and Context: • **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.** • **No livestock grazing (since 2006 on northwestern slope).** • **Until recently, full fire suppression management.** • **Date created: December 2010**
Vegetation classes: • *A-Early*: <10% cover rabbitbrush; 10-40% cover of grass; <50% cover mineral soil; 0-25 yrs • *B-Mid*1-*open*: 10-20% cover of black sagebrush and rabbitbrush; 10-30% grass cover; <40% cover of mineral soil; 25-119 yrs • *C-Late1-Open*: 1-10% pinyon-juniper sapling cover; 20-30% cover of black sagebrush; 10-30% cover of grasses; 120-194 yrs • *D-Late*1-*Closed*: 10-40% cover of pinyon or juniper 5-10m high; <10% black sagebrush cover; <10% grass cover; >195 yrs • *E-Mid-Open*: animal burrow; 20-80% cover of mineral soil and rocks; <20% cover of winterfat, Indian ricegrass, spiny hopsage, and salt bushes; 0-999yrs • *U-ES*: *Early*-Shrub;10-40% cover rabbitbrush species • *U-TE*: Tree-Encroached; >40% pinyon or juniper cover 5-10m; <5% shrub cover; <5% herbaceous cover • *U-DP*: Depleted; 20-50% cover of black sagebrush; <5% herbaceous cover; <10% pinyon or juniper sapling cover • *U-SAP*: Shrub-Annual-Grass-Perennial-Grass; 20-50% cover of black sagebrush; >5% cover of native grass; 5-20% cheatgrass cover; <10% pinyon or juniper sapling cover • *U-SA*: Shrub-Annual-Grass; 20-50% cover of black sagebrush; <5% cover of native grass; 5-20% cheatgrass cover; <10% pinyon or juniper sapling cover • *U-AG:* Annual-Grass; 10-30% cover of cheatgrass

Reference Condition:
 	
• **Natural Range of Variability**
  ➢ 17%: A-*Early*
  ➢ 47%: B-*Mid-open*
  ➢ 24%: C-*Mid--closed*
  ➢ 10%: D-*Late-open*
  ➢ 2%: E-*Late-closed*
  ➢ 0%: U
• **Model Tracker Status**
  ➢ Updated Model Tracker December 2010 for the Black Sagebrush biophysical setting

(ASM) 1079an

Succession:

Succession follows the 4-box pathway with vegetation starting as predominantly herbaceous and ending with pinyon and juniper dominance and a viable shrub and herbaceous understory. A fifth succession class representing an animal burrow (*BS-E*) variant to the *early succession* class (*BS-A*) is present, but a very minor part of the landscape. The succession pathway is not entirely deterministic as we used the *tree-invasion* probabilistic disturbance to cause a transition from the *late-succession open* class (*BS-C*) to the late-succession closed (*BS-D*) class. This rate of transition is 0.001/year pixels from ages 120 to 149 years and 0.005/year for ≥150 years. This rate is lower than the 0.01/year rate needed to reproduce the 50-year interval for each of phases Phase 1 to Phase 3 by Miller and Tausch (2001). We assumed that the Black Sagebrush biophysical setting was more resistant to tree encroachment than the big sagebrush communities. Succession transitions occur at the following ages:

- Early to mid-succession open: 24 years
- Mid-succession open to late-succession open: 119 years
- Late-succession open to closed: ≥120 years (probabilistic)
- Early-succession to animal burrowing mound: 0-24 years (probabilistic)
- Animal burrowing mound to early-succession: ≥5 years (probabilistic)

Natural Disturbances:

Replacement fire was the primary stochastic disturbance (Young and Sparks 2002). *Replacement fire* restarted the succession clock to age zero within the reference condition. The duration of mean fire return interval was 250 years (therefore, the *replacement fire* disturbance rate is 0.004/year) in the *early-succession* class (*BS-A*) and shortened to 150 years (0.0067/year) in the three other succession classes. *Replacement fire* in vegetation classes that already experienced a threshold transition also caused a threshold transition to less desirable vegetation classes, such as *annual grassland* (*AG*) if cheatgrass was present in the originating class and, *early shrub* (*ES*) if cheatgrass was absent (Tausch *et al*., 1993; Freilich and Reich, 1998; Tausch and Nowak, 1999; Anderson and Inouye, 2001). One exception was the shrubland with mixed annual and perennial grasses class (*SAP*) where *replacement fire* caused a transition to the early-succession class (*BS-A*) 5% of times and annual grassland (*AG*) for the other 95% of times. The shortest rates are in the *annual grassland* class (*AG*) at 0.1/year (10-year mean fire return interval) and in the *shrub with annual grass* class (*SA*) at 0.01/year (100-year mean fire return interval); otherwise, the *replacement fire* rate was 0.0067/year in other uncharacteristic classes.

Drought caused stand-replacing and stand-thinning events. In most cases *drought* created tree and shrub mortality under the assumption that prolonged and decreased soil moisture weakened plants that might ultimately be killed by insects or disease. Therefore, we did not double-count mortality. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant shrubs and trees. For vegetation classes in the reference condition, drought induced mortality either caused a transition to the early-development class (*BS-A*), or a transition to the previous succession class or a reversal of woody succession within the same vegetation class. The allocation between thinning and stand-replacement varied from 50%/50% in the *early succession* class (*BS-A*) to 75% thinning versus 25% replacement in the other classes. In uncharacteristic classes, *drought* caused a transition to early-succession shrub (*ES*) from depleted shrubland (*DP*) and tree-encroached shrubland (*TE*) and to annual grassland (*AG*) from shrub with annual grasses (*SA*) and tree-encroached with annual grasses (*TA*). For these uncharacteristic classes, the partitioning of thinning to replacement events was 90% to 10%. The shrubland with mixed annual and perennial grasses class (*SAP*) was again an exception where *drought* mostly thinned the shrubs or trees 95% of times, but also caused a 5% transition to the early-succession class (*AB-A*) and 5% transition to annual grassland (*AG*).

Tree-invasion (i.e., pinyon-juniper encroachment) has been discussed above. A standard rate of pinyon-juniper encroachment was 0.005/year (1 of 200 pixels per year) often starting in the late-development or uncharacteristic shrub-dominated vegetation classes of shrublands at a succession age ≥120 years. For uncharacteristic classes, *tree-invasion* caused a transition to tree-encroached shrub (TE) from depleted shrubs (*DP*) and to tree-encroached with annual grass (*TA*) from shrubland with mixed annual and perennial grasses class (*SAP*) and shrub with annual grass (*SA*).

Cheatgrass invasion (*AG-invasion*) is present in all succession classes and in nearly all uncharacteristic classes with shrubs and trees, but was absent from classes already invaded by cheatgrass. A moderate rate was 0.005/year (1 out of 200 pixels converted to a cheatgrass-invaded class per year) was chosen. A base rate of 0.001/year was estimated from data of northwest Utah collected by the Utah Division of Wildlife Resources in black sagebrush semi-desert. Black sagebrush semi-desert is usually considered more resistant to cheatgrass invasion than Wyoming big sagebrush semi-desert or other big sagebrush dominated biophysical settings. Because NPS, BLM or USFS did not have similar data, we defaulted to five times the rate estimated from the Utah data. The higher rates indicated greater susceptibility to cheatgrass because 1) soils were more productive in the upland zone (higher elevation) of the Park than the semi-desert zone and 2) cheatgrass seed sources are abundant in Snake Valley to which the black sagebrush biophysical setting extends from. Only the *early-succession* class (*BS-A*) had an invasion rate different than the 0.005/year; a very low rate of 0.0001/year applied to the first 10 years followed by a rate of 0.001/year for the remainder of the class.

Three other natural disturbances occurred in the biophysical setting:

- Animal-burrowing creates or refreshes the mineral soil on burrow mounds at very low rate of 0.0001/year (a fitted rate) in the *early-succession* class (*BS-A*) and at a much higher rate of 0.1/year in the *animal mound* class (*BS-E*);
- Early-succession grass and shrub species typical of mixed salt desert communities (for example, winterfat) colonize animal mounds and allow *natural recovery* of vegetation back to the early-succession class at a rate equal to the creation of *animal mounds* (*BS-E*), 0.0001/year;
- *Tree-encroachment* is a disturbance that expresses the ultimate suppression of understory vegetation in the *late-succession closed* class (*BS-D*); therefore causing a transition to the *tree-encroached* class (*TE*) at rate that increased with succession (these rates were arbitrary and were obtained by trial-and-error):

    - 0.005/year from 300 to 399 years;
    - 0.0075/year from 400 to 499 years; and
    - 0.015/year for ≥500 years.

Management Actions:

Modeled management activities included various mechanical treatments, prescribed burning, herbicide, and seeding. As a rule of thumb, management actions not followed by seeding were applied to reference states where the native perennial understory vegetation was present and was assumed to be releasable.

- Prescribed fire in late-succession classes (*BS-C* and *BS-D*) with 70% of the burn perimeter charred, but 30% unburned in a typical mosaic fire pattern;
- Chainsaw lopping of young trees in classes *late-succession open* (*BS-C*), *depleted shrubs* (*DP*), and *shrubs with annual grasses* (*SA*) to completely remove trees in shrub dominated uncharacteristic classes or cause a transition to the *mid-succession open* class (*BS-B*) from the *late-succession open* class (*BS-C*);
- Thin shrubs then conduct spot herbicide application for annual grasses and seed native species in the *shrubs with annual grass* class (*SA*) with a 70% success rate leading to the *early-succession* class (*BS-A*) but a 30% failure rate causing a transition to the *annual grassland* class (*AG*);
- Chainsaw thin trees then spot application of herbicide for annual grasses and seed native species in *tree-encroached shrublands* (*TE*) and in *tree-encroached shrublands with annual grass* (*TA*). Success was a transition to the *early-succession* class (*BS-A*). The failure rate of these treatments increased with the presence of cheatgrass: from 30% in the *tree-encroached* class (*TE*) causing a transition to the *early shrub* class (*ES*) and 40% in the *tree-encroached shrublands with annual grass* (*TA*) with a transition to *annual grasslands* (*AG*); and
- Direct seeding in *depleted shrublands* (*DP*) was an action unique to the Park with a 50% failure rate (no change to vegetation). Successful seeding caused a transition to the *mid-succession closed* class (*BS-B*) for depleted shrublands between 26 and 119 years and to the *late-succession open* class (*BS-C*) for depleted shrublands ≥120 years.

Literature cited in LANDFIRE's Model Tracker:

USDA-NRCS 2003. Ecological site descriptions for Nevada. Technical Guide Section IIE. MLRAs 28B, 28A, 29, 25, 24, 23.

Biondi, F., Kozubowski. T.J., Panorska, A.K., and L. Saito. 2007. A new stochastic model of episode peak and duration for eco-hydro-climatic applications. Ecological Modelling 211:383-395.

Blackburn, W.H. and P.T. Tueller. 1970. Pinyon and juniper invasion in black sagebrush communities in east-central Nevada. Ecology 51(5):841-848.

Herbel, C.H. 1986. Seeding shrubs in the field. Reclamation and Revegetation Research. 5:377-385.

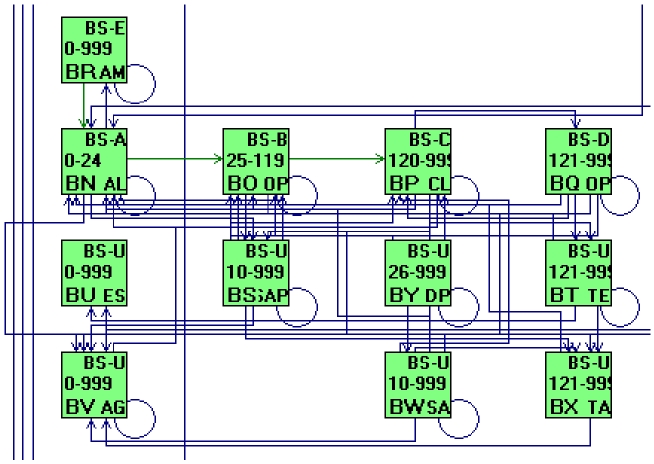
Kitchen, S. G and G. L.Jorgensen. 1999. Annualization of rodent burrow clusters and winterfat decline in a salt-desert community. USDA Forest Service Proceedings RMRS-P-11.

Ratzlaff, T.D. and J.E. Anderson. 1995. Vegetal recovery following wildfire in seeded and unseeded sagebrush steppe. Journal of Range Managenent 48:386-391.

Young, J.A. and D.E. Palmquist. 1992. Plant age/size distributions in black sagebrush (Artemisa nova): effects on community structure. Great Basin Naturalist 52(4):313-320.

Zamora, B. and P. T. Tueller. 1973. Artemisia arbuscula, A. longiloba, and A. nova habitat types in northern Nevada. Great Basin Naturalist 33: 225-242.

State-and-Transition Model (cropped):



Limber-Bristlecone Pine (LB) 1020

Area of Application and Context:

- **Great Basin National Park and “Keyhole” property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Date created: December 2010**

Vegetation classes:

- *A-Early: 0-10% limber and bristlecone pine cover 0-5m high, abundant mineral soil or talus cover; sparse ground cover; 0-99 yrs*
- *B-Mid1-Open: 11-30% limber and bristlecone pine cover 5-10m high, abundant mineral soil or talus cover; sparse ground cover; 100-249 yrs*
- *C-Late1-Open; very old trees; 11-30% limber and bristlecone pine cover 5-25m high, abundant mineral soil or talus cover; sparse ground cover; >250 yrs*
- U-*None*

Reference Condition:

- **Natural Range of Variability**
  - 9%: A-*Early*
  - 12%: B-*Mid-open*
  - 78%: C-*Late-open*
  - 0%: U
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Limber-Bristlecone Pine (LB) 1020

Succession:

Succession is simple in this three-box model:

- Early to mid-succession open: 99 years
- Mid-succession open to late-succession open: 249 years

Natural Disturbances:

Three natural disturbances apply to the Limber-Bristlecone Pine biophysical setting:

- Normally, the subalpine is not water limited, but more temperature limited. *Drought* only thins the early-succession class (*LB-A*) under the assumption that conifer seedlings might be sensitive to drought, although this effect is a small reversal of succession by 5 years. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant species.

- Fire was rare*:*

  - *Replacement fire* is caused by and limited to the area of lightning strikes or fire creeping up from lower elevation biophysical settings. All classes were affected. A small and arbitrary rate of 0.001/year was used to indicate the rarity of this disturbance; and
  - *Surface fire* was twice as frequent as for *replacement fire* (0.002/year) and originating from the same sources and affecting the same classes.

Management Actions:

None.

Literature cited in LANDFIRE's Model Tracker:

Biondi, F., Kozubowski. T.J., Panorska, A.K., and L. Saito. 2007. A new stochastic model of episode peak and duration for eco-hydro-climatic applications. Ecological Modelling 211:383-395.

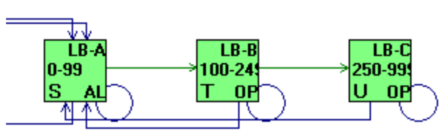
Howard, J. L. 2004. Pinus longaeva. In: Fire Effects Information Systems [Online]. USDA, Forest Service, Rocky Mountain Research Station, Forest Sciences Lab (Producer). Available: http://www.fs.fed.us/database/feis [2005, February 23].

Johnson, K. A. 2001. Pinus flexilis. In: Fire Effects Information System [Online]. USDA, Forest Service, Fire Sciences Lab (Producer). Available: http://www.fs.fed.us/database/feis [2005, February 23].

Little, E. L. 1971. Atlas of United States Trees: Volume 1, Conifers and Important Hardwoods. USDA Forest Service, Misc. Pub. 1146, Washington, DC.

Steele, R. in: Burns, R. M., and B. H. Honkala, tech coords. 1990. Silvics of North America: 1. Conifers. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. Vol 2, 877 p.

State-and-Transition Model (cropped):



Limber-Bristlecone Pine-mesic (LBm) 1020m
Area of Application and Context: • **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.** • **No livestock grazing (since 2006 on northwestern slope).** • **Until recently, full fire suppression management.** • **Date created: December 2010**
Vegetation classes: • A-*Early*: 0-10% limber and bristlecone pine cover 0-5m high, abundant soil or talus; *Ribes* and *P*oa present; 0-49 yrs • *B-Mid1-Open*: 11-20% limber and bristlecone pine cover 5-10m high; *Ribes* and *P*oa present; 50-199 yrs • *C-Late1-Closed*; old trees but not ancient; 20-40% limber and bristlecone pine cover 5-25m high; *Ribes* and *P*oa present; >200 yrs • U- None
Reference Condition: • **Natural Range of Variability** ➢ 17%: A-*Early* ➢ 47%: B-*Mid1-open* ➢ 36%: C-*Late-closed* ➢ 0%: U • **Model Tracker Status** ➢ Updated Model Tracker December 2010 for biophysical setting Limber-Bristlecone Pine-mesic (LBm) 1020m
Succession: Succession is simple in this three-box model: ➢ Early to mid-succession open: 49 years ➢ Mid-succession open to late-succession closed: 199 years
Natural Disturbances: Four natural disturbances apply to the Limber-Bristlecone Pine-mesic biophysical setting: • Normally, the subalpine is not water limited, but more temperature limited. *Drought* thinned the early-succession class (*LBm-A*) under the assumption that conifer seedlings might be sensitive to drought, although this effect is a small reversal of succession by 5 years. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and

western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant species.

- Fire was rare*:*

  - *Replacement fire* is caused by and limited to the area of lightning strikes or fire creeping up from lower elevation biophysical settings. All classes were affected. A small and arbitrary rate of 0.002/year was used to indicate the rarity of this disturbance; and
  - *Surface fire* was >2× as frequent as for *replacement fire* (0.005/year) and originating from the same sources and affecting the same classes.
- *Heartrot* is a disease killing older bristlecone pines growing on more mesic soils preventing tress from exceeding an age of 500 years. We chose an arbitrary small rate of 0.002/year in the *late-succession closed* class (*LBm-C*) that is the inverse of the age of senescence: 1/500 years.

Management Actions:

Prescribed fire was the only management action proposed by Park staff. Hand ignition and helicopters ignition would be required to cover large areas of remote terrain. Past wildfires in the Keyhole area in and outside the Park show that subalpine fires burn well and hot. It was assumed that 80% of the prescribed burn perimeter was charred (i.e., trees topkilled), whereas 20% remained untouched by fire following a natural mosaic pattern.

Literature cited in LANDFIRE's Model Tracker:

Biondi, F., Kozubowski. T.J., Panorska, A.K., and L. Saito. 2007. A new stochastic model of episode peak and duration for eco-hydro-climatic applications. Ecological Modelling 211:383-395.

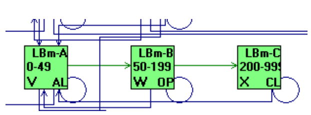
Howard, J. L. 2004. Pinus longaeva. In: Fire Effects Information Systems [Online]. USDA, Forest Service, Rocky Mountain Research Station, Forest Sciences Lab (Producer). Available: http://www.fs.fed.us/database/feis [2005, February 23].

Johnson, K. A. 2001. Pinus flexilis. In: Fire Effects Information System [Online]. USDA, Forest Service, Fire Sciences Lab (Producer). Available: http://www.fs.fed.us/database/feis [2005, February 23].

Little, E. L. 1971. Atlas of United States Trees:Volume 1, Conifers and Important Hardwoods. USDA Forest Service, Misc. Pub. 1146, Washington, DC.

Steele, R. in: Burns, R. M., and B. H. Honkala, tech coords. 1990. Silvics of North America: 1. Conifers. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. Vol 2, 877 p.

State-and-Transition Model (cropped):



Low Sagebrush Steppe (LSS) 1126
Area of Application and Context: • **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.** • **No livestock grazing (since 2006 on northwestern slope).** • **Until recently, full fire suppression management.** • **Date created: December 2010**
Vegetation classes: • A-*Early*: 15-25% herbaceous cover (bluebunch wheatgrass, Thurber's needlegrass); 0-10% cover of rabbitbrush; 0-25 yrs • *B-Mid*1-*open*: 11-20% cover of low sagebrush and mountain snowberry; 15-25% herbaceous cover (bluebunch wheatgrass, Thurber's needlegrass); 25-99 yrs • *C-Late1-Closed*: 21-30% cover of low sagebrush and Utah serviceberry; 10-15% herbaceous cover (bluebunch wheatgrass); >100 yrs • *U-TE:* 6-30% cover of trees; <5% herbaceous cover • *U-DP*: 5-20% cover of low sagebrush <0.5m, <5% herbaceous cover • *U-ES: Early*-Shrub;10-30% cover rabbitbrush species
Reference Condition: • **Natural Range of Variability** ➢ 25%: A-*Early* ➢ 56%: B-*Mid-open* ➢ 19%: C-*Late-closed* ➢ 0%: U • **Model Tracker Status** ➢ Updated Model Tracker December 2010 for biophysical setting Low Sagebrush Steppe (LSS) 1126
Succession: Succession is simple in this three-box model: ➢ Early to mid-succession open: 24 years ➢ Mid-succession open to late-succession closed: 119 years
Natural Disturbances: *Replacement fire* was found in all classes, except *depleted sagebrush* (*DP*) because it lacks fine fuels. In the reference pathway that supports high grass cover in the montane to subalpine elevations, the fire return interval ranged from 250 years (0.004/year) in the *early-succession* class (*LSS-A*), to 90 years (0.015/year) and 65 years (0.011/year), respectively, in the *mid-succession open* (*LSS-B*) and *late-succession closed* class (*LSS-C*). For uncharacteristic classes, the *early shrub* class (*ES*) supports a 200-

year fire return interval (0.005/year), whereas the interval lengthened to 250 years (0.004) in the tree-encroached shrubs (*TE*); less fine fuel but greater ability to carry crown fire.

Drought affected all classes except the *early shrub* class (*ES*). A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant species. Drought slowed down succession by weakly reversing it by one year increments for all chosen pixels in the *early-succession* class (*LSS-A*) and for 80% of pixels in the *mid-succession open* (*LSS-B*) and *late-succession closed* (*LSS-C*) classes. The remaining 20% in these last two classes caused stand-replacement. In the *depleted shrubs* class (*DP*), thinning becomes 90% of the disturbance with reversal of woody succession to age 25 years, whereas a stand replacing events represents a 10% shift to the *early shrub* class (*ES*). The *tree-encroached shrub* class (*TE*) has a different meaning in the Low Sagebrush Steppe biophysical setting than in other sagebrush communities because the harsh clay soils of low sagebrush maintain a very open canopy of pinyon, juniper, white fir, or limber pine that takes centuries to form. The open canopy allows shrubs and herbaceous species to persist during early encroachment such that drought will cause a transition to the *early-succession* class (*LSS-A*) from 200 to 300 years, but to *depleted shrubs* (*DP*) after 200 years under the assumption that low sagebrush as a species is much hardier than herbaceous species at surviving tree competition and shading.

Tree invasion applies to the *late-succession closed* class (*LSS-C*) and to the *depleted shrub* class (*DP*). It was assumed that grass cover slowed down establishment of tree seedlings in the former class at a rate of 0.001/year, whereas the loss of grass cover accelerated tree seedling establishment up to 0.005/year. The rate of 0.001/year is 10× lower than the transition of 0.01 probability/year pixels that approximately replicated encroachment levels proceeding in three phases of about 50 years (Miller and Tausch 2001).

Natural recovery applies only to the *early shrub* class (*ES*) and is possible because of the higher elevation and precipitation of the biophysical setting and the natural co-dominance of rabbitbrush species in the *early-succession* class (*LSS-A*). It is assumed that low sagebrush and other herbaceous species will re-establish naturally in the *early shrub* class (*ES*) after at least 25 years without fire or other stand replacing events. The rate of *natural recovery* was low at 0.001/year with transition to the *mid-succession open* class (*LSS-B*) from ages 25 to 119 years and to the *late-succession closed* class (*LSS-C*) for age ≥120 years.

Management Actions:

Park staff only retained *prescribed fire* as a strategy to burn late-succession classes with and without encroaching conifers. Unlike lower fine fuel levels in semi-desert low sagebrush, the higher grass cover in the Low Sagebrush Steppe biophysical setting allows fire spread. Prescribed fire can be ignited by hand or from helicopters while ignitions are conducted in adjacent biophysical settings. The portion of uncharred sagebrush was assumed to be 40%.

Literature cited in LANDFIRE's Model Tracker:

Biondi, F., Kozubowski. T.J., Panorska, A.K., and L. Saito. 2007. A new stochastic model of episode peak and duration for eco-hydro-climatic applications. Ecological Modelling 211:383-395.

Chambers, J. C. and Miller, J. editors. 2004. Great Basin riparian areas: ecology, management, and

restoration. Society for Ecological Restoration International, Island Press. Pp 24-48.
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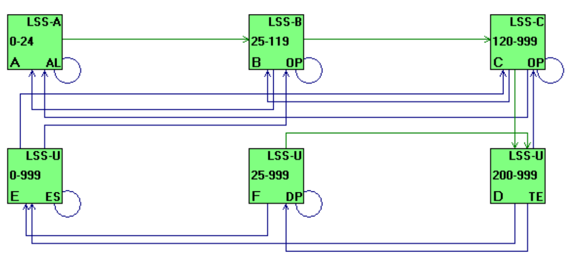
Miller, R. F. and J. A. Rose. 1999. Fire history and western juniper encroachment in sagebrush steppe. Journal of Range Management 52:550-559.
USDA-NRCS 2003. Ecological site descriptions for Nevada. Technical Guide Section IIE. MLRAs 28B, 28A, 29, 25, 24, 23.
Young, J. A., and R. A. Evans. 1978. Population Dynamics after Wildfires in Sagebrush Grasslands. Journal of Range Management 31:283-289.
Young, J. A., and R. A. Evans. 1981. Demography and Fire History of a Western Juniper Stand. Journal of Range Management 34:501-505.
Young, J. A. and D. E. Palmquist. 1992. Plant age/size distributions in black sagebrush (Artemisa nova): effects on community structure. Great Basin Naturalist 52(4):313-320.
Ratzlaff, T. D. and J. E. Anderson. 1995. Vegetal recovery following wildfire in seeded and unseeded sagebrush steppe. Journal of Range Managenent 48:386-391.
Zamora, B. and P. T. Tueller. 1973. Artemisia arbuscula, A. longiloba, and A. nova habitat types in northern Nevada. Great Basin Naturalist 33: 225-242.

State-and-Transition Model:



Mixed Conifer (MC) 1052
Area of Application and Context: • **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.** • **No livestock grazing (since 2006 on northwestern slope).** • **Until recently, full fire suppression management.** • **Date created: December 2010**
Vegetation classes: • *Early*; 0-29yrs; 0-15% cover of tree/shrub/grass; <5m; 0-29 yrs • *B-Mid*1-*closed*; 30-99yrs; 35-100% cover of conifers <24m; 30-99 yrs • *C-Mid*1-*open*; 31-99yrs; 0-35% cover of conifers <24m; 30-99 yrs • *D-Late*1-*open*; 100-999yrs; 0-35% cover of conifers 25-49m; >100 yrs • *E-Late*1-*closed*; 100-999yrs; 35-100% cover of conifers 25-49m; >100 yrs • *U-TA*; 10-100% cover of young and older conifers; >5% cheatgrass cover • *U-AG*: >10% cheatgrass cover; trees largely absent; charred logs or standing dead trees often present; native grasses and forbs may be present

Reference Condition:
 	
• **Natural Range of Variability**
  ➢ 11%: A-*Early*
  ➢ 19%: B-*Mid-closed*
  ➢ 24%: C-*Mid--open*
  ➢ 23%: D-*Late-open*
  ➢ 23%: E-*Late-closed*
  ➢ 0%: U
• **Model Tracker Status**
  ➢ Updated Model Tracker December 2010 for biophysical setting Mixed Conifer (MC) 1052

Succession:
 	
Succession is the standard five-box model with a dominant closed canopy succession and a probabilistic alternate succession conditional on the time since the last fire (in VDDT jargon, Time-Since-Disturbance or TSD):
• Closed canopy pathway
  ➢ Early to mid-succession closed: 9 years
  ➢ Mid-succession closed to late-succession closed: 49 years
• Open canopy pathway
  ➢ Mid-succession open to late-succession closed: 63 years
• Alternate succession

- Mid-succession open to mid-succession closed: 10-63 years conditional upon lack of any fire for 35 consecutive years
- Late-succession open to late-succession closed: ≥60 years conditional upon lack of any fire for 150 consecutive years

Natural Disturbances:

Fire is the dominant process in the Mixed Conifer biophysical setting. *Replacement fire* was present in all classes. A mean fire return interval of 125 years (0.008/year) applies to the *early-succession* (*MC-A*), *mid-succession closed* (*MC-B*), and *late-succession closed* (*MC-E*) classes. The mean fire return interval lengthened to 400 years (0.0025/year) in the *mid-succession open* (*MC-C*) and *late-succession open* (*MC-D*) classes that supported less heavy fuels than the closed classes. The fire return interval was as short as 10 years (0.1/year) in the *annual grassland* class (*AG*) and longer (190 years or 0.0053/year) in the *tree with annual grass* class (*TA*).

Mixed severity fire applied to both closed succession classes with a return interval of 50 years (0.02/year) causing thinning to the open classes of the same succession age. *Mixed severity fire* also occurred in the *tree with annual grass* class (TA) at a return interval of 65 years (0.0152/year); however, 75% of the burn caused a transition to the *annual grassland* class (*AG*) but 25% remains unburned.

Surface fire had a return interval equals to that of mixed severity fire, but only occurred in the open succession classes and caused no transition (but influences the time-since-disturbance function).

A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant species. *Drought* affected the *early-succession* class (*MC-A*) and both late-succession reference classes because older trees are more vulnerable to stress. The mid-succession classes are considered more resistant than other classes to *drought* because trees are in full vigor. *Drought* thinned the early-succession class (*MC-A*) under the assumption that conifer seedlings would be killed. Intraspecific competition among trees is assumed less in the *late-succession open* class (*MC-D*) where *drought* thins the older trees to the beginning of the succession classes (in VDDT jargon, RelAge = -999). Intraspecific competition is increased by greater tree cover (and presumably density) in the *late-succession closed* class (*MC-E*); therefore, *drought* thinning causes a transition to the *late-succession open* class (*MC-D*) while maintaining succession age (in VDDT jargon, RelAge = TRUE).

Insect/disease outbreaks are more frequent than the return interval of severe *drought* and found in all classes except *early-succession* (*MC-A*). A 25-year return interval (0.04/year) of *insect/disease* applies to the *mid-succession closed* class (*MC-B*) partitioned equally between thinning to the *mid-succession open* class (*MC-B*) and stand-replacement to the *early-succession* class (*MC-A*). The return interval of *insect/disease* outbreaks increased to 50 years (0.02/year) with 60% resulting in stand replacement and 40% thinning to the *late-succession open* class (*MC-D*). Open-succession classes are also affected by the *insect/disease* disturbance with thinning occurring within the class but without affecting the succession age. The rate of insect/disease disturbance decreases from 0.01/year (100-year return interval) in the *mid-succession open* class (*MC-C*) to 0.001/year (1,000-year return interval) in the *late-succession open* class (*MC-D*). The same internal thinning applied to the uncharacteristic *tree with annual grass* class (*TA*), although in this case the rate is equal to that of *drought*.

Annual grass invasion was weakly present in all mid-succession and late-succession classes at an arbitrary rate of 0.0001/year and caused a transition to the *tree with annual grass* class (*TA*).

Under the influence of tree competition and more moist soil conditions of the Mixed Conifer biophysical setting, *natural recovery* allows a transition from the *tree with annual grass* class (*TA*) to the *late-succession closed* class (*MC-E*).

Management Actions:

None chosen by Park staff, although *prescribed fire* would be appropriate.

Literature cited in LANDFIRE's Model Tracker:

Barrett, S.W., 1988. Fire suppression effects on Forest Succession within a Central Idaho Wilderness. Western J of Applied Forestry, 3(3): 76-80.

Barrett, S.W., 1994. Fire regimes on the Caribou National Forest, Southern Idaho. Final Report - Contract No. 53-02S2-3-05071.

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Biondi, F., Kozubowski. T.J., Panorska, A.K., and L. Saito. 2007. A new stochastic model of episode peak and duration for eco-hydro-climatic applications. Ecological Modelling 211:383-395.

Bradley, A.F., W.C. Fische, and N.V. Noste. 1992. Fire ecology of the forest habitat types of Eastern Idaho and Western Wyoming. Intermountain Research Station, Ogden, UT 84401. GTR-INT-290.

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Brown, J.K. S.F. Arno, S.W. Barrett, and J.P. Menakis. 1994. Comparing the prescribed natural fire program with presettlement fires in the Selway-Bitterroot Wilderness. Int. J. Wildland Fire 4(3):157-168.

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Morgan, P, S.C. Bunting, A.E. Black, T. Merrill and S. Barrett. 1996. Fire regimes in the Interior Columbia River Basin: Past and Present. Final report for RJVA-INT-94913: Coarse-scale classification and mapping of disturbance regimes in the Columbia River Basin. Submitted to Intermountain Fire Science Lab., Intermountain Research Station, Missoula, Montana, USDA Forest Service.

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Swetnam, T.W., B.E. Wickman, H.G., Paul, and C.H. Baisan. 19950 Historical patterns of western spruce budworm and Douglas-fir tussock moth outbreaks in the northern Blue Mountains, Oregon, since A.D. 1700. USDA Forest Service. Pacific Northwest Research Station. Research paper PNW-RP-484, 27 pp.

State-and-Transition Model (cropped):


MC-A
0-9
G AL
MC-B
10-49
H CL
MC-E
50-999
F CL
MC-C
10-63
I OP
MC-D
64-999
J OP
MC-U
0-999
AM AG
MC-U
10-999
AP TA

Montane-Subalpine Grassland (MG) 1146

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Date created: December 2010**

Vegetation classes:

- *A-Early*-open: 0-5 yrs; 0-10% herbaceous cover — graminoids, forbs, and sedges; abundant bare ground and rock cover; 0-4 yrs
- *B-Mid*--closed: 5-10 yrs; 11-30% herbaceous cover — graminoids, forbs, and sedges; abundant bare ground and rock cover; 5-9 yrs
- *C-Late*-open: >10 yrs; 11-30% herbaceous cover — graminoids, forbs, and sedges ; 9-30% low shrub cover; common bare ground and rock cover; >10 yrs
- *U*-None

Reference Condition:

- **Natural Range of Variability**
  - 4%: A-*Early*
  - 30%: B-*Mid-closed*
  - 66%: C-*Late-open*
  - 0%: U
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Montane-Subalpine Grassland (MG) 1146

Succession:

Succession is simple in this three-box model:
- Early to mid-succession closed: 4 years
- Mid-succession closed to late-succession open: 9 years

Natural Disturbances:

Replacement fire was found in all classes with a fire return interval ranged from 200 years (0.005/year). *Surface fire* is only present in the *late-succession open* class (*MG-C*) and, although low severity, top-kills graminoids and some shrubs (including resprouting shrubs) enough to cause a transition to the *mid-succession closed* class (*MG-B*).

The only other disturbance in this biophysical setting is *native grazing* by deer and small mammals. *Native grazing* is widespread; half of the biophysical setting is grazed each year (0.5/year) in the first two succession classes. In the *early-succession* class (*MG-A*), *native grazing* reverses woody succession by one year, but had no effect on woody succession in other classes. The proportion of the biophysical setting decreased to 10% of the biophysical setting in the *late-succession open* class (*MG-C*).

Management Actions:

None chosen by Park staff, although fire importation from prescribed fire in adjacent biophysical settings could be considered.

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Allen, C. D., 1984. Montane grasssland in the landscape of the Jemez Mountains, New Mexico, Master's Thesis, Univ. Wisconsin, Madison, WI.

Brewer, D., G., R, K. Jorgensen, L, P. Munk, W, A. Robbie and J, L. Travis. 1991. Terrestrial Ecosystem Survey of the Kaibab National Forest. USDA Forest Service, Southwestern Region. 319 pps.

Danker, R, C., W. Robbie and C. Landers. 1979. Terrestrial Ecosystem Report for Smokey Bear Ranger District. USDA Forest Service, Southwestern Region. 245pps. w/maps.

DickPeddie, W. A. 1993. New Mexico Vegetation; Past, Present and Future.University of New Mexico Press. Albuquerque, NM.

Edwards, M., G. Miller, J. Redders, R. Stein and K. Dunstan. 1987. Terrestrial Ecosystem Survey of the Carson National Forest. USDA Forest Service Southwestern Region. 552 pps.

Miller, G., N. Ambos, P. Boness, D. Ryher, G. Robertson, K. Scalzone, R. Steinke and T. Subirge. 1995. Terrestrial Ecosystem Survey of the Coconino National Forest. USDA Forest Service, Southwestern Region. 405pp.

Miller, G., J. Redders, R. Stein, M. Edwards, J. Phillips, V. Andrews, S. Sebring and C. Vaandrager. 1993. Terrestrial Ecosystem Survey of the Santa Fe National Forest. USDA Forest Service Southwestern Region. 563 pps. Maps.

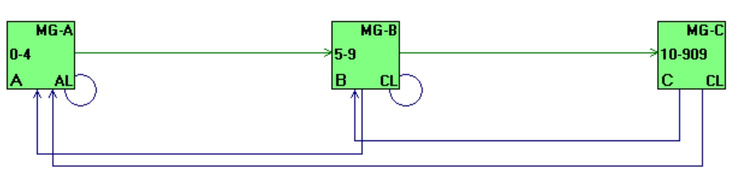
Moir, W. H., 1967. The subalpine tall grass, Festuca thurberi, community of Sierra Blanca, New Mexico. The Southwest Naturalist. 12:321-328.

Muldavin, E. and P. Tonne. 2003. A Vegetation Survey and Preliminary Ecological Assessment of the Valles Caldera National Preserve, New Mexico. Final Report. New Mexico Natural Heritage Program. Albuquerque, NM.

Swetnam, T. W. 1990. Fire History and Climate in the Southwestern United States. USDA Forest Service. Rocky Mtn. Forest and Range Exp. Sta. GTR-RM-191.

Touchan, R., C. D. Allen and T. W. Swetnam. 1996. Fire History and Climatic Patterns in the Ponderosa Pine and Mixed-Conifer Forests of the Jemez Mountains, Northern New Mexico. IN: Proceedings of the Second La Mesa Fire Symposium, Fire Effects in Southwestern Forests. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. RM-GTR-2

State-and-Transition Model:



Mountain Mahogany (MM) 1062

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Date created: December 2010**

Vegetation classes:

- *A-Early*: 10-55% cover mountain mahogany seedlings and saplings, 0-2m; mineral soil abundant; grasses and shrubs present but not abundant; 0-19 yrs
- *B-Mid*1-*Open*: 30-45% cover of mountain mahogany, mountain sagebrush, snowberry, and mountain snowberry 2-5m high; 60-59 yrs
- *C-Mid*1-C*losed*: 0-30% cover mountain mahogany 2-5m; mineral soil abundant; grasses and mountain sagebrush, snowberry, and mountain snowberry common; 20-59 yrs
- *D-Late*1-*Open*: 0-30% cover of mountain mahogany 5-25m; grasses and mountain sagebrush, snowberry, and mountain snowberry common; >60 yrs
- *E- Late*1-*Closed*: 30-55% cover of mountain mahogany, 5-25m; >49 yrs;
- *U-TA*: Tree-Annual-Grass; 10-55% cover of mountain mahogany; 5-20% cheatgrass cover
- *U-AG*: Annual-Grasses; 5-30% cheatgrass cover

Reference Condition:

- **Natural Range of Variability**
  - 8%: A-*Early*
  - 13%: B-*Mid-closed*
  - 15%: C-*Mid--closed*
  - 23%: D-*Late-open*
  - 41%: E-*Late-closed*
  - 0%: U
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Mountain Mahogany (MM) 1062

Succession:

Succession is the standard five-box model with a dominant closed canopy succession and a probabilistic alternate succession conditional on the time since the last fire (in VDDT jargon, Time-Since-Disturbance or TSD):

- Deterministic succession
  - Early to mid-succession closed: 19 years
  - Mid-succession closed to mid-succession open: 59 years

- Mid-succession open to late-succession closed: 149 years
- Alternate succession
  - Late-succession open to late-succession closed: ≥60 years conditional upon lack of any fire for 150 consecutive years

Natural Disturbances:

Replacement fire was present in all classes. The mean fire return interval varies with succession:

- 500 years (0.002/year) applies to the *early-succession* class (*MM-A*);
- 145 years (0.007/year) for the *mid-succession open* (*MM-B*), mid-succession closed (MM-C), and *tree with annual grass* (*TA*) classes;
- 300 years (0.003/year) for the *late-succession open* class (MM-D);
- 500 years (0.002/year) for the *late-succession closed* (*MM-E*) classes; and
- 10 years (0.1/year) in the *annual grassland* class (*AG*).

Mixed severity fire applied to the *mid-succession closed* class (*MM-C*) with a return interval of 200 years (0.005/year) causing thinning to the *late-succession open* class (*MM-D*). This thinning is unique because is separates thickets from savannas of curl-leaf mountain mahogany, which is very sensitive to fire. Further research is needed to determine whether or not this transition exists. NRCS considers that the *late-succession closed* (*MM-E*) and *late-succession open* (*MM-D*) classes belong to distinct ecological sites (i.e., soils); the *late-succession open* class (*MM-D*) is found on soil with bouldering.

Surface fire had a return interval of 40 years (0.025/year) that maintained the open savanna-like character of the *late-succession open* class (*MM-E*). The assumption is that fire from the surrounding mountain big sagebrush communities would be the source of this surface fire creeping among old curl-leaf mountain mahogany trees. Again, more research is needed to confirm the presence of *surface fire* given the great sensitivity of curl-leaf mountain mahogany to fire.

Native grazing is an important disturbance earlier in succession because the seedlings and saplings of curl-leaf mountain mahogany are high in nitrogen and very palatable to small mammals and ungulates (Arno and Wilson, 1986; Schultz *et al*., 1996; Ross, 1999). The effect of *native grazing* is to slow down succession. In the *early-succession* class (*MM-A*), the rate of *native grazing* assumed that herbivory is present every year with only 2% of the area with removal of the seedlings and saplings (0.02/year). Browse of branches continues at a decreasing rate from 0.01/year in the *mid-succession open* class (*MM-B*) to 0.001/year in the *mid-succession closed* class (*MM-C*).

Annual grass invasion (*AG-invasion*) is present in both late-succession classes at a rate of 0.001/year and causes a transition to the *tree with annual grass* class (*TA*). Annual invasion is tied to a base rate of 0.001/year estimated from data of northwest Utah collected by the Utah Division of Wildlife Resources in black sagebrush semi-desert. Black sagebrush semi-desert is usually considered resistant to cheatgrass invasion. We retained this rate because curl-leaf mountain mahogany is at higher elevations where native perennial grasses can outcompete cheatgrass and grows on harsh, shallow soils.

Management Actions:

None chosen by Park staff.

Literature cited in LANDFIRE's Model Tracker:

Arno, S. F. and A. E. Wilson. 1986. Dating past fires in curlleaf mountain-mahogany communities. Journal of Range Management 39:241-243.

Billings, W.D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin. In: Proc. Ecology and management of annual rangelands. USDA USFS GTR-INT-313.

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Gruell, G., S. Bunting, and L. Neuenschwander. 1984. Influence of fire on curlleaf mountain mahogany in the Intermountain West. Proc. Symposium on fire's effects on wildlife habitat. Missoula, Montana.

Marshall, K.A. 1995. Cercocarpus ledifolius. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2004, November 16].

Monsen, S. B. and E. D. Mc Arthur. 1984. Factors influencing establishment of seeded broadleaf herbs and shrubs following fire. Pp 112-124. In: K. Sanders and J. Durham (eds). Proc. Symp.: Rangelands fire effects. USDI Bureau of Land Management, Idaho Field Office, Boise, Idaho.

Natural Resources Conservation Service. 2003. Major land resource area 29. Southern Nevada Basin and Ragne. Ecological site descriptions. US Department of Agriculture.

Peters, E. F. and S. C. Bunting. 1994. Fire conditions pre- and post-occurrence of annula grasses on the Snake River plain. In: In: Proc. Ecology and management of annual rangelands. USDA USFS GTR-INT-313.

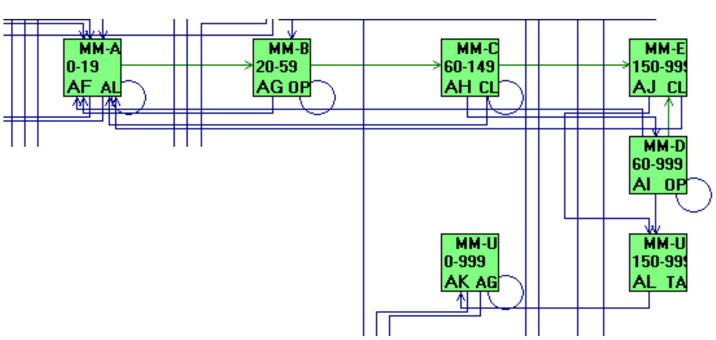
Ross, C. 1999. Population dynamics and changes in curlleaf mountain mahogany in two adjacent sierran and Great Basin mountain ranges. Pp. 111.

Schultz, B.W., R.J. Tausch, P.T. Tueller. 1996. Spatial relationships amoung young Cercocarpus ledifolius (curlleaf mountain mahogany). Great Basin Naturalist 56: 261-266.

Tausch, R. J., P. E. Wigand, and J. W. Burkhardt. 1993. Viewpoint: Plant community thresholds, multiple steady states, and multiple successional pathways: legacy of the Quaternary? Journal of Range Management 46:439-447.

Whisenant, S. G. 1990. Changing fire frequencies on Idaho's Snake River plains: Ecological and management implications. In: Proc. Symp., Cheatgrass Invasion, shrub die-off, and other aspects of shrub biology and management. USDS USFS INT 276, Ogden, Utah.

State-and-Transition Model (cropped):



Montane Riparian (MR) 1154
Area of Application and Context: • **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.** • **No livestock grazing (since 2006 on northwestern slope).** • **Until recently, full fire suppression management.** • **Date created: December 2010**
Vegetation: • *A-Early*: 0-50% cover of cottonwood, willow, Wood's rose <3m; carex present; 0-5 yrs • *B-Mid*1-*open*: 31-100% cover of cottonwood, aspen, willow, young conifers, Wood's rose <10m; 5-20 yrs; • *C-Late*1-*closed*; 31-100% cover of cottonwood, alder, aspen, conifer, willow 10-24m; >20 yrs • *U-SFE*: Shrub-Forb-Encroached; 10-50% cover of Wood's rose and skinkbush (*Rhus trilobata*) in open areas or under tree canopy • *U-EF*: Exotic-Forbs; 10-100% cover of exotic forbs (knapweed, tall whitetop, purple loosetrife), salt cedar, or Russian olive • *U-DE*: Desertification; Entrenched river/creek with 10-50% cover of upland shrubs (e.g., big sage); >5% native grass cover • *U-AG*: Annual-Grass; 10-30% cover of cheatgrass on dry incised banks; < 10% shrub cover • *U-SAP: Shrub-Annual-Grass-Perennial Grass*: Entrenched river/creek with 10-50% cover of upland shrubs (e.g., big sage); >5% cheatgrass cover; >5% native grass cover • *U-SD: Seeded*; Entrenched river/creek with >20% crested wheatgrass cover • *U-SDA: Seeded-Annual-Grass*; Entrenched river/creek with >20% crested wheatgrass cover; >5% cheatgrass cover • *U-TE: Tree-Encroached*; Entrenched river/creek with >20% pinyon or juniper cover 5-10m; <5% shrub cover; <5% herbaceous cover • *U-DW: Dewatered*; Riparian floodplain with dry channel due entirely to water withdrawal; vegetation dominated by riparian and sub-xeric shrubs and trees; frequent evidence of branch pruning or dead cottonwoods or willows in what would have been *Late1-Closed* class. • *U-PD: Partially-Dewatered*; Riparian floodplain with partially dewatered channel due entirely to water withdrawal; vegetation as described for *Early*, *Mid1-Open, and Late1-Closed* classes; water level substantially below bankfull; evidence of branch pruning or dead cottonwoods or willows in *Late1-Closed* class. • *U-EFD: Exotic-Forb-Dewatered*; 10-100% cover of exotic forbs (knapweed, tall whitetop, purple loosetrife), salt cedar, or Russian olive in either dewatered or partially dewatered channel. • *U-DEP: Desertified-Partially-Dewatered;* Entrenched riparian floodplain with partially dewatered channel due entirely to water withdrawal; vegetation as described in *DE* class.
Reference Condition:

- **Natural Range of Variability**
    - 21%: A-*Early*
    - 36%: B-*Mid-closed*
    - 43%: C-*Late-closed*
    - 0%: U
- **Model Tracker Status**
    - Updated Model Tracker December 2010 for biophysical setting Montane Riparian (MR) 1154

Succession:

Succession follows the 3-box pathway with heterogeneous vegetation starting with willow and narrow-leaf cottonwood, and wet meadows and ending with a forested mix of willow, cottonwoods, montane and subalpine conifers, aspen, and wet meadows. The succession pathway is entirely deterministic with transitions occurring at the following ages:

- Early to mid-succession closed: 4 years
- Mid-succession closed to late-succession closed: 19 years

Natural Disturbances:

The Montane Riparian biophysical setting is deceptively simple but contains some of the most complex dynamics of all biophysical settings due to the interaction of hydrological and floodplain vegetation processes.

Flooding dominated the dynamics of this biophysical setting. Three levels of *flooding* were 7-yr events (0.13/year) that killed or removed only herbaceous vegetation in the *early-succession* class (*MR-A*), 20-year events (0.05/year) that killed or removed shrubs and young trees in the *mid-succession closed* class (*MR-B*), and 100-year events (0.01/year) that top-killed larger trees and everything else in the *late-succession closed* class (*MR-C*).

Beaver-herbivory is considered a non-native disturbance by Park biologists mostly restricted to the reaches outside the Park and to lower elevations inside the Park. The beaver population is currently low on the Snake Range; therefore, the rates in this model are also low. *Beaver-herbivory* functioned as a rotating disturbance where beaver fells woody vegetation, leaves the creek reach, and only returns after substantial regrowth of aspen and willow had occurred, usually after 20-25 years. The effect of *beaver herbivory* is assumed to decrease from early- to later-development vegetation classes. A rate of 0.005 is used in the *early-succession* class (*MR-A*) with a reversal of woody succession by one year for chosen pixels (RelAge = -1 in VDDT jargon). This rate is maintained in the *mid-succession closed* class (*MR-B*); however, 50% of the herbivory is a stand replacing event, whereas the rest of the disturbance thins within the *mid-succession closed* class (*MR-B*) to the beginning of the class. The rate of *beaver herbivory* drops in the late-succession class (*MR-C*) to 0.002/year partitioned equally between thinning within this class by reversal of woody succession by 5 years for chosen pixels and thinning to the *mid-succession closed* class (*MR-B*).

Another important disturbance was the invasion by exotic forbs (*exotic invasion*) represented mainly by tall whitetop, knapweeds (*Centaurea* spp.), and thistles. *Exotic invasion* causes a transition to the *exotic* *forb* class (*EF*). Workshop participants agreed to a moderately high rate (0.01/year) to plan for a worst case scenario, although they did not feel that this was reflective of the current situation. Roadways, off-highway vehicles, and animals are usually the greatest vectors of exotic forbs. *Exotic invasion* occurs in five classes: *mid-succession closed* (*MR-B*), *late-succession closed* (*MR-B*), *shrub and forb encroached* (*SFE*), *partially dewatered* (*PD*), and *dewatered* (*DW*).

A class reflecting historic grazing was the dominance of riparian corridors by native forbs and shrub species unpalatable to domestic sheep and cattle (*shrub and forb encroached* or *U-SFE*). Although livestock no longer graze in the Park, the legacy of past management has left sections of creeks with dense midstory of Wood's rose (*Rosa woodsii*) and shinkbush (*Rhus trilobata*) representing this vegetation class in mostly Snake Creek and Strawberry Creek.

The Park's roads adjacent to creeks channel rain and snowmelt that often flow laterally into creeks. The disturbance *road lateral flow* causes entrenchment, or incision, of creek banks. The disturbance applies to the three succession and *partially dewatered* (*PD*) classes. The consequence of entrenchment was a drop of the water table, leading to a moist or wet system becoming a sub-xeric shrubland (*Desertification = DE*). Simple assumptions are built in the rate for *road lateral flow*, which is 0.0132/year: the return interval of major road flooding events correspond to precipitation events of at least 25 years (0.04/year) and roads are adjacent to creeks for about a third of the major creeks (therefore, 0.025/year × 0.33 = 0.0132/year). Another condition must be met for entrenchment to happen: a reach and its adjacent road must not have been managed or restored to prevent entrenchment for at least 20 years, which is reasonable for the naturally armored creeks (heavily bouldered) of the Park. Finer sediments would likely be far more vulnerable to blow outs after storms.

Replacement fire originates from the surrounding landscape and restarts the succession clock to age zero after sweeping through the riparian corridor. Fire activity was varied:

- A common 50-year fire return interval (0.02/year) applies to the *mid-succession closed* (*MR-B*), *late-succession closed* (*MR-C*), *desertified* (*DE*), *dewatered* (*DW*), *exotic forb* (*EF*), *exotic forb dewatered* (*EFD*), *partially dewatered* (*PD*), *desertified and partially dewatered* for <150 years of succession (*DEP*), and *shrub forb encroached* (*SFE*) classes;
- *Annual grassland* (0.1/year; *AG*);
- *Desertified and partially dewatered* for ≥150 years of succession (0.0068/year; *DEP*);
- *Shrub with annual grass* (0.04/year; *U-SAP*) resulting in 90% *annual grassland* (*AG*) and 10% unburned,
- *Seeded with crested wheatgrass and invaded by annual grass* (0.04/year; *SDA*) with 80% burned and remaining in this class, 10% converting to annual grasslands (*AG*), and 10% in transitioning to the *seeded with crested wheatgrass* class (*SD*); and
- *Tree-encroached (i.e., pinyon and juniper) desertified shrubland* (*TE*) burning at a rate of 0.0068/year (150 years) but with only 50% of the wooded area transitioning to the *annual grassland* class (*AG*).

Water withdrawal is the action of diverting any surface water or groundwater that will result in varying degree of dewatering for a creek. Currently, Snake Creek is the only one with surface water diversion. In the model, w*ater withdrawa*l translates into acres being dewatered in all succession classes, of which 75% where partially dewatered (*PD*) and 25% completely dewatered (*DW*). The percentage for partitioning water is arbitrary and was discussed with workshop participants. The rate of *water withdrawal* is treated differently than all other disturbances because a water right is a fixed allocation, therefore a fixed amount of acres are affected. The area of *water withdrawal* cannot increase with the area of reference classes relative to others; therefore, the Area Limit function of VDDT was set at a fixed value. Hence, a fixed area of the riparian floodplain gets dewatered every year. The loss of watered acres to the dewatered classes must be balanced by resetting the same amount of water back to the creek (*yearly reset withdrawal*) using again the Area Limit function, i.e., rewatering the dewatered classes. The net effect of these two disturbances imitating a water right permit is that the dewatered classes are maintained at the area set for w*ater withdrawa*l in Area Limits; otherwise, dewatered classes become 100% of the biophysical setting. The value of the Area Limit for both disturbances should be tied to the actual effect of water right permits, which was not available. Therefore, we chose a working value of 13 acres as it created reasonable values after trial-and-error tests.

A *partially dewatered* class (*PD*) behaves like a succession class with the same disturbances, but the riparian vegetation will be narrower than the original floodplain and cottonwood may show signs of stress, such as pruning of higher branches. As indicated above, this class can become incised from *road lateral flow*, thus transitioning to *desertified partially dewatered* class (*DEP*). When the *yearly reset withdrawal* disturbance is applied to this later class, it becomes *desertified* (*DE*), which means that the creek is fully flowing and entrenched.

A *dewatered* class (*DW*) supports a mixture of more drought-tolerant riparian plants and subxeric species. Cottonwoods will be dead or self-pruning. *Hundred-year flood* events (flash floods) and *replacement fire* are the only disturbances that reset the succession age to zero, but do not cause a change of class. *Exotic forb invasion* will cause a transition to the *exotic forb dewatered* class (*EFD*), whereas this latter class will convert to the *exotic forb* class (*EF*) with rewatering (*yearly reset withdrawal* disturbance). (The reverse process from *exotic forb* (*EF*) to *exotic forb dewatered* (*EFD*) is caused by the *water withdrawal* disturbance.)

Desertification of riparian vegetation, either from past management or currently from *road lateral flow*, opens up dynamics more typical of sagebrush communities. In the Park, past U.S. Forest Service management includes a legacy of old crested wheatgrass seedings on the south side of Snake Creek that are also part of an entrenched floodplain. The *desertified* class (*DE*) often behaves as a shrub-encroached basin wildrye communities dominated by rabbitbrush and basin big sagebrush. Due to the proximity of creeks, *100-year flooding* events have the power to substantially rework sediments over 10% of the area and cause a transition to the *early-succession* class (*MR-A*), whereas 90% of the remaining area is returned to age zero of the *desertified* class (*DE*). Two other disturbances can “restore” desertified riparian vegetation: a) flows will naturally rework banks and promote riparian vegetation at a low rate of 0.001/year (*natural recovery* disturbance) if and only if *road lateral flows* are absent for 10 consecutive years (a time since disturbance function), which implies removing a road or no storm events and b) *beaver herbivory* in the form of dam building can elevate the water table and cause a transition to the *shrub forb encroached* class at a rate of 0.002/year. It is assumed that subxeric vegetation is most similar to the *shrub forb encroached* class.

If hydrological processes do not change the *desertified* class (*DE*), *tree* (pinyon and juniper) *invasion* after 40 years of shrub growth will convert this class to the *tree encroached* class at a rate of 0.01/year, consistent with Miller and Tausch’s (2001) three phases of tree establishment in about 50 years each. The *desertified* class (*DE*) can also be invaded by cheatgrass (*AG invasion*) at a rate of 0.005/year and become the *shrub with annual and perennial grass* class (for model simplicity, we lumped subxeric shrubs with annual grasses and shrubs with a mixed annual and perennial grass understory into the *shrub with annual and perennial grass* class [*SAP*] into the latter class). A base rate of 0.001/year was estimated from data of northwest Utah collected by the Utah Division of Wildlife Resources in black sagebrush semi-desert. Black sagebrush semi-desert is usually considered more resistant to cheatgrass invasion than big sagebrush dominated biophysical settings. Because NPS, BLM or USFS did not have similar data, we defaulted to five times the rate estimated from the Utah data. The higher rates indicated greater susceptibility to cheatgrass because soils were more productive.

The *seeded* class (*SD*) is not created from other classes, but its dynamics are almost identical to those of the *desertified* class (*DE*). *Annual grass invasion* at a low rate of 0.001/year causes a transition to the *seeded with annual grass* class (*SDA*) which is found on the southern Snake Creek floodplain. Crested wheatgrass is assumed more resistant to cheatgrass invasion than the *desertified* class (*DE*) (Cox and Anderson 2004). *Tree-invasion* leads to the *tree encroached* class (*TE*) where the role of created wheatgrass is absent. Other disturbances are as described above in the *desertified* class (*DE*).

The *shrub with annual and perennial grass* class (*SAP*) is affected by *beaver-herbivory*, *100-year flooding*, and *replacement fire* with outcomes slightly more complicated for the latter two disturbances than the other classes. B*eaver-herbivory* simply transforms this class into the *early-succession* class (*MR-A*) at a rate of 0.002/year. *Hundred-year flooding* (0.01/year) results in three transitions allocated as 89% to the *seeded* class (*SD*), 10% to the *annual grass* class (*AG*), and 1% to the early-succession class (*MR-A*) due to major sediment reworking. Similarly, *replacement fire* results in three outcomes already described (see above under *replacement fire*).

The *annual grass* class (*AG*) can burn as a self loop about every 10 years (0.1/year). *Beaver herbivory* can result is the flooding and killing of cheatgrass resulting in *early-succession* class (*MR-A*) at the rate of 0.002/year. *Hundred-year flooding* (0.01/year) predominantly (99% of times) maintains this class, but major reworking of sediments can restore the vegetation to the *early-succession* class (*MR-A*) for the remaining of 1% of times.

Management Actions:

Despite the complexity of the Montane Riparian biophysical setting, workshop participants focused on keeping exotic forbs out of the Park through persistent (every year) *weed inventory* in all locations of the biophysical setting. Upon detection of weed patches, Park staff would *control exotic forbs* with herbicides. Lack of weed inventory in a chosen pixel for five consecutive years initiates weed invasion. Lack of weed control in an invaded pixel for 20 consecutive years makes the pixel permanently converted to the *exotic forb* class (*EF*; i.e., control is no longer possible). The failure rate of herbicide application was 40%, thus requiring respraying in future years.

Although not chosen in the PREFERRED MANAGEMENT scenario, *floodplain restoration* was considered in the MAXIMUM MANAGEMENT scenario. In many Great Basin riparian systems characterized by incision (Chambers and Miller 2004), restoration of entrenched creek is needed but often not accomplished because of high costs ($2,000/acre in Appendix 4). Workshop participants recognized that Snake Creek, especially its southern lower floodplain where crested wheatgrass is found, could benefit from "primitive" *floodplain restoration*, such as rock weirs directing flows to the south, that would cost much less than $2,000/acre. Testing such methods and obtaining a cost estimate should be considered by the Park. In the model, the success rate of this method was 90%.

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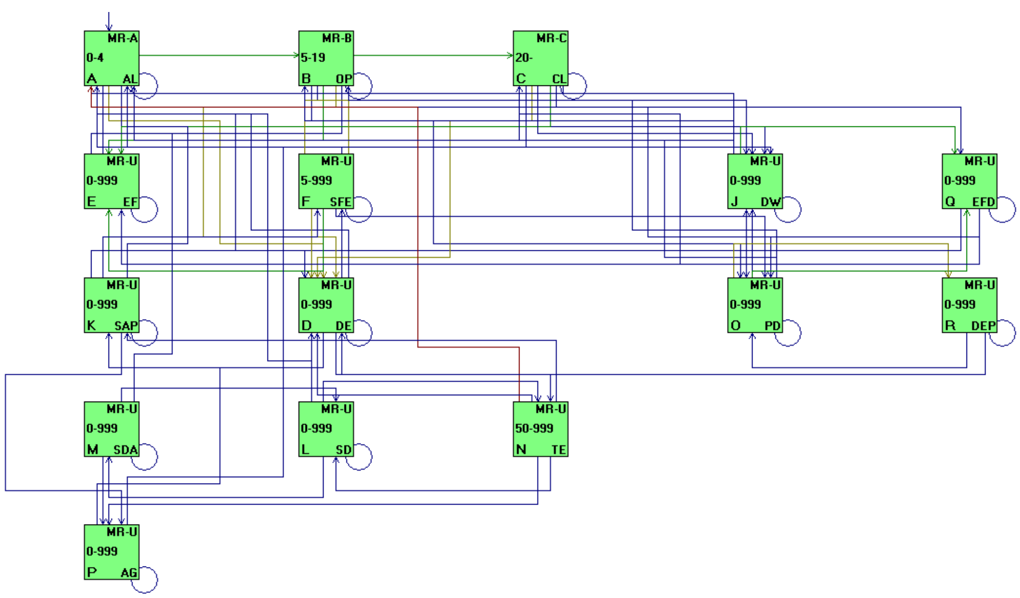
State-and-Transition Model (cropped):



Montane Sagebrush Steppe-mountain (MSm) 1126m

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Date created: December 2010**

Vegetation classes:

The mountain and upland sites of the two Montane Sagebrush Steppe biophysical settings are nearly identical; however, the higher elevations of the mountain sites explain the greater importance of montane and subalpine mixed conifers replacing pinyon and juniper and the near absence of cheatgrass, except as spotty and temporary occurrences after fires. Mountain sites are also very resilient to disturbances.

- *A-Early*: 0-10% canopy of mountain sagebrush/ mountain brush, >50% grass/forb cover; ; 0-12 yrs;
- *B-Mid--open*: 11-30% cover of mountain sagebrush / mountain brush, >50% herbaceous cover; 13-37 yrs;
- *C-Mid--closed*; 31-50% cover of mountain sagebrush / mountain brush, 25-50% herbaceous cover, <10% conifer sapling cover; >38 yrs
- *D-Late-open*: 10-30% cover conifer <10m, 25-40% cover of mountain sagebrush / mountain brush, <30% herbaceous cover, 80-129 yrs
- *E-Late-closed*: 31-80% conifer cover 10-25m, 6-20% shrub cover, <20% herbaceous cover; >129 yrs
- *U-ES: Early*-Shrub; 0-40% cover rabbitbrush species
- *U-TE*: Tree-Encroached; 31-80% conifer cover 10-25m, <5% shrub cover, <5% herbaceous cover; >130 yrs
- *U-DP*: Depleted; 20-50% cover of mountain sage/mountain brush; <5% herbaceous cover; <10% conifer sapling cover
- *U-SAP*: Shrub-Annual-Grass-Perennial-Grass; 10-50% cover of mountain sage/mountain brush; >5% cover of native grass; 5-10% cheatgrass cover; <10% conifer sapling cover (this class is uncommon and assumed temporary)
- *U-AG:* Annual-Grass; 10-30% cover of cheatgrass (this class is uncommon and assumed temporary)

Reference Condition:

- **Natural Range of Variability**
  - 21%: A-*Early*
  - 44%: B-*Mid-open*
  - 22%: C-*Mid--closed*

- 10%: D-*Late-open*
- 3%: E-*Late-closed*
- 0%: U

- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Montane Sagebrush Steppe-mountain (MSm) 1126m

Succession:

Succession follows the 5-box pathway with vegetation starting as predominantly herbaceous and ending with pinyon and juniper dominance and a viable shrub and herbaceous understory. The succession pathway is not entirely deterministic as we used the *tree-invasion* probabilistic disturbance to cause a transition from the mid-succession open (*MSm-B*) and closed (*MSm-C*) to the late-succession open (*MSm-D*) classes. This rate of transition is 0.01 probability/year pixels starting at age 40 in the mid-succession open class (*MSm-B*). This rate is consistent with the transition from Phase 1 to Phase 2 by Miller and Tausch (2001): this rate approximately replicated encroachment levels proceeding in three phases of about 50 years each. Deterministic succession transitions occur at the following ages:

- Early to mid-succession open: 11 years
- Mid-succession open to Late-succession open: 40-49 years (probabilistic)
- Mid-succession open to closed: 49 years
- Mid-succession closed to late-succession open: ≥50 years (probabilistic)
- Late-succession open to closed: 114 years

Natural Disturbances:

Replacement fire was the primary stochastic disturbance. *Replacement fire* restarted the succession clock to age zero within the reference condition, which was labeled the *early-succession* or *MSm-A* class. The mean return interval of *replacement fire* changed with vegetation classes: from 80 years (0.0125/year) in the *early-succession* class (*MSm-A*), 40 years (0.025/year) in the *mid-succession open* class (*MSm-C*), 50 years (0.02/year) in the *mid-succession closed* and *late-succession open* classes (*MSm-C* and *MSm-D*), to 75 years (0.013/year) in the more wooded *late-succession closed* class (*MSm-E*). *Replacement fire* in vegetation classes that already experienced a threshold transition also caused a threshold transition to other uncharacteristic classes. Fire in the *tree encroached shrubland* class (*TE*) with a mean fire return interval of 120 years (0.0085/year) causes a transition to the *early shrub* class (*ES*). The *depleted shrubland* class (*DP*) burns with a 50-year return interval (0.02/year) and converts to *early shrub* (*ES*). Fire in this latter class (50-year fire return interval) simply promotes rabbitbrush as a self-loop for 95% of outcomes, whereas for a small 5% of outcomes the vegetation reverts to the *early-succession* class (*MSm-E*). A 50-year fire cycle applies to the ephemeral *annual grass* class (*AG*) and behaves as a self-loop. A longer 50-year return interval compared to a 10-year return interval more typical of annual grassland (Young et al. 1987; Young and Sparks 2002) was chosen because it was assumed that cheatgrass patches are small and, therefore, fire is imported from the larger sagebrush communities. The patchy *shrub with a mixed understory of annual and perennial grasses* class (*SAP*) will become *annual grassland* (*AG*) 50% of times and the *early-succession* class (*MSm-A*) the other 50% of occurrences for *replacement fire* with a 50-year return interval caused by fire importation from the surrounding sagebrush community (0.02/year).

Drought affected older shrub classes and classes with trees. It was assumed that water is not limiting in this subalpine sagebrush community at >14 inches of precipitation; however, montane and subalpine trees will suffer from *drought* because they will be found in the warmer spectrum of their ecological niche. In most cases *drought* created tree and older shrub mortality under the assumption that prolonged and decreased soil moisture weakened plants that might ultimately be killed by insects or disease. Therefore, we did not double-count mortality. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant shrubs and trees. For vegetation classes in the reference condition, drought affected the *late-succession open* (*MSm-D*) and *late-succession* closed (*MSm-E*) classes (i.e., not the first three classes of succession) in different ways. *Drought* partitioned the *late-succession open* class (*MSm-D*) into three pathways that resulted from thinning young conifers or old shrubs: 10% thinning within the class, 60% thinning to the previous class (*mid-succession closed* or *MSm-C*), and 30% to the *mid-succession open* class (*MSm-B*) where young trees were dense enough to start suppressing shrub cover. The *late-succession closed* class (*MSb-E*), which is wooded, behaves differently than others to drought. Because trees have already suppressed the understory, 10% of the effect of thinning kills trees but releases the low cover of shrubs and grass more typical of the *mid-succession open* class (*MSm-B*), whereas for the remaining 90% *drought* from increases resource competition to the detriment of shrubs and the herbaceous understory, and accelerates woody succession by 5 years when a pixel is chosen.

Drought affects two uncharacteristic classes. D*rought* in the *depleted* shrubland (*DP*) causes a transition to early-succession shrub (*ES*) 10% of times and slightly thins shrubs within the *depleted* shrubland class (*DP*) (minor thinning using the VDDT function RelAge = -1). Drought thins the *tree-encroached shrubland* class (*TE*) to the *early-succession shrub* class (*ES*).

Tree-invasion (i.e., white fir, Douglas-fir, pinyon, juniper, and limber pine encroachment) has been discussed above. Tree encroachment of shrublands was a time-dependent process because seedlings required mature shrubs (we used between 40-100 years of succession but 100 years for uncharacteristic classes), such as sagebrush and bitterbrush, for nurse plants. A standard rate of tree encroachment was 0.01/year (1 of 100 pixels per year) often starting in the late-development or uncharacteristic shrub-dominated vegetation classes of shrublands. For uncharacteristic classes, *tree-invasion* caused a transition to the *tree-encroached shrub* class (*TE*) from depleted shrubs (*DP*) and the *shrubland with mixed annual and perennial grasses* class (*SAP*).

Cheatgrass invasion (*AG-invasion*) is set at a small rate of 0.0001/year (1 out of 10,000 pixels converted to a cheatgrass-invaded class per year). A base rate of 0.001/year was estimated from data of northwest Utah collected by the Utah Division of Wildlife Resources in black sagebrush semi-desert. Black sagebrush semi-desert is usually considered more resistant to cheatgrass invasion than Wyoming big sagebrush semi-desert or other big sagebrush dominated biophysical settings. Because NPS, BLM or USFS did not have similar data, we defaulted to five times the rate estimated from the Utah data. The lower rate used in this model reflects the fact that the higher precipitation greatly favors native perennial grasses over cheatgrass. Cheatgrass invasion (*AG-invasion*) started in the mid-succession closed class (*MSm-C*) and continued in the late-succession open class (*MSm-D*), causing a transition to the *shrubland with mixed annual and perennial grasses* class (*SAP*). *Annual grass invasion* was absent from the *late-succession closed* (wooded; *MSm-E*) and the *tree-encroached class* (*TE*) due to shading. The *depleted shrub* (*DP*) converts to the *shrub with annual and perennial grass* class (*SAP*) with *annual* *grass invasion* at a rate of 0.001/year.

Natural recovery is an age-dependent transition that allows the *early-succession shrub* class (*ES*) and the *shrubland with mixed annual and perennial grasses* class (*SAP*) to return to reference classes at a very slow rate of 0.001/year to 0.01/year. The *early-succession shrub* class (*ES*), which is assumed very stable or resistant to change, starts conversion at a rate to 0.001/year to the *mid-succession open* class (*MSm-B*) between ages 12 and 49 and to the *mid-succession closed* class (*MSm-C*) for ages ≥50. The *shrubland with mixed annual and perennial grasses* class (*SAP*) transitions more rapidly (at a rate of 0.01/year) than the previous one: to the early-succession class (*MSm-A*) from ages 5-11 year, to the *mid-succession* class (*MSm-B*) from ages 12-49 year, and to the *late-succession closed* class (*MSm-C*). Increasing rates indicates a greater starting cover of native species.

Management Actions:

None chosen, although prescribed fire and removal of trees with chainsaws would be appropriate.

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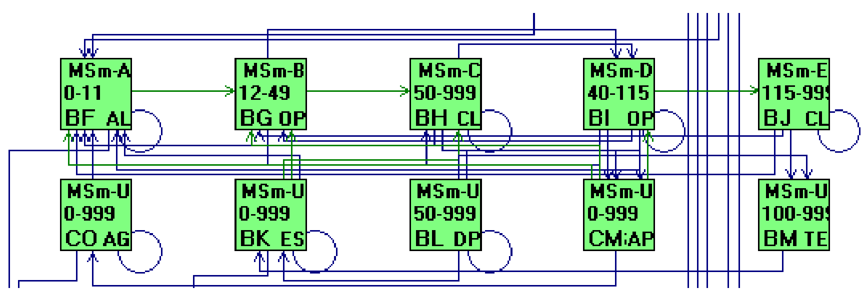
State-and-Transition Model:



Montane Sagebrush Steppe-upland (MSu) 1126u

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Date created: December 2010**

Vegetation classes:

The upland and mountain sites of the two Montane Sagebrush Steppe biophysical settings are nearly identical; however, the lower elevations of the upland sites explain the greater importance of pinyon and juniper compared to white fir, and the greater importance of cheatgrass. Upland sites are also less resilient to disturbances than mountain sites.

- *A-Early*: 0-12 yrs; 0-10% canopy of mountain sage/mountain brush; 10-80% grass/forb cover
- *B-Mid--open*: 13-38 yrs; 11-30% cover of mountain sage/mountain brush; >50% herbaceous cover
- *C-Mid--closed*; : 38+ yrs; 31-50% cover of mountain sage/mountain brush; 25-50% herbaceous cover, <10% conifer sapling cover
- *D-Late-open*: : 80-129 yrs; 10-30% cover conifer <5m for PJ and <10m for mixed conifers; 25-40% cover of mountain sage/mountain brush; <30% herbaceous cover
- *E-Late-closed*: 130+ yrs; 31-80% conifer cover (lower for PJ, greater for mixed conifers) 10-25m; 6-20% shrub cover; <20% herbaceous cover
- *U-ES*: *Early*-Shrub;20-50% cover rabbitbrush species
- *U-TE*: Tree-Encroached; 31-80% conifer cover 10-25m; <5% shrub cover; <5% herbaceous cover
- *U-DP*: Depleted; 20-50% cover of mountain sage/mountain brush; <5% herbaceous cover; <10% conifer sapling cover
- *U-SAP*: Shrub-Annual-Grass-Perennial-Grass; 21-50% cover of mountain sage/mountain brush; >5% cover of native grass; 5-10% cheatgrass cover; <10% conifer sapling cover
- *U-SA*: Shrub-Annual-Grass; 21-50% cover of mountain sage/mountain brush; ≤5% cover of native grass; ≥5% cheatgrass cover; <10% conifer sapling cover
- *U-AG:* Annual-Grass; 10-30% cover of cheatgrass

Reference Condition:

- **Natural Range of Variability**
  - 21%: A-*Early*
  - 44%: B-*Mid-open*
  - 22%: C-*Mid--closed*
  - 10%: D-*Late-open*
  - 3%: E-*Late-closed*
  - 0%: U
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Montane Sagebrush

Steppe-upland (MSu) 1126u

Succession:

Succession follows the 5-box pathway with vegetation starting as predominantly herbaceous and ending with pinyon and juniper dominance and a viable shrub and herbaceous understory. The succession pathway is not entirely deterministic as the *tree-invasion* probabilistic disturbance is used to cause a transition from the mid-succession open (*MSu-B*) and closed (*MSu-C*) to the late-succession open (*MSu-D*) classes. This rate of transition is 0.01 probability/year pixels starting at age 40 in the mid-succession open class (MSu-*B*). This rate is consistent with the transition from Phase 1 to Phase 2 by Miller and Tausch (2001): this rate approximately replicated encroachment levels proceeding in three phases of about 50 years each. Deterministic succession transitions occur at the following ages:

- Early to mid-succession open: 11 years
- Mid-succession open to Late-succession open: 40-49 years (probabilistic)
- Mid-succession open to closed: 49 years
- Mid-succession closed to late-succession open: ≥50 years (probabilistic)
- Late-succession open to closed: 114 years

Natural Disturbances:

Replacement fire was the primary stochastic disturbance. *Replacement fire* restarted the succession clock to age zero within the reference condition, which was labeled the *early-succession* or *MSu-A* class. The mean return interval of *replacement fire* changed with vegetation classes: from 80 years (0.0125/year) in the *early-succession* class (*MSu-A*), 50 years (0.02/year) in the *mid-succession open* and *late-succession open* classes (*MSu-B* and *MSu-D*), 40 years (0.025/year) in the *mid-succession closed* class (*MSu-C*), to 75 years (0.013/year) in the more wooded *late-succession closed* class (*MSu-E*). *Replacement fire* in vegetation classes that already experienced a threshold transition also caused a threshold transition to other uncharacteristic classes. Fire in the *tree encroached shrubland* with annual grass class (*TEA*) for a mean fire return interval of 120 years (0.0085/year) causes a transition to the *annual grass* class (*AG*) 50% of times and the *early shrub* class (*ES*) for the remainder of outcomes. The *depleted shrubland* class (*DP*) burns with a 50-year return interval (0.02/year) and converts to *early shrub* (*ES*). Fire in this latter class (50-year fire return interval) simply promotes rabbitbrush as a self-loop for 95% of outcomes, whereas for a small 5% of outcomes the vegetation reverts to the *early-succession* class (*MSu-E*). A 10-year fire cycle applies to the *annual grass* class (*AG*) and behaves as a self-loop. Due to the presence of cheatgrass, the fire return interval is shorter (25 years or 0.04/year) in the *shrub with annual grass* class (*SA*) than the *depleted shrub* class (*DP*). Fire causes a conversion to the *annual grass* class (*AG*). The *shrub with a mixed understory of annual and perennial grasses* class (*SAP*) will become *annual grassland* (*AG*) 50% of times and the *early-succession* class (*MSu-A*) the other 50% of occurrences with a *replacement fire* of 25 years (0.04/year). The *seeded* class (*SD*) is a USFS legacy of seeding crested wheatgrass near the lower Lehman Creek. Crested wheatgrass does not burn well; therefore, *replacement fire* was set at a 200-year fire return interval (0.005/year) that returns the seeding to age zero.

Drought is found in most classes and causes stand replacing events (generally 10% of times) or stand thinning (90% of times). In most cases *drought* created tree and shrub mortality under the assumption that prolonged and decreased soil moisture weakened plants that might ultimately be killed by insects or disease. Therefore, we did not double-count mortality. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant shrubs and trees. For vegetation classes in the reference condition, drought affected the *mid-succession closed* (*MSu-C*) to *late-succession* closed (*MSu-E*) classes (i.e., not the first two classes of succession) in different ways. The *mid-succession closed* class (*MSu-C*) followed the more traditional 90% thinning within the class (to its beginning) and 10% to the *early-succession* class (*MSu-A*). Drought partitioned the *late-succession open* class (*MSu-D*) into three pathways that resulted from thinning young pinyon, juniper, or old shrubs: 10% thinning within the class, 60% thinning to the previous class (*mid-succession closed* or *MSu-C*), and 30% to the *mid-succession open* class (*MSu-B*). The *late-succession closed* class (*MSb-E*), which is wooded, behaves differently than others to drought. Because trees have already suppressed the understory, 10% of the effect of thinning kills trees but releases the low cover of shrubs and grass more typical of the *mid-succession open* class (*MSu-B*), whereas for the remaining 90% *drought* from increases resource competition to the detriment of shrubs and the herbaceous understory, and accelerates woody succession by 5 years when a pixel is chosen.

Drought affects four uncharacteristic classes. D*rought* in the *depleted* shrubland (*DP*) caused a transition to early-succession shrub (*ES*) 10% of times and thins shrubs within the *depleted* shrubland class (*DP*) to its beginning 90% of times. The fate of the *shrub with annual grass* class (*SA*) is similar to the *depleted shrubland* class (*DP*) except the *annual grassland* class *(*AG) replaces *early-succession shrubs* (*ES*). Drought thins the *tree-encroached shrubland with annual grass* (*TEA*) to three classes: 5% to the *annual grassland* class (*AG*), 5% to *early-succession shrub* class (*ES*), and 90% as a self-loop to the beginning of the class. The *shrubland with mixed annual and perennial grasses* class (*SAP*) follows the same pattern except that the *early-succession* class (*MSu-A*) replaces the *tree-encroached shrubland with annual grass* class (*TEA*), but the *early-succession* class (*MSu-A*) replaces the *early-succession shrub* class (*ES*).

Cheatgrass invasion (*AG-invasion*) is set at a moderate rate was 0.005/year (1 out of 200 pixels converted to a cheatgrass-invaded class per year) was chosen. A base rate of 0.001/year was estimated from data of northwest Utah collected by the Utah Division of Wildlife Resources in black sagebrush semi-desert. Black sagebrush semi-desert is usually considered more resistant to cheatgrass invasion than Wyoming big sagebrush semi-desert or other big sagebrush dominated biophysical settings. Because NPS, BLM or USFS did not have similar data, we defaulted to five times the rate estimated from the Utah data. The higher rates indicated greater susceptibility to cheatgrass because soils were more productive. Cheatgrass invasion (*AG-invasion*) started in the mid-succession closed class (*MSu-C*) and continued in the late-succession open class (*MSu-D*), causing a transition to the *shrubland with mixed annual and perennial grasses* class (*SAP*). *Annual grass invasion* was absent from the *late-succession closed* (wooded; *MSu-E*) and the *tree-encroached class* (*TE*) due to shading. The *depleted shrub* (*DP*) converts to the *shrub with annual grass* class (*SA*) with *annual grass invasion* at a rate of 0.005/year, whereas the *seeded* class transitions to the sh*rub with a mixed annual and perennial grass* class (*SAP*) at a lower rate of 0.001/year because the class is more resistant to cheatgrass invasion.

Management Actions:

Modeled management activities included various mechanical treatments, herbicide, and seeding.

- Chainsaw lopping of young trees in the *late-succession open* class (*MSu-D*) and older *depleted shrubs*

(*DP*) and *shrubs with annual and perennial grasses* (*SAP*) classes;

- Chainsaw thinning of older trees in *tree-encroached shrublands* (*TE*) followed chip or piling woody material, then conducting spot herbicide application for annual grasses, and seeding native plant species seeding. Failure rate is 20% of which 10% leads to the *annual grassland* class (*AG*) and 10% to the *early shrub* class (*ES*); and
- Herbicide application to control annual grasses in *shrublands with an understory of annual and perennial grasses* (*SAP*). The failure rate is 20%.

In theory, other management actions, such as prescribed fire, can be used. Because the Montane Sagebrush Steppe-upland biophysical setting is at the lower elevations of the Park, prescribed fire is a riskier action than mechanical ones because it can escape and move uphill over large areas of remote terrain before suppression efforts control the fire perimeter.

Literature from LANDFIRE Model Tracker:

Anderson, J. E. and R. S. Inouye 2001. Landscape-scale changes in plant species abundance and biodiversity of a sagebrush steppe over 45 years. Ecological Monographs 71:531-556.

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Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. G. Gregg, and C. S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. Journal of Range Management 57:2-19.

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Miller, R. F. and R. J. Tausch. 2001. The role of fire in juniper and pinyon woodlands: a descriptive analysis. Proceedings: The First National Congress on Fire, Ecology, Prevention, and Management. San Diego, CA, Nov. 27- Dec. 1, 2000. Tall Timbers Research Station, Tallahassee, FL. Miscellaneous Publication 11, p:15-30.

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Pedersen, E. K., J. W. Connelly, J. R. Hendrickson, and W. E. Grant. 2003. Effect of sheep grazing and fire on sage grouse populations in southeastern Idaho. Ecological Modeling 165:23-47.

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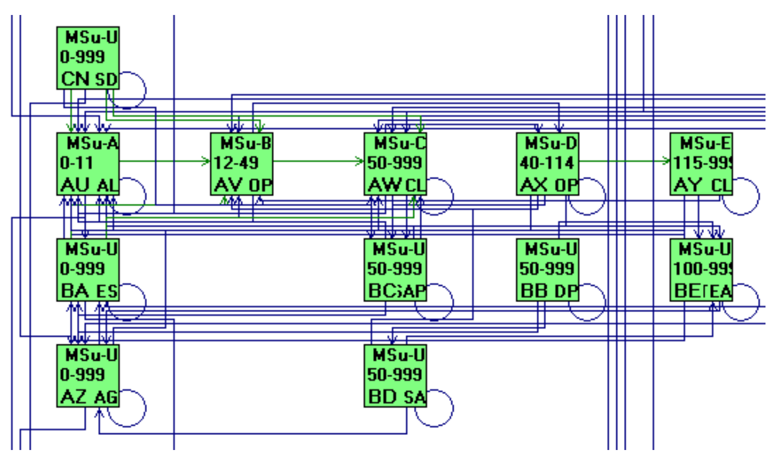
Winward, A. H. 2004. Sagebrush of Colorado; taxonomy, distribution, ecology, & management. Colorado Division of Wildlife, Department of Natural Resources, Denver, CO.

State-and-Transition Model:



Mountain Shrub (MSb) 1126ms
Area of Application and Context: • **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.** • **No livestock grazing (since 2006 on northwestern slope).** • **Until recently, full fire suppression management.** • **Very small biophysical setting <20 acres.** • **Date created: December 2010**
Vegetation classes: • *A-Early*: 0-10% canopy of Utah serviceberry, squaw apple (*Peraphyllum ramosissimum*, a rare shrub), antelope bitterbrush; 10-80% grass/forb cover; 0-12 yrs • *B-Mid--open*: 11-30% cover of Utah serviceberry/squaw apple/antelope bitterbrush; >50% herbaceous cover; 13-38 yrs • *C-Mid--closed*: 31-50% cover of Utah serviceberry/squaw apple/antelope bitterbrush/mountain big sagebrush; 25-50% herbaceous cover, <10% conifer sapling cover; 38+ yrs • *D-Late-open*: 10-20% pinyon pine-white fir cover <5m; 25-40% cover of Utah serviceberry/squaw apple/antelope bitterbrush/mountain big sagebrush; <30% herbaceous cover; 80-129 yrs • *U-ES*: *Early*-Shrub; 20-50% cover rabbitbrush species • *U-TE:* Tree-Encroached; >21% pinyon pine-white fir cover 10-25m; <5% shrub cover; <5% herbaceous cover

Reference Condition:
 	
• **Natural Range of Variability**
    ➢ 7%: A-*Early*
    ➢ 23%: B-*Mid-closed*
    ➢ 41%: C-*Mid--closed*
    ➢ 29%: D-*Late-open*
    ➢ 0%: U
• **Model Tracker Status**
    ➢ Updated Model Tracker December 2010 for biophysical setting Mountain Shrub (MS) 1126ms

Succession: This biophysical setting is considered a special case of Montane Sagebrush Steppe-upland with mountain shrubs providing a clear community signature. Succession follows the 4-box pathway with vegetation starting as predominantly herbaceous and ending with pinyon, juniper, or white fir dominance and a viable shrub and herbaceous understory. Deterministic succession transitions occur at the following ages:

- Early to mid-succession open: 4 years
- Mid-succession open to mid-succession closed: 19 years
- Mid-succession closed to late-succession closed: 79 years

Natural Disturbances:

Replacement fire was the primary stochastic disturbance. Because the biophysical setting is small, the source of fire is importation from the surrounding biophysical settings, which would be mostly montane sagebrush steppe-upland. *Replacement fire* restarted the succession clock to age zero within the reference condition, which was labeled the *early-succession* or *MSb-A* class. The mean return interval of *replacement fire* changed with vegetation classes: from 80 years (0.0125/year) in the *early-succession* class (*MSb-A*), 50 years (0.02/year) in the *mid-succession open* class (*MSb-B*), 40 years (0.025/year) in the *mid-succession closed* class (*MSb-C*), to 150 years (0.0067/year) in the more wooded *late-succession open* class (*MSb-D*). *Replacement fire* in vegetation classes that already experienced a threshold transition also caused a threshold transition to other uncharacteristic classes. Fire in tree encroached shrubland (*TE*) causes a transition to the early shrub class (*ES*). Fire in this latter class simply promotes rabbitbrush as a self-loop.

Drought causes stand replacing events (generally 10% of times) and stand thinning (90% of times) in most classes. D*rought* generally created tree and shrub mortality under the assumption that prolonged and decreased soil moisture weakened plants that might ultimately be killed by insects or disease. Therefore, we did not double-count mortality. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant shrubs and trees. For vegetation classes in the reference condition, drought induced mortality either caused a transition to the previous succession class (10%) or a reversal of woody succession within the same vegetation class (90%). In the *early-succession* class (*MSb-A*), woody succession is reversed to age 0. In uncharacteristic classes, *drought* caused a transition to early-succession shrub (*ES*) from tree-encroached shrubland (*TE*), but had no effect on the *early shrub* class (*ES*).

Tree-encroachment of shrublands by pinyon, juniper, or white fir occurs in the *late-succession open* class (*MSb-D*) causes a transition to the *tree-encroached* class (*TE*).

Management Actions:

None proposed. The Mountain Shrub biophysical setting is likely to benefit from prescribed fire importation from ignitions conducted in the Montane Sagebrush Steppe-upland biophysical setting. Moreover, any chainsaw thinning or lopping operations conducted in sagebrush can easily be extended in the biophysical setting without chainsaw operators even knowing they changed biophysical setting.

Literature from LANDFIRE Model Tracker:

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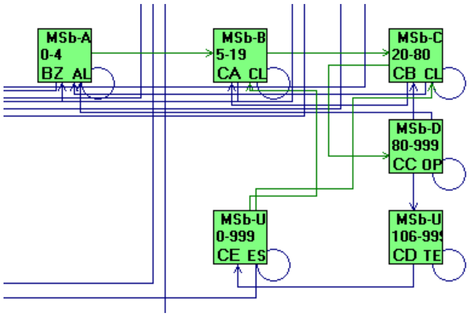
Winward, A. H. 2004. Sagebrush of Colorado; taxonomy, distribution, ecology, & management. Colorado Division of Wildlife, Department of Natural Resources, Denver, CO.

State-and-Transition Model:



Pinyon-Juniper Woodland (PJ) 1019

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Date created: December 2010**

Vegetation classes:

- *A-Early-open*: 5-20% herbaceous cover; 0-9 yrs
- *B-Mid*1-*open*: 11-20% cover big sage or black sage <1.0m; 10-40% herbaceous cover; 10-29 yrs
- *C-Mid*2-*open*; 11-30% cover of pinyon and/or juniper <5m; 10-40% shrub cover; <20% herbaceous cover; 30-99 yrs
- *D-Late*1-*open*: old growth, 31-50% cover of pinyon and/or juniper <5m-9m; 10-40% shrub cover; <20% herbaceous cover; >99 yrs
- *U-TA*: Tree-Annual-Grass; 31-50% cover of pinyon and/or juniper <5m-9m; 10-40% shrub cover; <20% cheatgrass cover
- *U-AG*: Annual-Grasses; 5-30% cheatgrass cover

Reference Condition:

- **Natural Range of Variability**
  - 2%: A-*Early*
  - 6%: B-*Mid1-open*
  - 26%: C-*Mid2--open*
  - 65%: D-*Late-open*
  - 0%: U
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Pinyon-Juniper Woodland (PJ) 1019

Succession:

Succession follows the 4-box pathway with vegetation starting as predominantly herbaceous and ending with old (>300 years) pinyon and juniper and generally with a viable shrub and herbaceous understory. The succession pathway is entirely deterministic. Deterministic succession transitions occur at the following ages:

- Early to mid-succession open: 9 years
- Mid1-succession open to mid2-succession open: 29 years
- Mid2-succession open to late-succession open: 99 years

Natural Disturbances:

Replacement fire restarted the succession clock to age zero within the reference condition, which was labeled the *early-succession* or *PJ-A* class. The *early development* class represented a native condition of woodlands with a dominant cover of usually annual early-succession and perennial herbaceous species. The mean return interval of *replacement fire* was 200 years (0.005/year) in the *early-succession* class (*PJ-A*), *mid1-succession open,* and *mid2-succession open.* A longer return interval of 500 years (0.002/year) is used in the *late-succession open* classes (*PJ-D*). *Replacement fire* in vegetation classes that already experienced a threshold transition also causes a threshold transition to other uncharacteristic classes. The fire return interval remains at 200 years in the *tree with annual grass* class (*TA*). Fire causes a conversion to the *annual grass* class (*AG*). A 10-year fire cycle applies to the *annual grass* class (*AG*) and behaves as a self-loop. *Surface fire* is present in older woodlands (*late-succession open* classes or *PJ-D*) with a 1,000-year fire return interval (0.001/year) indicating rare events (Bauer and Weisberg 2009).

Drought is found in most classes and causes stand replacing events (generally 10% of times) or stand thinning (90% of times). In most cases *drought* created tree and shrub mortality under the assumption that prolonged and decreased soil moisture weakened plants that might ultimately be killed by insects or disease. Therefore, we did not double-count mortality. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant shrubs and trees. For vegetation classes in the reference condition, drought affected the *mid2-succession open* (*PJ-C*) and *late-succession* open (*PJ-D*) classes (i.e., not the first two classes of succession). The *mid2-succession closed* class (*PJ-C*) follows 90% thinning within the class (to its beginning) and 10% to the previous succession class, *mid1-succession open* class (*PJ-B*), which assumed older trees were more affected. *Drought* behaves differently with the *late-succession open* class (*PJ-D*) because older trees become more vulnerable to the baseline 178-year return interval of severe *droughts* and additional insect attacks (both sources are assumed in the total 0.0168/year rate [60 years] for *drought* in the model). *Drought* effects for the *late-succession open* class (*PJ-D*) were partitioned into three pathways: 90% thinning within the class to age 100 year, 7% thinning to the previous class (*mid2-succession open* or *PJ-C*), and 3% to the *mid1-succession open* class (*PJ-B*). The only uncharacteristic class affected is *tree with annual grass* class (*TA*), with 90% thinned within the class and 10% converted to the *annual grassland* class (*AG*).

Cheatgrass invasion (*AG-invasion*) is set at a slow rate was 0.001/year (1 out of 1,000 pixels converted to a cheatgrass-invaded class per year) was chosen. A base rate of 0.001/year was estimated from data of northwest Utah collected by the Utah Division of Wildlife Resources in black sagebrush semi-desert. Black sagebrush semi-desert is usually considered more resistant to cheatgrass invasion than Wyoming big sagebrush semi-desert or other big sagebrush dominated biophysical settings. Because NPS, BLM or USFS did not have similar data, we defaulted to five times the rate estimated from the Utah data. The soils of pinyon-juniper woodlands are either harsher or similar to those of black sagebrush. Cheatgrass invasion (*AG-invasion*) started in the mid2-succession open class (*PJ-C*) and continued in the late-succession open class (*PJ-D*), causing a transition to the *tree with annual grass* class (*TA*).

Management Actions:

None proposed.

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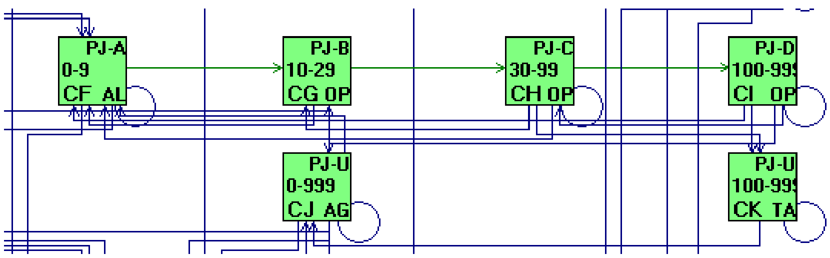
State-and-Transition Model:



Ponderosa Pine (PP) 1054

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Date created: December 2010**

Vegetation classes:

- *A-Early*: 0-60% cover of shrub/grass; conifer seedlings can be abundant <5m; 0-39yrs;
- *B-Mid*1-*closed*: 31-60% cover of ponderosa pine, Douglas-Fir, and white fir 5-10m; dense shrub cover possible; 40-159yrs
- *C-Mid*1-*open*: 10-30% cover of ponderosa pine (dominant), Douglas-Fir, and limber pine 5-10m; abundant shrub and grass cover; 40-159yrs
- *D-Late*1-*open*: 10-30% cover of ponderosa pine (dominant), Douglas-Fir, and limber pine 11--50m; abundant shrub and grass cover; >160 yrs
- *E-Late*1-*closed*: 31-80% cover of ponderosa pine, Douglas-Fir, and limber pine 11-50m; mountain snowberry common; ; >160 yrs
- *U-TA*; 10-80% cover of young and older ponderosa pine and other conifers; >5% cheatgrass cover; native grass and shrubs present to abundant
- *U-AG*: >10% cheatgrass cover; trees largely absent; charred logs or standing dead trees often present; native grasses and forbs present to abundant

Reference Condition:

- **Natural Range of Variability**
  - 11%: A-*Early*
  - 2%: B-*Mid-closed*
  - 29%: C-*Mid--open*
  - 57%: D-*Late-open*
  - 1%: E-*Late-closed*
  - 0%: U
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Ponderosa Pine (PP) 1054

Succession:

Succession is the standard five-box model with a dominant closed canopy succession and a probabilistic alternate succession conditional on the time since the last fire (in VDDT jargon, Time-Since-Disturbance or TSD):

- Closed canopy pathway
  - Early to mid-succession closed: 39 years
  - Mid-succession closed to late-succession closed: 159 years
- Open canopy pathway

  - Mid-succession open to late-succession closed: 159 years
- Alternate succession (*AltSuccession*)
  - Mid-succession open to mid-succession closed: 40-159 years conditional upon lack of any fire for 80 consecutive years
  - Late-succession open to late-succession closed: ≥160 years conditional upon lack of any fire for 100 consecutive years

Natural Disturbances:

Fire is the dominant process in the Ponderosa Pine biophysical setting.

Replacement fire was present in all classes. A mean fire return interval of 100 years (0.01/year) applies to the *early-succession* (*PP-A*), whereas and 400-year fire return interval (0.0025/year) applies to the *mid-succession open* (*PP-C*), and *late-succession open* (*PP-D*) classes. In the closed pathway with more standing woody fuels, the fire return interval is shorter at 150 years (0.0067/year) for both classes. The fire return interval was as short as 10 years (0.1/year) in the *annual grassland* class (*AG*) and longer (150 years or 0.0067/year) in the *tree with annual grass* class (*TA*).

Mixed severity fire was more frequent in closed classes with a fire return interval varying from 25 years (0.04/year) in the *mid-succession closed* class (*PP-B*) to 20 years in the *late-succession closed* class (*PP-E*) due to more fuel build up. *Mixed severity fire* thins younger trees and results in a transition to the open classes while keeping the same succession age (in VDDT jargon: KeepAge = TRUE). The fire return interval lengthens to 35 years (0.028/year) in the *mid-succession open* and late-succession open classes (*PP-C* and *PP-D*). Thinning is within the class and woody succession is reverse by 10 years for burned pixels (in VDDT jargon: RelAge = -10). *Mixed severity fire* also occurs in the *tree with annual grass* class (*TA*) at a return interval of 25 years (0.04/year); however, 25% of the burn causes a transition to the *annual grassland* class (*PP-AG*) but leaves 75% unaffected.

Surface fire only occurred in the open succession classes and caused no transition (but influences the time-since-disturbance function). The fire return interval was 25 years (0.04/year) in mid-succession and shorter at 20 years (0.02/year) in the late-succession class.

Insect/disease outbreaks are more frequent than the return interval of severe *drought* found by Biondi et al. (2007). A 25-year return interval (0.04/year) of *insect/disease* applies to *mid-succession closed* class (*PP-B*) causing thinning to the *mid-succession open* class (*PP-C*) class. The same fire return interval applied to the uncharacteristic *tree with annual grass* class *(TA*); however, 10% converts to annual grassland (*AG*), whereas the remaining 90% suffers single tree mortality that is not sufficient to cause a change in succession age. The *late-succession closed class* (*PP-E*) is thinned to the *late-succession open* class (*PP-D*) by *insects and disease* with a return interval of 50 years (0.02/year). *Insect and disease* attacks are assumed greater in younger than older closed classes because intra-specific competition is stronger in the first decades of succession.

Annual grass invasion was weakly present in all mid-succession and late-succession classes at a low arbitrary rate of 0.0001/year in the more shaded closed classes. Under more open canopies, the rate of *annual grass invasion* increased by 5 times. All invasions cause a transition to the *tree with annual grass* class *(TA*) with succession age maintained (in VDDT jargon: KeepAge = TRUE).

Under the influence of tree competition and more moist soil conditions of the Ponderosa Pine biophysical setting, *natural recovery* allows a transition from the *tree with annual grass* class *(TA*) to the *mid-succession closed* class (*PP-B*) from ages 20 to 99 years and to the *late-succession closed* class (*PP-E*) from age ≥100 years.

Management Actions:

None chosen by Park staff, although *prescribed fire* and mechanical thinning would be appropriate.

Literature cited in LANDFIRE's Model tracker:

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Barrett, S. W. 1994. Fire Regimes on the Caribou National Forest, Southern Idaho. Final Report – Contract No. 53-02S2-3-05071. September 1994.

Biondi, F., Kozubowski. T.J., Panorska, A.K., and L. Saito. 2007. A new stochastic model of episode peak and duration for eco-hydro-climatic applications. Ecological Modelling 211:383-395.

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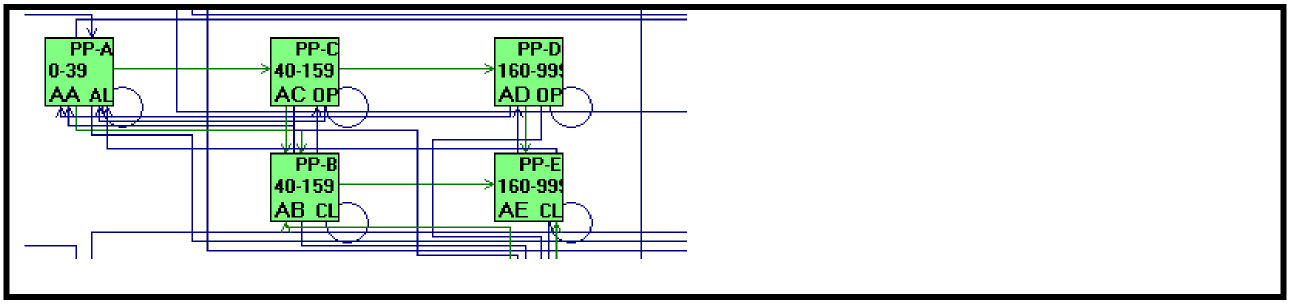
State-and-Transition Model (cropped):


PP-A
0-39
AA AL
PP-C
40-159
AC OP
PP-D
160-999
AD OP
PP-B
40-159
AB CL
PP-E
160-999
AE CL

Riparian Ponderosa Pine (RPP) 1154pp
Area of Application and Context: • **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.** • **No livestock grazing (since 2006 on northwestern slope).** • **Until recently, full fire suppression management.** • **Date created: December 2010**
Vegetation classes: This biophysical setting is unusual because it contains classic ponderosa pine features, supports abundant riparian shrub and herbaceous species, and fire and flooding strongly affect succession. • *A-Early*: 0-60% cover of cottonwood, willow (early in succession) and ponderosa pine (later in succession) saplings <5m high; carex may be abundant; 0-20yrs • *B-Mid*1-*closed*: 41-60% cover of ponderosa pine (dominant), white fir 5-10m; dense willow cover possible; 20-99yrs • *C-Mid*1-*open*: 11-40% cover of ponderosa pine 5-10m; abundant willow and carex cover; 20-99 yrs • *D-Late*1-*open*: 11-40% cover of ponderosa pine 11--25m; abundant willow and carex cover; 100-999yrs • *E-Late*1-*closed*: 41-60% cover of ponderosa pine and white fir 11-25m; willow and carex common; 100-999yrs • U-None
Reference Condition: • **Natural Range of Variability** ➢ 26%: A-*Early* ➢ 9%: B-*Mid-closed* ➢ 47%: C-*Mid--open* ➢ 17%: D-*Late-open* ➢ 1%: E-*Late-closed* ➢ 0%: U • **Model Tracker Status** ➢ Updated Model Tracker December 2010 for biophysical setting Riparian Ponderosa Pine (PP) 1154pp
Succession: Succession is the standard five-box model with a dominant closed canopy succession and a probabilistic alternate succession conditional on the time since the last fire (in VDDT jargon, Time-Since-Disturbance or TSD): • Closed canopy pathway ➢ Early to mid-succession closed: 19 years

- Mid-succession closed to late-succession closed: 99 years
- Open canopy pathway
  - Mid-succession open to late-succession closed: 99 years
- Alternate succession (*AltSuccession*)
  - Mid-succession open to mid-succession closed: 40-159 years conditional upon lack of any fire for 80 consecutive years
  - Late-succession open to late-succession closed: ≥160 years conditional upon lack of any fire for 50 consecutive years

Natural Disturbances:

Fire and flooding are equally dominant processes in the Ponderosa Pine biophysical setting.

Replacement fire was present in all classes. A mean fire return interval of 100 years (0.01/year) applies to the *early-succession* (*PP-A*), whereas a 400-year fire return interval (0.0025/year) applies to the *mid-succession open* (*PP-C*), and *late-succession open* (*PP-D*) classes. In the closed pathway with more standing woody fuels, the fire return interval is shorter at 150 years (0.0067/year) for both classes.

Mixed severity fire was more frequent in closed classes with a fire return interval varying from 25 years (0.04/year) in the *mid-succession closed* class (*PP-B*) to 20 years in the *late-succession closed* class (*PP-E*) due to more fuel build up. *Mixed severity fire* thins younger trees and results in a transition to the open classes while keeping the same succession age (in VDDT jargon: KeepAge = TRUE). The fire return interval lengthens to 40 years (0.025/year) in the *mid-succession open* and late-succession open classes (*PP-C* and *PP-D*). Thinning is within the class and woody succession reverses to the beginning of each class for burned pixels (in VDDT jargon: RelAge = -999) because the riparian midstory vegetation provides fuel ladders into the canopy of ponderosa pine trees.

Surface fire only occurred in the open succession classes and caused no transition (but influences the time-since-disturbance function). The fire return interval was 25 years (0.04/year) in mid-succession and shorter at 20 years (0.02/year) in the late-succession class.

Flooding codominates the dynamics of this biophysical setting. Two levels of *flooding* were 20-year events (0.05/year) that killed or removed shrubs and young trees in the *early-succession* class (*RPP-A*), and 100-year events (0.01/year) that top-killed larger trees and everything else in the *mid-succession closed* and *open* classes (*RPP-B* and *RPP-C*). The late-succession classes with large trees are more resistant to 100-year flood events than younger trees. Therefore, in the open class (*RPP-D*) where water would cause less piling of heavy woody material, 10% of the flooding event causes a transition to the *early-succession* class (*RPP-A*), whereas the remaining pixels are unaffected. In the more dense *late-succession closed* class (*RPP-E*), 20% of pixels transition to the *early-succession* class (*RPP-A*), whereas 80% of pixels are thinned to the *late-succession open* class (*RPP-D*).

Severe drought should have a profound effect of the Riparian Ponderosa Pine because lack of water for tree species habituated to perennial flows should be harsh. A *drought* return interval rate of every 178 years (a rate of 0.0056/year) was used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant species. *Drought* affected all classes. The *early-succession* class (*RPP-A*) is thinned to age zero, indicating complete mortality of ponderosa pine seedlings. The closed canopy classes suffer more mortality of trees than open classes because of more intense intra-specific competition. In these closed classes, 30% of tree mortality results in a transition to the *early*-succession class (*RPP-A*), whereas the remaining 70% is thinning to the *open* class (*RPP-C* or *RPP-D*) of the same age. *Drought* causes stand replacement in 10% of open classes, but 90% of times thing is within the class and return succession age to its beginning.

Management Actions:

None chosen by Park staff, although *prescribed fire* and mechanical thinning would be appropriate. If prescribed fire is used, special attention should be give to duff management as duff can be thick in these riparian systems. Duff would need to be rapidly burned a little at a time over several years, otherwise feeder roots can be killed and trunks girdled.

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Barbour, M. G., and J. Major, editors. 1977. Terrestrial vegetation of California. John Wiley and Sons, New York. 1002 pp.

Barrett, S. W. 1988. Fire Suppression effects on Forest Succession within a Central Idaho Wilderness. Western J. of Applied Forestry. 3(3):76-80. July 1988.

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Biondi, F., Kozubowski. T.J., Panorska, A.K., and L. Saito. 2007. A new stochastic model of episode peak and duration for eco-hydro-climatic applications. Ecological Modelling 211:383-395.

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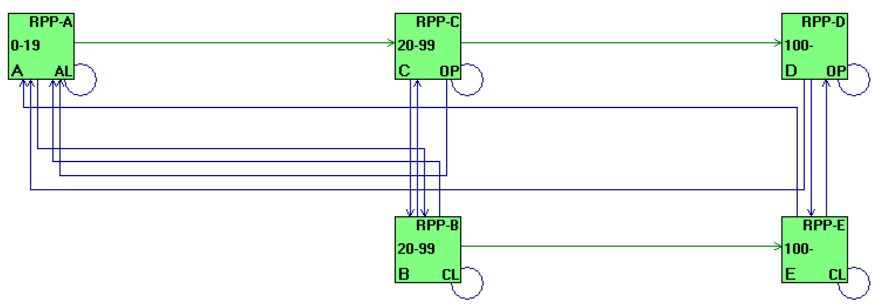
State-and-Transition Model:



Spruce (SP) 1056

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Date created: December 2010**

Vegetation classes:

- *A-Early*: 0-100% cover of Engelman spruce seedling/shrub/grass <5m; 0-39 yrs
- *B-Mid*1-*closed*: 40-100% cover of Engelman spruce and aspen present 5-24m; 40-129yrs
- *C-Mid*1-*open*: 0-40% cover of Engelman spruce 5-24m pole size; ; 40-129yrs
- *D-Late*1-*closed*: 40-100% cover of Engelman spruce 25-49m; >129 yrs
- U-None

Reference Condition:

- **Natural Range of Variability**
  - 18%: A-*Early*
  - 36%: B-*Mid-closed*
  - 2%: C-*Mid--open*
  - 43%: D-*Late-closed*
  - 0%: U
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Spruce (SP) 1056

Succession:

Succession is a four-box model with a dominant closed canopy succession and a probabilistic alternate succession to one class conditional on the time since the last fire (in VDDT jargon, Time-Since-Disturbance or TSD):

- Closed canopy pathway
  - Early to mid-succession closed: 39 years
  - Mid-succession closed to late-succession closed: 129 years
- Open canopy pathway
  - Mid-succession open to late-succession closed: 129 years
- Alternate succession
  - Mid-succession open to mid-succession closed: 40-129 years conditional upon lack of any fire for 60 consecutive years

Natural Disturbances:

Fire is the dominant process in the Spruce biophysical setting.

Replacement fire was present in all classes. A mean fire return interval of 75 years (0.0133/year) from age 0 to 10 years and then 200 years (0.005/year) from ages 11 to 39 years applies to the *early-succession* class (*SP-A*). The *mid-succession closed* (*SP-B*) experiences fire about every 400 years (0.0025/year). The *late-succession closed* (*SP-D*) class experiences fire about every 250 years (0.004/year) due to accumulation of woody live and dead biomass. The highest fire return interval is found in the *mid-succession open* class (*SP-C*) where fine fuels under a more open canopy and dead woody debris can maintain a fire cycle of 125 years (0.008/year).

Surface fire was present in all classes except the first and caused no transitions (but influences the time-since-disturbance function). The return interval was 400 years (0.0025/year) in the *mid-succession closed* class (*SP-B*) and as low as 715 years (0.0014/year) in the *late-succession closed* class (*SP-D*). The shortest return interval was 125 years (0.008/year) in the *mid-succession open* class (*SP-C*) where greater sunlight favors fine fuel growth.

A *drought* return interval rate of every 178 years (a rate of 0.0056/year) is used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant species. *Drought* only affected the *late-succession closed* class (*SP-D*) causing benign internal thinning.

Insect/disease outbreaks are more widespread among classes than *drought*. A 145-year return interval (0.007/year) of *insect/disease* converts the *mid-succession closed* class (*SP-B*) to the *mid-succession open* class (*SP-C*). The return interval of *insect/disease* outbreaks increased to 500 years (0.002/year) in the *mid-succession open* (*SP-C*) and *late-succession closed* (*SP-D*) classes with 100% resulting in stand replacement.

Competition/maintenance slows down woody succession due to crowding among young trees. A small rate of 0.002/year applies to the *early-succession* class (*SP-A*); therefore, a small number of selected pixels have their age stunted by -10 years (in VDDT jargon, RelAge = -10). The same process applies in the *mid-succession closed* class (*SP-B*), except that the rate is even smaller at 0.001/year.

Management Actions:

Prescribed fire was proposed by Park staff. However, due to the high elevations, remoteness, and rugged topography where the biophysical setting is usually found, helicopter ignitions are more practical than hand ignitions. The fire prescription should mostly include replacement fire.

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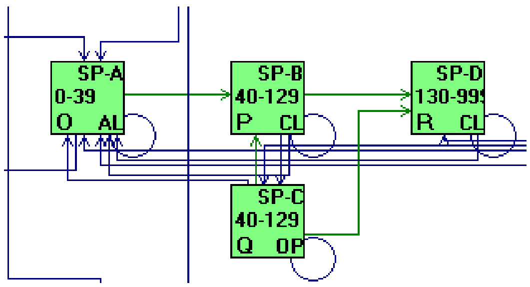
State-and-Transition Model (cropped):



Subalpine Riparian (SR) 1160

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Very small biophysical setting.**
- **Date created: December 2010**

Vegetation classes:

- *A-Early*: 0-50% cover of willow, <3m; large patches of basin wildrye, sedges, and tufted grasses; 0-2 yrs
- *B-Mid*1-*open*: 10-30% cover of subalpine conifers 0-5m; aspen and willow abundant; large patches of basin wildrye, sedges, and tufted grasses; 3-22 yrs
- *C-Late*1-*closed*: 31-50% cover of subalpine conifers 5-10m; aspen and willow abundant; >22 yrs
- *U-None*

Reference Condition:

- **Natural Range of Variability**
  - 13%: A-*Early*
  - 58%: B-*Mid-closed*
  - 29%: C-*Late-closed*
  - 0%: U
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Subalpine Riparian (SR) 1160

Succession:

Succession follows the 3-box pathway with heterogeneous vegetation starting with willow and wet meadows and ending with a forested mix of willow, subalpine conifers, aspen, and wet meadows. The succession pathway is entirely deterministic with transitions occurring at the following ages:

- Early to mid-succession closed: 2 years
- Mid-succession closed to late-succession closed: 22 years

Natural Disturbances:

Flooding dominates the dynamics of this biophysical setting. Three levels of *flooding* were 7-yr events (0.13/year) that killed or removed only herbaceous vegetation in the *early-succession* class (*MR-A*), 20-year events (0.05/year) that killed or removed shrubs and young trees in the *mid-succession closed* class (*MR-B*), and 100-year events (0.01/year) that top-killed larger trees and everything else in the *late-succession closed* class (*MR-C*).

Replacement fire is found in all three classes and originates from ignitions in the surrounding sagebrush and forest biophysical settings. A fire return interval of 50 years (0.02/year) was chosen to reflect the mean fire return interval of montane sagebrush steppe and several aspen communities.

As subalpine riparian woody vegetation develops into more mature vegetation often with large subalpine conifers, *mixed severity fire* is possible. A 70-year *mixed severity fire* return interval (0.013/year) thins the *late-succession closed* class (*SR-C*) to the *mid-succession closed* class (*SR-B*).

Management Actions:

None chosen by Park staff.

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Chambers, J. C. and J. R. Miller. 2003. Great Basin Riparian Ecosystems: Ecology, Management, and Restoration. Island Pres, Washington, D.C.

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Tuhy, J., P. Comer, D. Dorfman, M. Lammert, B. Neely, L. Whitham, S. Silbert, G. Bell, J. Humke, B. Baker, and B. Cholvin. 2002. An ecoregional assessment of the Colorado Plateau. The Nature Conservancy, Moab Project Office. 112 pp. plus maps and appendices.
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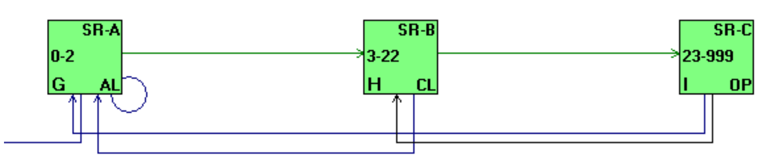
State-and-Transition Model (cropped):



Wet Meadow (WM) 1145

Area of Application and Context:

- **Great Basin National Park and "Keyhole" property (private) of LongNow Foundation.**
- **No livestock grazing (since 2006 on northwestern slope).**
- **Until recently, full fire suppression management.**
- **Small biophysical setting.**
- **Date created: December 2010**

Vegetation:

- *A-Early*-open: 0-60% herbaceous cover — mostly graminoids; 0-2 yrs
- *B-Mid*--closed: 61-100% herbaceous cover — mostly graminoids; 3-22 yrs
- *C-Late*-open: 0-10% tree-shrub (aspen, willow, Wood's rose, sagebrush), cover; 60-80% herbaceous cover — mostly graminoids; >22 yrs
- *U-SFE-All*: Shrub-Forb-Encroached; >10%% cover of less palatable grasses and forbs (e.g., *Iris missouriensis*); OR >10% shrub cover; bare ground cover 10-30% cover
- *U-EF*: Exotic-Forbs; 20-100% exotic forbs (knapweed, tall whitetop, purple loosetrife)
- *U-DE*: Desertification; Entrenched water table with 10-50% cover of sagebrush
- *U-SA*; Shrub-Annual-Grass; >10% cover of native shrubs; <5% native grass cover; 5-30% cover of cheatgrass
- *U-AG*: Annual-Grass; 10-30% cover of cheatgrass; < 10% shrub cover
- *U-TE*: Tree-Encroached; 31-80% conifer cover 10-25m; <5% shrub cover; <5% herbaceous cover

Reference Condition:

- **Natural Range of Variability**
  - 5%: A-*Early*
  - 38%: B-*Mid-closed*
  - 58%: C-*Late-closed*
  - 0%: U
- **Model Tracker Status**
  - Updated Model Tracker December 2010 for biophysical setting Wet Meadow (WM) 1145

Succession:

Succession follows the 3-box pathway. Vegetation is always dominated by graminoid. The succession pathway is entirely deterministic with transitions occurring at the following ages:

- Early to mid-succession closed: 2 years
- Mid-succession closed to late-succession closed: 22 years

Natural Disturbances:

A *drought* return interval rate of every 178 years (a rate of 0.0056/year) is used based on the frequency of severe drought intervals estimated by Biondi *et al*. (2007) from 2,300 years of western juniper (*Juniperus occidentalis)* tree ring data from the Walker River drainage of eastern California and western Nevada. Although we recognized that droughts may be more common than every 178 years, severe droughts, which were >7-year drought events with consecutive far-below average soil moisture (narrow tree rings), killed naturally drought resistant species. *Drought* has opposite effects on succession between the *early-succession* class (*WM-A*) and *mid-succession closed* class (*WM-B*). *Drought* will act as a stand replacing event, killing young graminoids, in the *early-succession* class (*WM-A*). In the *mid-succession closed* class (*WM-B*), *drought* slightly accelerates succession by two years for chosen pixels (in VDDT jargon, RelAge = 2) because it allows less water-tolerant species to establish during dry periods.

Drought also affects uncharacteristic classes. The *desertified* class (*DE*) experiences a reversal of woody succession of 10 years by *drought* for chosen pixels (in VDDT jargon, RelAge = -10). Woody succession similarly reverses by drought for 90% of the *shrub with annual grass* class (*SA*) and *tree encroached* class (*TE*) pixels, whereas 10% of the remaining pixels in each classes undergoes stand replacement, respectively, to the *annual grassland* class (*AG*) and *desertified* class (*DE*).

Native grazing by deer, elk, and small mammals is restricted to the early-succession class (WM-A) and behaves like a stand replacing event. A small rate of 1/1,000 pixels (0.001/year) is used.

Replacement fire originates from the surrounding landscape and restarts the succession clock to age zero after sweeping through a wet meadow. Fire activity was varied:

- A common 40-year fire return interval (0.025/year) applies to the *mid-succession closed* (*WM-B*), *late-succession closed* (*WM-C*), *desertified* (*DE*), *exotic forb* (*EF*), *shrub with annual grass* (*SA*), and *shrub forb encroached* (*SFE*) classes;
- *Annual grassland* (0.1/year; *AG*); and
- *Tree-encroached (i.e., conifers) meadow* (*TE*) burning at a rate of 0.0068/year (150 years).

When burned, the *desertified* class stays in this class, but succession age is reset to age zero (a grassier phase). The same fate (i.e., self-loop) applies to the *shrub forb encroached* class (*SFE*), *annual grassland* class (*AG*), and *exotic forb* class (*EF*). The *shrub with annual grass* class (*SA*) coverts to the *annual grassland* class *(*AG) with fire, whereas the *tree-encroached* class transitions to the *desertified* class (*DE*).

Another important disturbance was the invasion by exotic forbs (*exotic invasion*) represented mainly by tall whitetop, knapweeds (*Centaurea* spp.), and thistles. *Exotic invasion* causes a transition to the *exotic forb* class (*EF*). It is assumed that invasion can only start if a pixel is not inventoried for weeds for five consecutive years. Workshop participants agreed to a moderately high rate (0.01/year) as planning for a worst case scenario, although they did not feel that this was necessarily reflective of the current situation. Roadways, off-highway vehicles, and animals are usually the greatest vectors of exotic forbs. *Exotic invasion* occurs in five classes: *mid-succession closed* (*WM-B*), *late-succession closed* (*WM-C*), and *shrub and forb encroached* (*SFE*).

The Park's roads adjacent to valley bottoms direct rain and snowmelt that often flows laterally into small creeks that often discharge from meadows. The disturbance *road lateral flow* causes entrenchment, or incision, of creek banks. The disturbance applies to the three succession and *the shrub forb encroached class* (*SFE*) classes. The consequence of entrenchment was a drop of the water table, leading to a moist or wet system becoming a sub-xeric shrubland (*Desertification = DE*). Simple assumptions are built in the rate for *road lateral flow*, which is 0.0004/year: the return interval of major road flooding events correspond to precipitation events of at least 25 years (0.04/year) and roads are adjacent to wet meadows for about a hundreth of the valley bottoms (therefore, 0.025/year × 0. 01= 0.0004/year). Another condition must be met for entrenchment to happen: a reach and its adjacent road must not have been managed or restored to prevent entrenchment for at least 20 years.

A class reflecting historic grazing was the dominance of wet meadows by native forbs and shrub species unpalatable to domestic sheep and cattle (*shrub and forb encroached* or *SFE*). Although livestock no longer graze in the Park, the legacy of past management has left wet meadows with dense midstory of Wood's rose (*Rosa woodsii*) and shinkbush (*Rhus trilobata*) representing this vegetation class in mall patches of Baker Creek and Strawberry Creek.

If hydrological processes do not change the *desertified* (*DE*) and *shrub with annual grass* (*SA*) classes, *tree* (pinyon and juniper) *invasion* after 50 years of shrub growth will convert this class to the *tree encroached* class at a rate of 0.01/year, consistent with Miller and Tausch's (2001) three phases of tree establishment in about 50 years each.

The *desertified* class (*DE*) can also be invaded by cheatgrass (*AG invasion*) at a rate of 0.005/year and become the *shrub with annual* class (*SA*; for model simplicity, we lumped subxeric shrubs with annual grasses and shrubs with a mixed annual and perennial grass understory into a single *shrub with annual grass* class (*SA*) into the latter class). A base rate of 0.001/year was estimated from data of northwest Utah collected by the Utah Division of Wildlife Resources in black sagebrush semi-desert. Black sagebrush semi-desert is usually considered more resistant to cheatgrass invasion than big sagebrush dominated biophysical settings. Because NPS, BLM or USFS did not have similar data, we defaulted to five times the rate estimated from the Utah data. The higher rates indicated greater susceptibility to cheatgrass because soils were more productive.

Management Actions:

Workshop participants focused on keeping exotic forbs out of the Park through persistent (every year) *weed inventory* in all locations of the biophysical setting. Upon detection of weed patches, Park staff would *control exotic forbs* with herbicides. Lack of weed inventory in a chosen pixel for five consecutive years initiates weed invasion. Lack of weed control in an invaded pixel for 20 consecutive years makes the pixel permanently converted to the *exotic forb* class (*EF;* i.e., control is no longer possible). The failure rate of herbicide application was 40%, thus requiring respraying in future years.

Although not chosen in the PREFERRED MANAGEMENT scenario, *floodplain restoration* was considered in the MAXIMUM MANAGEMENT scenario. In many Great Basin wet meadows characterized by incision (Chambers and Miller 2004), restoration of entrenched meadows is needed but often not accomplished because of high costs ($2,000/acre in Appendix 4). Workshop participants recognized that that wet meadows could benefit from "primitive" *floodplain restoration*, such as rock weirs retaining flows in the meadow, that would cost much less than $2,000/acre. Testing such methods and obtaining a cost estimate should be considered by the Park. In the model, a 100% success rate is assumed.

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Cooper, D. J. 1986b. Community structure and classification of Rocky Mountain wetland ecosystems. Pages 66-147 in: J. T. Windell, et al. An ecological characterization of Rocky Mountain montane and subalpine wetlands. USDI Fish & Wildlife Service Biological Report 86(11). 298 pp.

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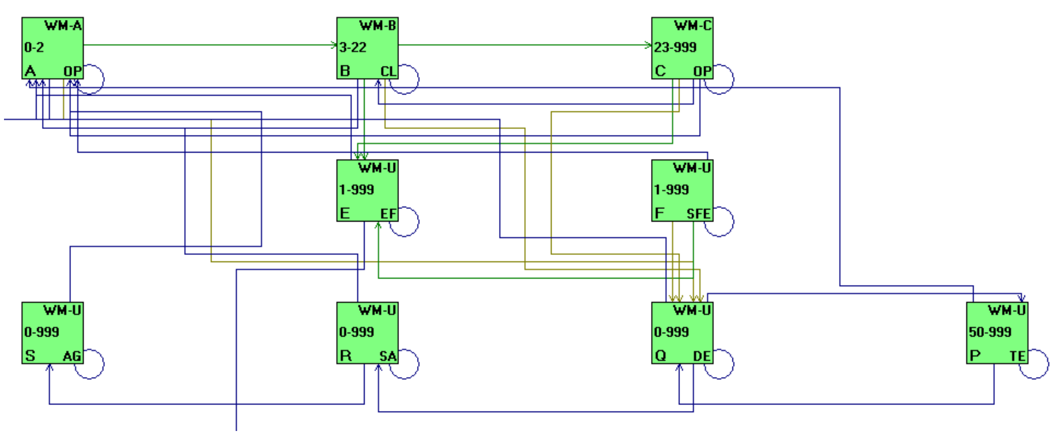
State-and-Transition Model (cropped):



Appendix 3. Probabilistic transitions for biophysical settings of Great Basin National Park. Output obtained from VDDT database. Legend: AB = Antelope Bitterbrush; ALP = Alpine; ASC = Aspen-Subalpine Conifer; ASM = Aspen-Mixed conifer; ASP = Aspen Woodland; BS = Black Sagebrush; BW = Basin Wildrye; LB = Limber-Bristlecone Pine; LBm = Limber-Bristlecone Pine-mesic; LSS = Low Sagebrush Steppe; MC = Mixed Conifer; MG = Montane-Subalpine Grassland; MM = Mountain Mahogany; MR = Montane Riparian; MSb = Mountain Shrub; MSm = Montane Sagebrush Steppe-mountain sites; MSu = Montane Sagebrush Steppe-upland sites; PJ = Pinyon-Juniper woodland; PP = Ponderosa Pine; RPP = Riparian Ponderosa Pine; SP = Spruce; SR = Subalpine Riparian; and WM = Wet Meadow.

Disturbance	From Class	From Structure	To Class	To Structure	MinAge	MaxAge	TSDMin	TSDMax	Prob.	Prop.	Relative Age	Keep-Rel-Age
ReplacementFire	AB-A	AL	AB-A	AL	0	11	0	9999	0.0125	1	-12	FALSE
ReplacementFire	AB-B	OP	AB-A	AL	12	49	0	9999	0.025	1	0	FALSE
Tree-Invasion	AB-B	OP	AB-D	OP	40	49	0	9999	0.01	1	0	TRUE
AG-Invasion	AB-C	CL	AB-U	SAP	50	999	0	9999	0.005	1	0	TRUE
Drought	AB-C	CL	AB-B	OP	50	999	0	9999	0.006	0.1	0	FALSE
Drought	AB-C	CL	AB-C	CL	50	999	0	9999	0.0056	0.9	-999	FALSE
ReplacementFire	AB-C	CL	AB-A	AL	50	999	0	9999	0.02	1	0	FALSE
RxFire	AB-C	CL	AB-A	AL	50	999	0	9999	0.01	0.7	0	FALSE
RxFire	AB-C	CL	AB-C	CL	50	999	0	9999	0.01	0.3	0	FALSE
Tree-Invasion	AB-C	CL	AB-D	OP	50	999	0	9999	0.01	1	0	TRUE
AG-Invasion	AB-D	OP	AB-U	SAP	40	114	0	9999	0.005	1	0	TRUE
Chainsaw-Lopping	AB-D	OP	AB-D	OP	40	114	0	9999	0.01	1	-999	FALSE
Drought	AB-D	OP	AB-B	OP	40	114	0	9999	0.0057	0.3	0	FALSE
Drought	AB-D	OP	AB-C	CL	40	114	0	9999	0.0057	0.6	0	FALSE
Drought	AB-D	OP	AB-D	OP	40	114	0	9999	0.006	0.1	-999	FALSE
ReplacementFire	AB-D	OP	AB-A	AL	40	114	0	9999	0.02	1	0	FALSE
RxFire	AB-D	OP	AB-A	AL	40	114	0	9999	0.01	0.7	0	FALSE
RxFire	AB-D	OP	AB-D	OP	40	114	0	9999	0.01	0.3	0	FALSE
Chainsaw-Thinning	AB-E	CL	AB-B	OP	115	999	0	9999	0.01	1	0	FALSE
Drought	AB-E	CL	AB-B	OP	115	999	0	9999	0.006	0.1	0	FALSE
Drought	AB-E	CL	AB-E	CL	115	999	0	9999	0.0056	0.9	5	FALSE
Mastication	AB-E	CL	AB-A	AL	115	999	0	9999	0.01	1	0	FALSE
ReplacementFire	AB-E	CL	AB-A	AL	115	999	0	9999	0.013	1	0	FALSE

RxFire	AB-E	CL	AB-A	AL	115	999	0	9999	0.01	0.7	0	FALSE
RxFire	AB-E	CL	AB-E	CL	115	999	0	9999	0.01	0.3	0	FALSE
Tree-Encroachment	AB-E	CL	AB-U	TE	140	999	0	9999	0.2	1	0	TRUE
Herbicide+Seed	AB-U	AG	AB-U	AG	0	3	0	9999	1	0.3	0	FALSE
Herbicide+Seed	AB-U	AG	AB-A	AL	0	3	0	9999	1	0.7	0	FALSE
ReplacementFire	AB-U	AG	AB-U	AG	1	999	0	9999	0.1	1	0	FALSE
AG-Invasion	AB-U	DP	AB-U	SA	50	999	0	9999	0.005	1	0	FALSE
Chainsaw-Lopping	AB-U	DP	AB-U	DP	71	999	0	9999	0.01	1	-999	FALSE
Drought	AB-U	DP	AB-U	DP	50	999	0	9999	0.0056	0.9	-999	FALSE
Drought	AB-U	DP	AB-U	ES	50	999	0	9999	0.006	0.1	0	FALSE
ReplacementFire	AB-U	DP	AB-U	ES	50	999	0	9999	0.02	1	0	FALSE
Spot-Herbicide+Seed	AB-U	DP	AB-U	ES	50	999	0	9999	0.01	0.3	0	TRUE
Spot-Herbicide+Seed	AB-U	DP	AB-A	AL	50	999	0	9999	0.01	0.7	0	TRUE
Tree-Invasion	AB-U	DP	AB-U	TE	100	999	0	9999	0.01	1	0	TRUE
ReplacementFire	AB-U	ES	AB-U	ES	0	999	0	9999	0.02	1	0	FALSE
Drought	AB-U	SA	AB-U	SA	50	999	0	9999	0.0056	0.9	-999	FALSE
Drought	AB-U	SA	AB-U	AG	50	999	0	9999	0.006	0.1	0	FALSE
ReplacementFire	AB-U	SA	AB-U	AG	50	999	0	9999	0.04	1	0	FALSE
Spot-Herbicide+Seed	AB-U	SA	AB-U	AG	50	999	0	9999	0.01	0.3	0	FALSE
Spot-Herbicide+Seed	AB-U	SA	AB-A	AL	50	999	0	9999	0.01	0.7	0	FALSE
Tree-Invasion	AB-U	SA	AB-U	TA	100	999	0	9999	0.01	1	0	TRUE
Chainsaw-Lopping	AB-U	SAP	AB-U	SAP	75	999	0	9999	0.01	1	-999	FALSE
Drought	AB-U	SAP	AB-U	SAP	50	999	0	9999	0.0056	0.9	-999	FALSE
Drought	AB-U	SAP	AB-U	AG	50	999	0	9999	0.006	0.05	0	FALSE
Drought	AB-U	SAP	AB-A	AL	50	999	0	9999	0.006	0.05	0	FALSE
Herbicide-Plateau	AB-U	SAP	AB-C	CL	50	999	0	9999	0.01	0.9	0	FALSE
Herbicide-Plateau	AB-U	SAP	AB-U	SAP	50	999	0	9999	0.01	0.1	0	FALSE
ReplacementFire	AB-U	SAP	AB-A	AL	50	999	0	9999	0.04	0.5	0	FALSE
ReplacementFire	AB-U	SAP	AB-U	AG	50	999	0	9999	0.04	0.5	0	FALSE
Tree-Invasion	AB-U	SAP	AB-U	TA	100	999	0	9999	0.01	1	0	TRUE
Drought	AB-U	TA	AB-U	TA	100	999	0	9999	0.0056	0.9	-999	FALSE
Drought	AB-U	TA	AB-U	AG	100	999	0	9999	0.0056	0.1	0	FALSE
ReplacementFire	AB-U	TA	AB-U	AG	100	999	0	9999	0.0084	1	0	FALSE

Spot-Herbicide+Seed	AB-U	TA	AB-A	AL	100	999	0	9999	0.01	0.7	0	FALSE
Spot-Herbicide+Seed	AB-U	TA	AB-U	AG	100	999	0	9999	0.01	0.3	0	FALSE
Thin+Herbicide+Seed	AB-U	TA	AB-A	AL	100	999	0	9999	0.01	0.8	0	FALSE
Thin+Herbicide+Seed	AB-U	TA	AB-U	AG	100	999	0	9999	0.01	0.2	0	FALSE
Drought	AB-U	TE	AB-U	ES	100	999	0	9999	0.0056	1	0	FALSE
ReplacementFire	AB-U	TE	AB-U	ES	100	999	0	9999	0.0084	1	0	FALSE
Spot-Herbicide+Seed	AB-U	TE	AB-U	AG	100	999	0	9999	0.01	0.4	0	FALSE
Spot-Herbicide+Seed	AB-U	TE	AB-A	AL	100	999	0	9999	0.01	0.6	0	FALSE
Thin+Herbicide+Seed	AB-U	TE	AB-A	AL	100	999	0	9999	0.01	0.8	0	FALSE
Thin+Herbicide+Seed	AB-U	TE	AB-U	ES	100	999	0	9999	0.01	0.2	0	FALSE
CC-Conversion	ALP-A	AL	LBm-A	AL	0	1	0	9999	0.03	0.4	2	TRUE
CC-Conversion	ALP-A	AL	SP-A	AL	0	1	0	9999	0.03	0.2	2	TRUE
CC-Conversion	ALP-A	AL	LB-A	AL	0	1	0	9999	0.03	0.4	2	TRUE
Snow-Deposition	ALP-A	AL	ALP-A	AL	0	2	0	9999	0.01	1	-999	FALSE
CC-Conversion	ALP-B	CL	LBm-A	AL	3	4	0	9999	0.03	0.4	2	TRUE
CC-Conversion	ALP-B	CL	LB-A	AL	3	4	0	9999	0.03	0.4	2	TRUE
CC-Conversion	ALP-B	CL	SP-A	AL	3	4	0	9999	0.03	0.2	2	TRUE
Drought	ALP-B	CL	ALP-B	CL	3	999	0	9999	0.0056	1	-999	FALSE
ReplacementFire	ALP-B	CL	ALP-A	AL	3	999	0	9999	0.0001	1	0	FALSE
Aspen-Spring-2ndFreeze	ASC-A	CL	SP-A	AL	0	9	0	9999	0	1	0	FALSE
Avalanches	ASC-A	CL	ASC-A	CL	0	9	0	9999	0.13	0.05	-999	FALSE
CC-Conversion	ASC-A	CL	MSm-A	AL	0	1	0	9999	0.03	0.5	2	TRUE
CC-Conversion	ASC-A	CL	MC-A	AL	0	1	0	9999	0.03	0.5	2	TRUE
Aspen-Spring-2ndFreeze	ASC-B	CL	SP-A	AL	10	39	0	9999	0.0001	1	0	FALSE
Avalanches	ASC-B	CL	ASC-A	CL	10	39	0	9999	0.13	0.05	0	FALSE
ReplacementFire	ASC-B	CL	ASC-A	CL	10	39	0	9999	0.008	1	0	FALSE
Aspen-Spring-2ndFreeze	ASC-C	OP	SP-C	OP	40	169	0	9999	0.0001	1	0	FALSE
Avalanches	ASC-C	OP	ASC-A	CL	40	169	0	9999	0.13	0.05	0	FALSE
Insect/Disease	ASC-C	OP	ASC-C	OP	40	169	0	9999	0.0055	0.9	0	FALSE
Insect/Disease	ASC-C	OP	ASC-A	CL	40	169	0	9999	0.0056	0.1	0	FALSE
NativeGrazing	ASC-C	OP	ASC-C	OP	70	169	0	9999	0.001	1	-10	FALSE
NativeGrazing	ASC-C	OP	ASC-B	CL	40	69	0	9999	0.001	1	0	FALSE
ReplacementFire	ASC-C	OP	ASC-A	CL	40	169	0	9999	0.008	1	0	FALSE

Aspen-Spring-2ndFreeze	ASC-D	CL	SP-D	CL	170	300	0	9999	0.0001	1	0	FALSE
Avalanches	ASC-D	CL	ASC-A	CL	170	300	0	9999	0.13	0.05	0	FALSE
Drought	ASC-D	CL	ASC-D	CL	170	300	0	9999	0.0056	1	1	FALSE
Insect/Disease	ASC-D	CL	ASC-A	CL	170	300	0	9999	0.004	1	0	FALSE
LosingClone	ASC-D	CL	SP-D	CL	250	300	0	9999	0.02	1	0	FALSE
NativeGrazing	ASC-D	CL	ASC-D	CL	170	300	0	9999	0.001	1	10	FALSE
ReplacementFire-Forest	ASC-D	CL	ASC-A	CL	170	300	0	9999	0.005	1	0	FALSE
SurfaceFire	ASC-D	CL	ASC-D	CL	170	300	0	9999	0.0014	1	-1	FALSE
Avalanches	ASM-A	AL	ASM-A	AL	0	9	0	9999	0.13	0.05	-999	FALSE
CC-Conversion	ASM-A	AL	MSm-A	AL	0	1	0	9999	0.03	1	2	TRUE
NativeGrazing	ASM-A	AL	ASM-A	AL	0	9	0	9999	0.01	0.05	-999	FALSE
NativeGrazing	ASM-A	AL	ASM-A	AL	0	9	0	9999	0.01	0.95	0	FALSE
Avalanches	ASM-B	CL	ASM-A	AL	10	39	0	9999	0.13	0.05	0	FALSE
ReplacementFire	ASM-B	CL	ASM-A	AL	10	39	0	9999	0.02	1	0	FALSE
Avalanches	ASM-C	CL	ASM-A	AL	40	79	0	9999	0.13	0.05	0	FALSE
Chainsaw-Thinning	ASM-C	CL	ASM-C	CL	40	79	0	9999	0	0.33	-40	FALSE
Insect/Disease	ASM-C	CL	ASM-B	CL	40	79	0	9999	0.005	0.8	0	FALSE
Insect/Disease	ASM-C	CL	ASM-A	AL	40	79	0	9999	0.005	0.2	0	FALSE
MixedFire	ASM-C	CL	ASM-A	AL	40	79	0	9999	0.02	0.75	0	FALSE
MixedFire	ASM-C	CL	ASM-C	CL	40	79	0	9999	0.02	0.25	0	FALSE
NativeGrazing	ASM-C	CL	ASM-B	CL	40	79	0	9999	0.001	1	0	FALSE
AltSuccession	ASM-D	OP	ASM-E	CL	80	300	100	9999	1	1	0	FALSE
Avalanches	ASM-D	OP	ASM-A	AL	80	300	0	9999	0.13	0.05	0	FALSE
Chainsaw-Thinning	ASM-D	OP	ASM-B	CL	200	300	0	9999	0	0.33	0	FALSE
MixedFire	ASM-D	OP	ASM-C	CL	80	300	0	9999	0.02	0.1	0	FALSE
NativeGrazing	ASM-D	OP	ASM-D	OP	80	300	0	9999	0.001	1	10	FALSE
ReplacementFire	ASM-D	OP	ASM-A	AL	80	300	0	9999	0.02	0.9	0	FALSE
RxFire	ASM-D	OP	ASM-A	AL	80	300	0	9999	0.01	1	0	FALSE
Avalanches	ASM-E	CL	ASM-A	AL	100	300	0	9999	0.13	0.05	0	FALSE
Chainsaw-Thinning	ASM-E	CL	ASM-C	CL	150	300	0	9999	0.01	0.75	0	FALSE
Chainsaw-Thinning	ASM-E	CL	ASM-A	AL	150	300	0	9999	0.01	0.25	0	FALSE
Insect/Disease	ASM-E	CL	ASM-D	OP	100	300	0	9999	0.003	1	0	FALSE
LosingClone	ASM-E	CL	MC-E	CL	250	300	0	9999	0.02	1	0	FALSE

MixedFire-Forest	ASM-E	CL	ASM-D	OP	100	300	0	9999	0.02	0.1	0	FALSE
NativeGrazing	ASM-E	CL	ASM-E	CL	100	300	0	9999	0.001	1	10	FALSE
ReplacementFire-Forest	ASM-E	CL	ASM-A	AL	100	300	0	9999	0.008	1	0	FALSE
RxFire	ASM-E	CL	ASM-A	AL	100	300	0	9999	0.01	1	0	FALSE
Aspen-Spring-2ndFreeze	ASP-A	CL	MSu-A	AL	0	9	0	9999	0.001	1	0	FALSE
Avalanches	ASP-A	CL	ASP-A	CL	0	9	0	9999	0.13	0.01	-999	FALSE
CC-Conversion	ASP-A	CL	MSu-A	AL	0	1	0	9999	0.03	1	2	TRUE
NativeGrazing	ASP-A	CL	ASP-A	CL	0	9	0	9999	0.002	0.95	-999	FALSE
NativeGrazing	ASP-A	CL	MSu-A	AL	0	9	0	9999	0.002	0.05	0	FALSE
ReplacementFire	ASP-A	CL	ASP-A	CL	0	9	0	9999	0.02	1	0	FALSE
Aspen-Spring-2ndFreeze	ASP-B	CL	MSu-B	OP	10	39	0	9999	0.001	1	0	FALSE
Avalanches	ASP-B	CL	ASP-A	CL	10	39	0	9999	0.13	0.01	0	FALSE
ReplacementFire	ASP-B	CL	ASP-A	CL	10	39	0	9999	0.02	1	0	FALSE
AltSuccession	ASP-C	CL	ASP-D	OP	40	300	100	9999	0.33	1	0	FALSE
Aspen-Spring-2ndFreeze	ASP-C	CL	MSu-C	CL	40	300	0	9999	0.001	1	0	FALSE
Avalanches	ASP-C	CL	ASP-A	CL	40	300	0	9999	0.13	0.01	0	FALSE
Insect/Disease	ASP-C	CL	ASP-A	CL	40	300	0	9999	0.005	0.2	0	FALSE
Insect/Disease	ASP-C	CL	ASP-C	CL	40	300	0	9999	0.005	0.8	0	FALSE
NativeGrazing	ASP-C	CL	ASP-B	CL	40	300	0	9999	0.001	1	0	FALSE
ReplacementFire	ASP-C	CL	ASP-A	CL	40	300	0	9999	0.02	1	0	FALSE
RxFire	ASP-C	CL	ASP-A	CL	40	300	0	9999	0.01	0.7	0	FALSE
RxFire	ASP-C	CL	ASP-C	CL	40	300	0	9999	0.01	0.3	0	FALSE
SurfaceFire	ASP-C	CL	ASP-C	CL	40	300	0	9999	0.002	1	0	FALSE
Aspen-Spring-2ndFreeze	ASP-D	OP	MSu-C	CL	100	300	0	9999	0.001	1	0	FALSE
Avalanches	ASP-D	OP	ASP-A	CL	100	300	0	9999	0.13	0.01	0	FALSE
Insect/Disease	ASP-D	OP	ASP-C	CL	100	300	0	9999	0.005	1	0	FALSE
LosingClone	ASP-D	OP	ASP-U	DP	250	300	0	9999	0.02	1	0	FALSE
MixedFire	ASP-D	OP	ASP-C	CL	100	300	0	9999	0.002	1	0	FALSE
NativeGrazing	ASP-D	OP	ASP-B	CL	100	300	0	9999	0.001	1	0	FALSE
ReplacementFire	ASP-D	OP	ASP-A	CL	100	300	0	9999	0.018	1	0	FALSE
RxFire	ASP-D	OP	ASP-A	CL	100	300	0	9999	0.01	0.7	0	FALSE
RxFire	ASP-D	OP	ASP-D	OP	100	300	0	9999	0.01	0.3	0	FALSE
Aspen-Spring-2ndFreeze	ASP-U	DP	MSu-B	OP	100	999	0	9999	0.0001	0.5	0	FALSE

Aspen-Spring-2ndFreeze	ASP-U	DP	MSu-C	CL	100	999	0	9999	0.0001	0.5	0	FALSE
Chainsaw-Thinning	ASP-U	DP	ASP-A	CL	100	999	0	9999	0.01	0.7	0	FALSE
Chainsaw-Thinning	ASP-U	DP	MSu-B	OP	100	999	0	9999	0.01	0.15	0	FALSE
Chainsaw-Thinning	ASP-U	DP	MSu-C	CL	100	999	0	9999	0.01	0.15	0	FALSE
Drought	ASP-U	DP	ASP-A	CL	100	999	0	9999	0.0056	0.1	0	FALSE
Drought	ASP-U	DP	MSu-B	OP	100	999	0	9999	0.0056	0.45	0	FALSE
Drought	ASP-U	DP	MSu-C	CL	100	999	0	9999	0.0056	0.45	0	FALSE
Insect/Disease	ASP-U	DP	ASP-A	CL	100	999	0	9999	0.005	0.8	0	FALSE
Insect/Disease	ASP-U	DP	MSu-B	OP	100	999	0	9999	0.005	0.1	0	FALSE
Insect/Disease	ASP-U	DP	MSu-C	CL	100	999	0	9999	0.005	0.1	0	FALSE
NativeGrazing	ASP-U	DP	ASP-A	CL	100	999	0	9999	0.001	0.8	0	FALSE
NativeGrazing	ASP-U	DP	MSu-B	OP	100	999	0	9999	0.001	0.1	0	FALSE
NativeGrazing	ASP-U	DP	MSu-C	CL	100	999	0	9999	0.001	0.1	0	FALSE
ReplacementFire	ASP-U	DP	ASP-A	CL	100	999	0	9999	0.02	0.7	0	FALSE
ReplacementFire	ASP-U	DP	MSu-A	AL	100	999	0	9999	0.02	0.3	0	FALSE
RxFire	ASP-U	DP	ASP-U	DP	100	999	0	9999	0.01	0.3	0	FALSE
RxFire	ASP-U	DP	ASP-A	CL	100	999	0	9999	0.01	0.49	0	FALSE
RxFire	ASP-U	DP	MSu-A	AL	100	999	0	9999	0.01	0.21	0	FALSE
AG-Invasion	BS-A	AL	BS-U	SAP	10	24	0	9999	0.001	1	0	TRUE
AG-Invasion	BS-A	AL	BS-U	AG	0	9	0	9999	0.0001	1	0	FALSE
Animal-Burrowing	BS-A	AL	BS-E	AM	0	24	0	9999	0.0001	1	0	TRUE
Drought	BS-A	AL	BS-A	AL	0	24	0	9999	0.0056	1	-1	FALSE
ReplacementFire	BS-A	AL	BS-A	AL	0	24	0	9999	0.004	1	-999	FALSE
AG-Invasion	BS-B	OP	BS-U	SAP	25	119	0	9999	0.005	1	0	TRUE
Drought	BS-B	OP	BS-B	OP	25	119	0	9999	0.0056	0.5	-999	FALSE
Drought	BS-B	OP	BS-A	AL	25	119	0	9999	0.0056	0.5	0	FALSE
ReplacementFire	BS-B	OP	BS-A	AL	25	119	0	9999	0.0067	1	0	FALSE
AG-Invasion	BS-C	CL	BS-U	SAP	120	999	0	9999	0.005	1	0	TRUE
Chainsaw-Lopping	BS-C	CL	BS-C	CL	120	999	0	9999	0.01	1	-999	FALSE
Drought	BS-C	CL	BS-C	CL	120	999	0	9999	0.0056	0.75	-999	FALSE
Drought	BS-C	CL	BS-B	OP	120	999	0	9999	0.0056	0.25	0	FALSE
Herbicide	BS-C	CL	BS-B	OP	120	999	0	9999	0.01	1	0	FALSE
ReplacementFire	BS-C	CL	BS-A	AL	120	999	0	9999	0.0067	1	0	FALSE

RxFire	BS-C	CL	BS-A	AL	120	999	0	9999	0.01	0.7	0	FALSE
RxFire	BS-C	CL	BS-C	CL	120	999	0	9999	0.01	0.3	0	FALSE
Tree-Invasion	BS-C	CL	BS-D	OP	120	149	0	9999	0.001	1	0	FALSE
Tree-Invasion	BS-C	CL	BS-D	OP	150	999	0	9999	0.005	1	0	FALSE
AG-Invasion	BS-D	OP	BS-U	TA	121	999	0	9999	0.005	1	0	TRUE
Chainsaw-Thinning	BS-D	OP	BS-B	OP	121	999	0	9999	0.01	1	0	FALSE
Drought	BS-D	OP	BS-D	OP	121	999	0	9999	0.0056	0.75	5	FALSE
Drought	BS-D	OP	BS-C	CL	121	999	0	9999	0.0056	0.25	0	FALSE
Mastication	BS-D	OP	BS-A	AL	121	999	0	9999	0.01	1	0	FALSE
ReplacementFire	BS-D	OP	BS-A	AL	121	999	0	9999	0.0067	1	0	FALSE
RxFire	BS-D	OP	BS-A	AL	121	999	0	9999	0.01	0.7	0	FALSE
RxFire	BS-D	OP	BS-D	OP	121	999	0	9999	0.01	0.3	0	FALSE
Tree-Encroachment	BS-D	OP	BS-U	TE	300	399	0	9999	0.005	1	0	TRUE
Tree-Encroachment	BS-D	OP	BS-U	TE	400	499	0	9999	0.0075	1	0	TRUE
Tree-Encroachment	BS-D	OP	BS-U	TE	500	999	0	9999	0.015	1	0	TRUE
Animal-Burrowing	BS-E	AM	BS-E	AM	0	999	0	9999	0.1	1	-999	FALSE
Natural-Recovery	BS-E	AM	BS-A	AL	5	999	0	9999	0.0001	1	0	FALSE
ReplacementFire	BS-E	AM	BS-E	AM	0	999	0	9999	0.004	1	-999	FALSE
Herbicide+Seed	BS-U	AG	BS-A	AL	0	999	0	9999	0.01	0.5	0	FALSE
Herbicide+Seed	BS-U	AG	BS-U	AG	0	999	0	9999	0.01	0.5	0	FALSE
ReplacementFire	BS-U	AG	BS-U	AG	0	999	0	9999	0.1	1	-999	FALSE
AG-Invasion	BS-U	DP	BS-U	SA	26	999	0	9999	0.005	1	0	TRUE
Chainsaw-Lopping	BS-U	DP	BS-U	DP	120	999	0	9999	0.01	1	-999	FALSE
Drought	BS-U	DP	BS-U	DP	26	999	0	9999	0.0056	0.9	-999	FALSE
Drought	BS-U	DP	BS-U	ES	26	999	0	9999	0.006	0.1	0	FALSE
ReplacementFire	BS-U	DP	BS-U	ES	26	999	0	9999	0.0067	1	0	FALSE
Seed	BS-U	DP	BS-U	DP	26	999	0	9999	0.01	0.5	0	FALSE
Seed	BS-U	DP	BS-B	OP	26	119	0	9999	0.01	0.5	0	TRUE
Seed	BS-U	DP	BS-C	CL	120	999	0	9999	0.01	0.5	0	TRUE
Tree-Invasion	BS-U	DP	BS-U	TE	120	999	0	9999	0.005	1	0	FALSE
Chainsaw-Lopping	BS-U	SA	BS-U	SA	120	999	0	9999	0.01	1	-999	FALSE
Drought	BS-U	SA	BS-U	SA	10	999	0	9999	0.0056	0.9	-999	FALSE
Drought	BS-U	SA	BS-U	AG	10	999	0	9999	0.006	0.1	0	FALSE

Herbicide+Seed	BS-U	SA	BS-A	AL	10	24	0	9999	0.01	0.2	0	TRUE
Herbicide+Seed	BS-U	SA	BS-U	SA	10	999	0	9999	0.01	0.8	0	FALSE
Herbicide+Seed	BS-U	SA	BS-B	OP	25	119	0	9999	0.01	0.2	0	TRUE
Herbicide+Seed	BS-U	SA	BS-C	CL	120	999	0	9999	0.01	0.2	0	TRUE
ReplacementFire	BS-U	SA	BS-U	AG	10	999	0	9999	0.01	1	0	FALSE
Thin+Herbicide+Seed	BS-U	SA	BS-A	AL	10	999	0	9999	0.01	0.7	0	FALSE
Thin+Herbicide+Seed	BS-U	SA	BS-U	AG	10	999	0	9999	0.01	0.3	0	FALSE
Tree-Invasion	BS-U	SA	BS-U	TA	120	999	0	9999	0.005	1	0	FALSE
Chainsaw-Lopping	BS-U	SAP	BS-U	SAP	120	999	0	9999	0.01	1	-999	FALSE
Drought	BS-U	SAP	BS-U	SAP	10	999	0	9999	0.0056	0.9	-999	FALSE
Drought	BS-U	SAP	BS-U	AG	10	999	0	9999	0.006	0.05	0	FALSE
Drought	BS-U	SAP	BS-A	AL	10	999	0	9999	0.006	0.05	0	FALSE
Herbicide	BS-U	SAP	BS-A	AL	10	24	0	9999	0.01	0.7	0	TRUE
Herbicide	BS-U	SAP	BS-U	SAP	10	999	0	9999	0.01	0.3	0	FALSE
Herbicide	BS-U	SAP	BS-B	OP	25	119	0	9999	0.01	0.7	0	TRUE
Herbicide	BS-U	SAP	BS-C	CL	120	999	0	9999	0.01	0.7	0	TRUE
ReplacementFire	BS-U	SAP	BS-U	AG	10	999	0	9999	0.0067	0.95	0	FALSE
ReplacementFire	BS-U	SAP	BS-A	AL	10	999	0	9999	0.006	0.05	0	FALSE
Tree-Invasion	BS-U	SAP	BS-U	TA	120	999	0	9999	0.005	1	0	FALSE
Chainsaw-Chip-Herb-Seed	BS-U	TA	BS-U	AG	121	999	0	9999	0.01	0.4	0	FALSE
Chainsaw-Chip-Herb-Seed	BS-U	TA	BS-A	AL	121	999	0	9999	0.01	0.6	0	FALSE
Drought	BS-U	TA	BS-U	AG	121	999	0	9999	0.0056	1	0	FALSE
ReplacementFire	BS-U	TA	BS-U	AG	121	999	0	9999	0.0067	1	0	FALSE
AG-Invasion	BS-U	TE	BS-U	TA	121	999	0	9999	0.005	1	0	TRUE
Chainsaw-Chip-Herb-Seed	BS-U	TE	BS-U	ES	121	999	0	9999	0.01	0.3	0	FALSE
Chainsaw-Chip-Herb-Seed	BS-U	TE	BS-A	AL	121	999	0	9999	0.01	0.7	0	FALSE
Drought	BS-U	TE	BS-U	TE	121	999	0	9999	0.0056	0.5	-999	FALSE
Drought	BS-U	TE	BS-U	ES	121	999	0	9999	0.0056	0.5	0	FALSE
ReplacementFire	BS-U	TE	BS-U	ES	121	999	0	9999	0.0067	1	0	FALSE
Exotic-Invasion	BW-A	OP	BW-U	EF	5	9	5	9999	0.01	1	0	FALSE
ReplacementFire	BW-A	OP	BW-A	OP	0	9	0	9999	0.02	1	-999	FALSE
Weed-Inventory	BW-A	OP	BW-A	OP	0	9	0	9999	0.01	1	0	FALSE
AG-Invasion	BW-B	CL	BW-U	SA	10	74	0	9999	0.0001	1	0	TRUE

Drought	BW-B	CL	BW-B	CL	10	74	0	9999	0.0056	1	-999	FALSE
Exotic-Invasion	BW-B	CL	BW-U	EF	10	74	5	9999	0.01	1	0	FALSE
ReplacementFire	BW-B	CL	BW-A	OP	10	74	0	9999	0.025	1	0	FALSE
Weed-Inventory	BW-B	CL	BW-B	CL	10	74	0	9999	0.01	1	0	FALSE
AG-Invasion	BW-C	OP	BW-U	SA	75	174	0	9999	0.002	1	0	TRUE
AG-Invasion	BW-C	OP	BW-U	TA	175	999	0	9999	0.002	1	0	TRUE
Chainsaw-Lopping	BW-C	OP	BW-C	OP	75	999	0	9999	0.01	1	-999	FALSE
Drought	BW-C	OP	BW-C	OP	75	999	0	9999	0.0056	0.9	-999	FALSE
Drought	BW-C	OP	BW-B	CL	75	999	0	9999	0.0056	0.1	0	FALSE
Exotic-Invasion	BW-C	OP	BW-U	EF	75	999	5	9999	0.01	1	0	FALSE
ReplacementFire	BW-C	OP	BW-A	OP	75	999	0	9999	0.015	1	0	FALSE
RxFire	BW-C	OP	BW-A	OP	75	999	0	9999	0.01	1	0	FALSE
Tree-Invasion	BW-C	OP	BW-U	TE	100	999	0	9999	0.01	1	0	TRUE
Weed-Inventory	BW-C	OP	BW-C	OP	75	999	0	9999	0.01	1	0	FALSE
Exotic-Invasion	BW-U	AG	BW-U	EF	0	999	5	9999	0.01	1	0	FALSE
Herbicide+Seed	BW-U	AG	BW-A	OP	0	3	0	9999	0.01	0.7	0	FALSE
Herbicide+Seed	BW-U	AG	BW-U	AG	0	3	0	9999	0.01	0.3	0	FALSE
ReplacementFire	BW-U	AG	BW-U	AG	0	999	0	9999	0.1	1	-999	FALSE
Weed-Inventory	BW-U	AG	BW-U	AG	0	999	0	9999	0.01	1	0	FALSE
AG-Invasion	BW-U	DP	BW-U	SA	11	174	0	9999	0.002	1	0	TRUE
AG-Invasion	BW-U	DP	BW-U	TA	175	999	0	9999	0.002	1	0	TRUE
Drought	BW-U	DP	BW-U	DP	11	999	0	9999	0.0056	0.9	-999	FALSE
Drought	BW-U	DP	BW-U	AG	11	999	0	9999	0.0056	0.1	0	FALSE
Exotic-Invasion	BW-U	DP	BW-U	EF	11	999	5	9999	0.01	1	0	FALSE
ReplacementFire	BW-U	DP	BW-U	DP	11	999	0	9999	0.01	0.5	-999	FALSE
Thin+Seed	BW-U	DP	BW-A	OP	11	999	0	9999	0.01	0.8	0	FALSE
Thin+Seed	BW-U	DP	BW-U	ES	11	999	0	9999	0.01	0.2	0	FALSE
Tree-Invasion	BW-U	DP	BW-U	TE	75	999	0	9999	0.005	1	0	FALSE
Weed-Inventory	BW-U	DP	BW-U	DP	11	999	0	9999	0.01	1	0	FALSE
Exotic-Control	BW-U	EF	BW-A	OP	0	999	0	20	0.01	0.5	0	FALSE
Exotic-Control	BW-U	EF	BW-U	EF	0	999	0	20	0.01	0.5	0	FALSE
ReplacementFire	BW-U	EF	BW-U	EF	0	999	0	9999	0.02	1	-999	FALSE
AG-Invasion	BW-U	ES	BW-U	SA	0	999	0	9999	0.001	1	0	FALSE

ReplacementFire	BW-U	ES	BW-U	ES	0	999	0	9999	0.01	1	-999	FALSE
Tree-Invasion	BW-U	ES	BW-U	TE	76	999	0	20	0.01	1	0	FALSE
Drought	BW-U	SA	BW-U	SA	11	999	0	9999	0.0056	0.9	-999	FALSE
Drought	BW-U	SA	BW-U	AG	11	999	0	9999	0.006	0.1	0	FALSE
Exotic-Invasion	BW-U	SA	BW-U	EF	11	999	5	9999	0.01	1	0	FALSE
Herbicide+Seed	BW-U	SA	BW-A	OP	11	999	0	9999	0.01	0.8	0	FALSE
Herbicide+Seed	BW-U	SA	BW-U	SA	11	999	0	9999	0.01	0.2	0	FALSE
ReplacementFire	BW-U	SA	BW-U	AG	11	999	0	9999	0.015	1	0	FALSE
RxFire+Herbicide+Seed	BW-U	SA	BW-A	OP	11	999	0	9999	0.01	0.8	0	FALSE
RxFire+Herbicide+Seed	BW-U	SA	BW-U	AG	11	999	0	9999	0.01	0.2	0	FALSE
Tree-Invasion	BW-U	SA	BW-U	TA	75	999	0	9999	0.01	1	0	FALSE
Weed-Inventory	BW-U	SA	BW-U	SA	11	999	0	9999	0.01	1	0	FALSE
Drought	BW-U	TA	BW-U	AG	76	999	0	9999	0.0056	0.1	0	FALSE
Drought	BW-U	TA	BW-U	TA	76	999	0	9999	0.0056	0.9	-999	FALSE
Masticate+Herbicide+Seed	BW-U	TA	BW-A	OP	76	999	0	9999	0.01	0.8	0	FALSE
Masticate+Herbicide+Seed	BW-U	TA	BW-U	AG	76	999	0	9999	0.01	0.2	0	FALSE
ReplacementFire	BW-U	TA	BW-U	AG	76	999	0	9999	0.008	1	0	FALSE
RxFire+Herbicide+Seed	BW-U	TA	BW-A	OP	76	999	0	9999	0.01	0.7	0	FALSE
RxFire+Herbicide+Seed	BW-U	TA	BW-U	TA	76	999	0	9999	0.01	0.3	0	FALSE
AG-Invasion	BW-U	TE	BW-U	TA	76	999	0	9999	0.005	1	0	FALSE
Drought	BW-U	TE	BW-U	TE	76	999	0	9999	0.0056	0.9	-999	FALSE
Drought	BW-U	TE	BW-U	ES	76	999	0	9999	0.0056	0.1	0	FALSE
Masticate+Herbicide+Seed	BW-U	TE	BW-A	OP	76	999	0	9999	0.01	0.8	0	FALSE
Masticate+Herbicide+Seed	BW-U	TE	BW-U	ES	76	999	0	9999	0.01	0.2	0	FALSE
ReplacementFire	BW-U	TE	BW-U	ES	76	999	0	9999	0.0068	1	0	FALSE
RxFire+Herbicide+Seed	BW-U	TE	BW-A	OP	76	999	0	9999	0.01	0.8	0	FALSE
RxFire+Herbicide+Seed	BW-U	TE	BW-U	TE	76	999	0	9999	0.01	0.2	0	FALSE
CC-Conversion	LB-A	AL	MM-A	AL	0	99	0	9999	0.03	1	2	TRUE
Drought	LB-A	AL	LB-A	AL	0	99	0	9999	0.0056	1	-5	FALSE
ReplacementFire-Forest	LB-A	AL	LB-A	AL	0	99	0	9999	0.001	1	-999	FALSE
SurfaceFire-Forest	LB-A	AL	LB-A	AL	0	99	0	9999	0.001	1	0	FALSE
ReplacementFire-Forest	LB-B	OP	LB-A	AL	100	249	0	9999	0.001	1	0	FALSE
SurfaceFire-Forest	LB-B	OP	LB-B	OP	100	249	0	9999	0.002	1	0	FALSE

ReplacementFire-Forest	LB-C	OP	LB-A	AL	250	999	0	9999	0.001	1	0	FALSE
SurfaceFire-Forest	LB-C	OP	LB-C	OP	250	999	0	9999	0.002	1	0	FALSE
CC-Conversion	LBm-A	AL	MC-A	AL	0	1	0	9999	0.03	0.75	2	TRUE
CC-Conversion	LBm-A	AL	MM-A	AL	0	1	0	9999	0.03	0.25	2	TRUE
Drought	LBm-A	AL	LBm-A	AL	0	49	0	9999	0.0056	1	-5	FALSE
ReplacementFire-Forest	LBm-A	AL	LBm-A	AL	0	49	0	9999	0.002	1	-999	FALSE
SurfaceFire-Forest	LBm-A	AL	LBm-A	AL	0	49	0	9999	0.005	1	0	FALSE
ReplacementFire-Forest	LBm-B	OP	LBm-A	AL	50	199	0	9999	0.002	1	0	FALSE
SurfaceFire-Forest	LBm-B	OP	LBm-B	OP	50	199	0	9999	0.005	1	0	FALSE
Heartrot	LBm-C	CL	LBm-A	AL	200	999	0	9999	0.002	1	0	FALSE
ReplacementFire-Forest	LBm-C	CL	LBm-A	AL	200	999	0	9999	0.002	1	0	FALSE
RxFire	LBm-C	CL	LBm-A	AL	200	999	0	9999	0.01	0.8	0	FALSE
RxFire	LBm-C	CL	LBm-C	CL	200	999	0	9999	0.01	0.2	0	FALSE
SurfaceFire-Forest	LBm-C	CL	LBm-C	CL	200	999	0	9999	0.005	1	0	FALSE
Drought	LSS-A	AL	LSS-A	AL	0	24	0	9999	0.0056	1	-1	FALSE
ReplacementFire	LSS-A	AL	LSS-A	AL	0	24	0	9999	0.004	1	-999	FALSE
Drought	LSS-B	OP	LSS-B	OP	25	119	0	9999	0.0056	0.8	-1	FALSE
Drought	LSS-B	OP	LSS-A	AL	25	119	0	9999	0.0055	0.2	0	FALSE
ReplacementFire	LSS-B	OP	LSS-A	AL	25	119	0	9999	0.011	1	0	FALSE
Chainsaw-Lopping	LSS-C	OP	LSS-C	OP	120	999	0	9999	0.01	1	-999	FALSE
Drought	LSS-C	OP	LSS-B	OP	120	999	0	9999	0.0055	0.2	0	FALSE
Drought	LSS-C	OP	LSS-C	OP	120	999	0	9999	0.0056	0.8	-1	FALSE
ReplacementFire	LSS-C	OP	LSS-A	AL	120	999	0	9999	0.015	1	0	FALSE
RxFire	LSS-C	OP	LSS-A	AL	120	999	0	9999	0.01	0.6	0	FALSE
RxFire	LSS-C	OP	LSS-C	OP	120	999	0	9999	0.01	0.4	0	FALSE
Tree-Invasion	LSS-C	OP	LSS-U	TE	200	999	0	9999	0.001	1	0	TRUE
Drought	LSS-U	DP	LSS-U	DP	25	999	0	9999	0.0056	0.9	-999	FALSE
Drought	LSS-U	DP	LSS-U	ES	25	999	0	9999	0.006	0.1	0	FALSE
Tree-Invasion	LSS-U	DP	LSS-U	TE	100	999	0	9999	0.005	1	0	FALSE
Natural-Recovery	LSS-U	ES	LSS-B	OP	25	119	0	9999	0.001	1	0	TRUE
Natural-Recovery	LSS-U	ES	LSS-C	OP	120	999	0	9999	0.001	1	0	TRUE
ReplacementFire	LSS-U	ES	LSS-U	ES	0	999	0	9999	0.005	1	-999	FALSE
Drought	LSS-U	TE	LSS-C	OP	200	300	0	9999	0.0056	1	0	TRUE

Drought	LSS-U	TE	LSS-U	DP	301	999	0	9999	0.0056	1	0	TRUE
ReplacementFire	LSS-U	TE	LSS-U	ES	200	999	0	9999	0.004	1	0	FALSE
CC-Conversion	MC-A	AL	PJ-A	AL	0	1	0	9999	0.03	0.95	2	TRUE
CC-Conversion	MC-A	AL	PP-A	AL	0	1	0	9999	0.03	0.05	2	TRUE
Drought	MC-A	AL	MC-A	AL	0	9	0	9999	0.0056	1	-999	FALSE
ReplacementFire-Forest	MC-A	AL	MC-A	AL	0	9	0	9999	0.008	1	-999	FALSE
AG-Invasion	MC-B	CL	MC-U	TA	10	49	0	9999	0.0001	1	0	TRUE
Insect/Disease	MC-B	CL	MC-A	AL	10	49	0	9999	0.04	0.5	0	FALSE
Insect/Disease	MC-B	CL	MC-C	OP	10	49	0	9999	0.04	0.5	0	TRUE
MixedFire-Forest	MC-B	CL	MC-C	OP	10	49	0	9999	0.02	1	0	TRUE
ReplacementFire-Forest	MC-B	CL	MC-A	AL	10	49	0	9999	0.008	1	0	FALSE
AG-Invasion	MC-C	OP	MC-U	TA	10	63	0	9999	0.0001	1	0	TRUE
AltSuccession	MC-C	OP	MC-B	CL	10	63	35	9999	1	0.33	0	TRUE
Insect/Disease	MC-C	OP	MC-C	OP	10	63	0	9999	0.01	1	0	FALSE
ReplacementFire-Forest	MC-C	OP	MC-A	AL	10	63	0	9999	0.0025	1	0	FALSE
SurfaceFire-Forest	MC-C	OP	MC-C	OP	10	63	0	9999	0.02	1	-999	FALSE
AG-Invasion	MC-D	OP	MC-U	TA	64	999	0	9999	0.0001	1	0	TRUE
AltSuccession	MC-D	OP	MC-E	CL	64	999	35	9999	1	1	0	TRUE
Drought	MC-D	OP	MC-D	OP	64	999	0	9999	0.0056	1	-999	FALSE
Insect/Disease	MC-D	OP	MC-D	OP	64	999	0	9999	0.001	1	0	FALSE
ReplacementFire-Forest	MC-D	OP	MC-A	AL	64	999	0	9999	0.0025	1	0	FALSE
SurfaceFire-Forest	MC-D	OP	MC-D	OP	64	999	0	9999	0.02	1	0	FALSE
AG-Invasion	MC-E	CL	MC-U	TA	50	999	0	9999	0.0001	1	0	FALSE
Drought	MC-E	CL	MC-D	OP	50	999	0	9999	0.0056	1	0	TRUE
Insect/Disease	MC-E	CL	MC-A	AL	50	999	0	9999	0.02	0.6	0	FALSE
Insect/Disease	MC-E	CL	MC-D	OP	50	999	0	9999	0.02	0.4	0	FALSE
MixedFire-Forest	MC-E	CL	MC-D	OP	50	999	0	9999	0.02	1	0	TRUE
ReplacementFire-Forest	MC-E	CL	MC-A	AL	50	999	0	9999	0.008	1	0	FALSE
RxFire	MC-E	CL	MC-A	AL	50	999	0	9999	0.01	1	0	FALSE
CC-Conversion	MC-U	AG	PJ-U	AG	0	1	0	9999	0.03	0.95	2	TRUE
CC-Conversion	MC-U	AG	PP-U	AG	0	1	0	9999	0.03	0.05	2	TRUE
ReplacementFire	MC-U	AG	MC-U	AG	0	999	0	9999	0.1	1	-999	FALSE
Insect/Disease	MC-U	TA	MC-U	TA	10	999	0	9999	0.0056	1	0	FALSE

MixedFire-Forest	MC-U	TA	MC-U	AG	10	999	0	9999	0.0151	0.75	0	FALSE
MixedFire-Forest	MC-U	TA	MC-U	TA	10	999	0	9999	0.0152	0.25	0	FALSE
Natural-Recovery	MC-U	TA	MC-E	CL	50	999	10	9999	0.01	1	0	TRUE
ReplacementFire-Forest	MC-U	TA	MC-U	AG	10	999	0	9999	0.0053	1	0	FALSE
NativeGrazing	MG-A	AL	MG-A	AL	0	4	0	9999	1	0.5	-1	FALSE
ReplacementFire	MG-A	AL	MG-A	AL	0	4	0	9999	0.005	1	-999	FALSE
NativeGrazing	MG-B	CL	MG-B	CL	5	9	0	9999	1	0.5	0	FALSE
ReplacementFire	MG-B	CL	MG-A	AL	5	9	0	9999	0.005	1	0	FALSE
Chainsaw-Lopping	MG-C	CL	MG-B	CL	50	909	0	9999	0.01	1	0	FALSE
NativeGrazing	MG-C	CL	MG-B	CL	10	909	0	9999	1	0.1	0	FALSE
ReplacementFire	MG-C	CL	MG-A	AL	10	909	0	9999	0.005	1	0	FALSE
SurfaceFire	MG-C	CL	MG-B	CL	10	909	0	9999	0.01	1	0	FALSE
CC-Conversion	MM-A	AL	BS-A	AL	0	1	0	9999	0.03	0.5	2	TRUE
CC-Conversion	MM-A	AL	WS-A	AL	0	1	0	9999	0.03	0.5	2	TRUE
NativeGrazing	MM-A	AL	MM-A	AL	0	19	0	9999	1	0.02	-999	FALSE
ReplacementFire	MM-A	AL	MM-A	AL	0	19	0	9999	0.002	1	-999	FALSE
NativeGrazing	MM-B	OP	MM-B	OP	20	59	0	9999	0.01	1	0	FALSE
ReplacementFire	MM-B	OP	MM-A	AL	20	59	0	9999	0.007	1	0	FALSE
MixedFire	MM-C	CL	MM-D	OP	60	149	0	9999	0.005	1	0	TRUE
NativeGrazing	MM-C	CL	MM-C	CL	60	149	0	9999	0.001	1	0	FALSE
ReplacementFire	MM-C	CL	MM-A	AL	60	149	0	9999	0.007	1	0	FALSE
AG-Invasion	MM-D	OP	MM-U	TA	60	999	0	9999	0.001	1	0	FALSE
AltSuccession	MM-D	OP	MM-E	CL	60	999	150	9999	1	1	0	TRUE
ReplacementFire	MM-D	OP	MM-A	AL	60	999	0	9999	0.003	1	0	FALSE
SurfaceFire	MM-D	OP	MM-D	OP	60	999	0	9999	0.025	1	0	FALSE
AG-Invasion	MM-E	CL	MM-U	TA	150	999	0	9999	0.001	1	0	TRUE
ReplacementFire	MM-E	CL	MM-A	AL	150	999	0	9999	0.002	1	0	FALSE
CC-Conversion	MM-U	AG	BS-U	AG	0	1	0	9999	0.03	0.5	2	TRUE
CC-Conversion	MM-U	AG	MSu-U	AG	0	1	0	9999	0.03	0.5	2	TRUE
ReplacementFire	MM-U	AG	MM-U	AG	0	999	0	9999	0.1	1	-999	FALSE
ReplacementFire	MM-U	TA	MM-U	AG	150	999	0	9999	0.007	1	0	FALSE
Beaver-Herbivory	MR-A	AL	MR-A	AL	0	4	0	9999	0.005	1	-1	FALSE
Flooding-7yr	MR-A	AL	MR-A	AL	0	4	0	9999	0.13	1	-5	FALSE

RoadLateralFlow	MR-A	AL	MR-U	DE	0	4	20	9999	0.04	0.33	0	TRUE
WaterWithdrawal	MR-A	AL	MR-U	DW	0	4	0	9999	0.005	0.25	0	TRUE
WaterWithdrawal	MR-A	AL	MR-U	PD	0	4	0	9999	0.005	0.75	0	TRUE
Weed-Inventory	MR-A	AL	MR-A	AL	0	4	0	9999	0.01	1	0	FALSE
Beaver-Herbivory	MR-B	OP	MR-A	AL	5	19	0	9999	0.005	0.5	0	FALSE
Beaver-Herbivory	MR-B	OP	MR-B	OP	5	19	0	9999	0.005	0.5	-20	FALSE
Exotic-Invasion	MR-B	OP	MR-U	EF	5	19	5	9999	0.01	1	0	FALSE
Flooding-20yr	MR-B	OP	MR-A	AL	5	19	0	9999	0.05	1	0	FALSE
ReplacementFire	MR-B	OP	MR-A	AL	5	19	0	9999	0.02	1	0	FALSE
RoadLateralFlow	MR-B	OP	MR-U	DE	5	19	20	9999	0.04	0.33	0	TRUE
RxFire	MR-B	OP	MR-A	AL	5	19	0	9999	0.01	1	0	FALSE
WaterWithdrawal	MR-B	OP	MR-U	DW	5	19	0	9999	0.005	0.25	0	TRUE
WaterWithdrawal	MR-B	OP	MR-U	PD	5	19	0	9999	0.005	0.75	0	TRUE
Weed-Inventory	MR-B	OP	MR-B	OP	5	19	0	9999	0.25	1	0	TRUE
Beaver-Herbivory	MR-C	CL	MR-B	OP	20	1019	0	9999	0.002	0.5	0	FALSE
Beaver-Herbivory	MR-C	CL	MR-C	CL	20	1019	0	9999	0.002	0.5	-5	FALSE
Exotic-Invasion	MR-C	CL	MR-U	EF	20	1019	5	9999	0.01	1	0	FALSE
Flooding-100yr	MR-C	CL	MR-A	AL	20	1019	0	9999	0.01	1	0	FALSE
ReplacementFire	MR-C	CL	MR-A	AL	20	1019	0	9999	0.02	1	0	FALSE
RoadLateralFlow	MR-C	CL	MR-U	DE	20	1019	20	9999	0.04	0.33	0	TRUE
RxFire	MR-C	CL	MR-A	AL	20	1019	0	9999	0.01	1	0	FALSE
WaterWithdrawal	MR-C	CL	MR-U	DW	20	1019	0	9999	0.005	0.25	0	TRUE
WaterWithdrawal	MR-C	CL	MR-U	PD	20	1019	0	9999	0.005	0.75	0	TRUE
Weed-Inventory	MR-C	CL	MR-C	CL	20	1019	0	9999	0.25	1	0	FALSE
AG-Herbicide+Seed	MR-U	AG	MR-U	DE	0	999	0	9999	0.01	0.8	0	FALSE
AG-Herbicide+Seed	MR-U	AG	MR-U	AG	0	999	0	9999	0.01	0.2	0	FALSE
Beaver-Herbivory	MR-U	AG	MR-A	AL	0	999	0	9999	0.002	1	0	FALSE
Flooding-100yr	MR-U	AG	MR-U	AG	0	999	0	9999	0.01	0.99	-999	FALSE
Flooding-100yr	MR-U	AG	MR-A	AL	0	999	0	9999	0.01	0.01	0	FALSE
Floodplain-Restoration	MR-U	AG	MR-A	AL	0	999	0	9999	0.01	0.9	0	FALSE
Floodplain-Restoration	MR-U	AG	MR-U	AG	0	999	0	9999	0.01	0.1	0	FALSE
ReplacementFire	MR-U	AG	MR-U	AG	0	999	0	9999	0.1	1	-999	FALSE
AG-Invasion	MR-U	DE	MR-U	SAP	0	999	0	9999	0.005	1	0	TRUE

Beaver-Herbivory	MR-U	DE	MR-U	SFE	0	999	0	9999	0.002	1	0	FALSE
Flooding-100yr	MR-U	DE	MR-U	DE	0	999	0	9999	0.01	0.99	-999	FALSE
Flooding-100yr	MR-U	DE	MR-A	AL	0	999	0	9999	0.01	0.01	0	FALSE
Floodplain-Recovery	MR-U	DE	MR-A	AL	0	999	10	9999	0.001	1	0	FALSE
Floodplain-Restoration	MR-U	DE	MR-A	AL	0	999	0	9999	0.01	0.9	0	FALSE
Floodplain-Restoration	MR-U	DE	MR-U	DE	0	999	0	9999	0.01	0.1	0	FALSE
ReplacementFire	MR-U	DE	MR-U	DE	0	999	0	9999	0.02	1	-999	FALSE
Tree-Invasion	MR-U	DE	MR-U	TE	40	999	0	9999	0.01	1	0	FALSE
Beaver-Herbivory	MR-U	DEP	MR-U	PD	0	999	0	9999	0.0005	1	0	TRUE
Chainsaw+Seed	MR-U	DEP	MR-U	DEP	150	999	0	9999	0.01	1	-999	FALSE
Flooding-100yr	MR-U	DEP	MR-U	DEP	0	999	0	9999	0.01	0.99	-999	FALSE
Flooding-100yr	MR-U	DEP	MR-U	PD	0	999	0	9999	0.01	0.01	0	FALSE
Floodplain-Restoration	MR-U	DEP	MR-U	PD	0	999	0	9999	0.01	1	0	FALSE
ReplacementFire	MR-U	DEP	MR-U	DEP	0	149	0	9999	0.02	1	-999	FALSE
ReplacementFire	MR-U	DEP	MR-U	DEP	150	999	0	9999	0.0068	1	-999	FALSE
Yearly-Reset-Withdrawal	MR-U	DEP	MR-U	DE	0	999	0	9999	0.01	1	0	TRUE
Exotic-Invasion	MR-U	DW	MR-U	EFD	0	999	5	9999	0.0011	1	0	FALSE
Flooding-100yr	MR-U	DW	MR-U	DW	0	999	0	9999	0.01	1	-999	FALSE
ReplacementFire	MR-U	DW	MR-U	DW	0	999	0	9999	0.02	1	-999	FALSE
Weed-Inventory	MR-U	DW	MR-U	DW	0	999	0	9999	0.01	1	0	FALSE
Yearly-Reset-Withdrawal	MR-U	DW	MR-A	AL	0	4	0	9999	0.01	1	0	FALSE
Yearly-Reset-Withdrawal	MR-U	DW	MR-B	OP	5	19	0	9999	0.01	1	0	FALSE
Yearly-Reset-Withdrawal	MR-U	DW	MR-C	CL	20	999	0	9999	0.01	1	0	FALSE
Exoctic-Control	MR-U	EF	MR-B	OP	0	999	0	20	1	0.6	0	TRUE
Exoctic-Control	MR-U	EF	MR-U	EF	0	999	0	20	1	0.4	0	FALSE
ReplacementFire	MR-U	EF	MR-U	EF	0	999	0	9999	0.02	1	-999	FALSE
WaterWithdrawal	MR-U	EF	MR-U	EFD	0	999	0	9999	0.005	1	0	TRUE
Exoctic-Control	MR-U	EFD	MR-U	PD	0	999	0	20	0.01	0.9	0	TRUE
Exoctic-Control	MR-U	EFD	MR-U	DW	0	999	0	20	0.01	0.1	0	TRUE
ReplacementFire	MR-U	EFD	MR-U	EFD	0	999	0	9999	0.02	1	-999	FALSE
Yearly-Reset-Withdrawal	MR-U	EFD	MR-U	EF	0	999	0	9999	0.01	1	0	TRUE
Beaver-Herbivory	MR-U	PD	MR-A	AL	0	4	0	9999	0.001	1	0	FALSE
Beaver-Herbivory	MR-U	PD	MR-B	OP	5	19	0	9999	0.001	1	0	FALSE

Beaver-Herbivory	MR-U	PD	MR-C	CL	20	999	0	9999	0.001	1	0	FALSE
Exotic-Invasion	MR-U	PD	MR-U	EFD	0	999	5	9999	0.01	1	0	TRUE
Flooding-100yr	MR-U	PD	MR-U	PD	20	999	0	9999	0.01	1	-999	FALSE
Flooding-20yr	MR-U	PD	MR-U	PD	5	19	0	9999	0.05	1	-999	FALSE
Flooding-7yr	MR-U	PD	MR-U	PD	0	4	0	9999	0.13	1	-999	FALSE
ReplacementFire	MR-U	PD	MR-U	PD	0	999	0	9999	0.02	1	-999	FALSE
RoadLateralFlow	MR-U	PD	MR-U	DEP	0	999	20	9999	0.04	0.33	0	FALSE
Weed-Inventory	MR-U	PD	MR-U	PD	0	999	0	9999	0.005	1	0	FALSE
Yearly-Reset-Withdrawal	MR-U	PD	MR-A	AL	0	4	0	9999	0.01	1	0	FALSE
Yearly-Reset-Withdrawal	MR-U	PD	MR-B	OP	5	19	0	9999	0.01	1	0	FALSE
Yearly-Reset-Withdrawal	MR-U	PD	MR-C	CL	20	999	0	9999	0.01	1	0	FALSE
AG-Herbicide	MR-U	SAP	MR-U	DE	0	999	0	9999	0.01	0.8	0	TRUE
AG-Herbicide	MR-U	SAP	MR-U	SAP	0	999	0	9999	0.01	0.2	0	FALSE
Beaver-Herbivory	MR-U	SAP	MR-U	SFE	0	999	0	9999	0.002	1	-1	FALSE
Flooding-100yr	MR-U	SAP	MR-U	SAP	0	999	0	9999	0.01	0.5	-999	FALSE
Flooding-100yr	MR-U	SAP	MR-U	AG	0	999	0	9999	0.01	0.49	0	FALSE
Flooding-100yr	MR-U	SAP	MR-A	AL	0	999	0	9999	0.01	0.01	0	FALSE
Floodplain-Restoration	MR-U	SAP	MR-A	AL	0	999	0	9999	0.01	0.9	0	FALSE
Floodplain-Restoration	MR-U	SAP	MR-U	SAP	0	999	0	9999	0.01	0.1	0	FALSE
ReplacementFire	MR-U	SAP	MR-U	SAP	0	999	0	9999	0.04	0.1	-999	FALSE
ReplacementFire	MR-U	SAP	MR-U	AG	0	999	0	9999	0.04	0.9	0	FALSE
AG-Invasion	MR-U	SD	MR-U	SDA	0	999	0	9999	0.001	1	0	TRUE
Beaver-Herbivory	MR-U	SD	MR-A	AL	0	999	0	9999	0.002	1	0	FALSE
Flooding-100yr	MR-U	SD	MR-U	SD	0	999	0	9999	0.01	0.99	-999	FALSE
Flooding-100yr	MR-U	SD	MR-A	AL	0	999	0	9999	0.01	0.01	0	FALSE
Floodplain-Recovery	MR-U	SD	MR-A	AL	0	999	10	9999	0.001	1	0	FALSE
Floodplain-Restoration	MR-U	SD	MR-A	AL	0	999	0	9999	0.01	0.9	0	FALSE
Floodplain-Restoration	MR-U	SD	MR-U	SD	0	999	0	9999	0.01	0.1	0	FALSE
ReplacementFire	MR-U	SD	MR-U	SD	0	999	0	9999	0.005	1	-999	FALSE
Tree-Invasion	MR-U	SD	MR-U	TE	50	999	0	9999	0.01	1	0	FALSE
AG-Herbicide	MR-U	SDA	MR-U	SD	0	999	0	9999	0.01	0.8	0	FALSE
AG-Herbicide	MR-U	SDA	MR-U	SDA	0	999	0	9999	0.01	0.2	0	FALSE
Beaver-Herbivory	MR-U	SDA	MR-A	AL	0	999	0	9999	0.002	1	0	FALSE

Flooding-100yr	MR-U	SDA	MR-U	SD	0	999	0	9999	0.01	0.89	0	FALSE
Flooding-100yr	MR-U	SDA	MR-U	AG	0	999	0	9999	0.01	0.1	0	FALSE
Flooding-100yr	MR-U	SDA	MR-A	AL	0	999	0	9999	0.01	0.01	0	FALSE
Floodplain-Restoration	MR-U	SDA	MR-A	AL	0	999	0	9999	0.01	0.9	0	FALSE
Floodplain-Restoration	MR-U	SDA	MR-U	SD	0	999	0	9999	0.01	0.1	0	FALSE
ReplacementFire	MR-U	SDA	MR-U	SDA	0	999	0	9999	0.04	0.8	-999	FALSE
ReplacementFire	MR-U	SDA	MR-U	AG	0	999	0	9999	0.04	0.1	0	FALSE
ReplacementFire	MR-U	SDA	MR-U	SD	0	999	0	9999	0.04	0.1	0	FALSE
Beaver-Herbivory	MR-U	SFE	MR-U	SFE	5	19	0	9999	0.01	1	-999	FALSE
Beaver-Herbivory	MR-U	SFE	MR-U	SFE	20	999	0	9999	0.002	1	-20	FALSE
Exotic-Invasion	MR-U	SFE	MR-U	EF	5	999	5	9999	0.01	1	-5	TRUE
Flooding-100yr	MR-U	SFE	MR-U	SFE	20	999	0	9999	0.01	1	-999	FALSE
Flooding-20yr	MR-U	SFE	MR-U	SFE	5	19	0	9999	0.05	1	-999	FALSE
ReplacementFire	MR-U	SFE	MR-U	SFE	5	999	0	9999	0.02	1	-999	FALSE
RoadLateralFlow	MR-U	SFE	MR-U	DE	5	999	20	9999	0.04	0.33	0	FALSE
RxFire+Herbicide	MR-U	SFE	MR-B	OP	5	19	0	9999	0.01	1	0	TRUE
RxFire+Herbicide	MR-U	SFE	MR-C	CL	20	999	0	9999	0.01	1	0	TRUE
WaterWithdrawal	MR-U	SFE	MR-U	DW	5	999	0	9999	0.005	0.25	0	TRUE
WaterWithdrawal	MR-U	SFE	MR-U	PD	5	999	0	9999	0.005	0.75	0	TRUE
Weed-Inventory	MR-U	SFE	MR-U	SFE	5	999	0	9999	0.25	1	0	FALSE
Beaver-Herbivory	MR-U	TE	MR-U	SD	50	999	0	9999	0.002	1	0	FALSE
Chainsaw+Seed	MR-U	TE	MR-U	DE	50	999	0	9999	0.01	0.8	0	FALSE
Chainsaw+Seed	MR-U	TE	MR-U	AG	50	999	0	9999	0.01	0.1	0	FALSE
Chainsaw+Seed	MR-U	TE	MR-U	SAP	50	999	0	9999	0.01	0.1	0	FALSE
Floodplain-Restoration	MR-U	TE	MR-A	AL	50	999	0	9999	0.01	1	0	FALSE
ReplacementFire	MR-U	TE	MR-U	AG	50	999	0	9999	0.0068	0.5	0	FALSE
ReplacementFire	MR-U	TE	MR-U	DE	50	999	0	9999	0.0068	0.5	0	FALSE
CC-Conversion	MSb-A	AL	MSu-A	AL	0	1	0	9999	0.03	1	2	TRUE
Drought	MSb-A	AL	MSb-A	AL	0	4	0	9999	0.0056	1	-999	FALSE
ReplacementFire	MSb-A	AL	MSb-A	AL	0	4	0	9999	0.0125	1	-999	FALSE
Drought	MSb-B	CL	MSb-A	AL	5	19	0	9999	0.006	0.1	0	FALSE
Drought	MSb-B	CL	MSb-B	CL	5	19	0	9999	0.0056	0.9	-999	FALSE
ReplacementFire	MSb-B	CL	MSb-A	AL	5	19	0	9999	0.02	1	0	FALSE

Drought	MSb-C	CL	MSb-B	CL	20	80	0	9999	0.006	0.1	0	FALSE
Drought	MSb-C	CL	MSb-C	CL	20	80	0	9999	0.0056	0.9	-999	FALSE
ReplacementFire	MSb-C	CL	MSb-A	AL	20	80	0	9999	0.025	1	0	FALSE
RxFire	MSb-C	CL	MSb-A	AL	20	80	0	9999	0.01	1	0	FALSE
Chainsaw-Thinning	MSb-D	OP	MSb-C	CL	80	999	0	9999	0.01	1	0	FALSE
Drought	MSb-D	OP	MSb-C	CL	80	999	0	9999	0.006	0.1	0	FALSE
Drought	MSb-D	OP	MSb-D	OP	80	999	0	9999	0.0056	0.9	-999	FALSE
ReplacementFire	MSb-D	OP	MSb-A	AL	80	999	0	9999	0.0067	1	0	FALSE
RxFire	MSb-D	OP	MSb-A	AL	80	999	0	9999	0.01	0.9	0	FALSE
RxFire	MSb-D	OP	MSb-D	OP	80	999	0	9999	0.01	0.1	0	FALSE
Tree-Encroachment	MSb-D	OP	MSb-U	TE	150	999	0	9999	0.33	1	0	TRUE
CC-Conversion	MSb-U	ES	MSu-U	ES	0	1	0	9999	0.03	1	2	TRUE
Natural-Recovery	MSb-U	ES	MSb-B	CL	5	19	0	9999	0.001	1	0	TRUE
Natural-Recovery	MSb-U	ES	MSb-C	CL	20	80	0	9999	0.001	1	0	TRUE
ReplacementFire	MSb-U	ES	MSb-U	ES	0	999	0	9999	0.02	1	-999	FALSE
Drought	MSb-U	TE	MSb-U	ES	106	999	0	9999	0.006	0.1	0	FALSE
Drought	MSb-U	TE	MSb-U	TE	106	999	0	9999	0.0056	0.9	-999	FALSE
ReplacementFire	MSb-U	TE	MSb-U	ES	106	999	0	9999	0.0067	1	0	FALSE
RxFire	MSb-U	TE	MSb-U	ES	106	999	0	9999	0.01	0.7	0	FALSE
RxFire	MSb-U	TE	MSb-U	TE	106	999	0	9999	0.01	0.3	0	FALSE
CC-Conversion	MSm-A	AL	MSu-A	AL	0	1	0	9999	0.03	1	2	TRUE
ReplacementFire	MSm-A	AL	MSm-A	AL	0	11	0	9999	0.0125	1	-999	FALSE
ReplacementFire	MSm-B	OP	MSm-A	AL	12	49	0	9999	0.025	1	0	FALSE
Tree-Invasion	MSm-B	OP	MSm-D	OP	40	49	0	9999	0.01	1	0	FALSE
AG-Invasion	MSm-C	CL	MSm-U	SAP	50	999	0	9999	0.0001	1	0	TRUE
ReplacementFire	MSm-C	CL	MSm-A	AL	50	999	0	9999	0.02	1	0	FALSE
RxFire	MSm-C	CL	MSm-A	AL	50	999	0	9999	0.01	0.7	0	FALSE
RxFire	MSm-C	CL	MSm-C	CL	50	999	0	9999	0.01	0.3	0	FALSE
Tree-Invasion	MSm-C	CL	MSm-D	OP	50	999	0	9999	0.01	1	0	FALSE
AG-Invasion	MSm-D	OP	MSm-U	SAP	40	115	0	9999	0.0001	1	0	TRUE
Chainsaw-Lopping	MSm-D	OP	MSm-C	CL	40	115	0	9999	0.01	1	0	FALSE
Drought	MSm-D	OP	MSm-C	CL	40	115	0	9999	0.0057	0.6	0	FALSE
Drought	MSm-D	OP	MSm-B	OP	40	115	0	9999	0.0057	0.3	0	FALSE

Drought	MSm-D	OP	MSm-D	OP	40	115	0	9999	0.006	0.1	-999	FALSE
ReplacementFire	MSm-D	OP	MSm-A	AL	40	115	0	9999	0.02	1	0	FALSE
RxFire	MSm-D	OP	MSm-A	AL	40	115	0	9999	0.01	0.7	0	FALSE
RxFire	MSm-D	OP	MSm-D	OP	40	115	0	9999	0.01	0.3	0	FALSE
Drought	MSm-E	CL	MSm-B	OP	115	999	0	9999	0.006	0.1	0	FALSE
Drought	MSm-E	CL	MSm-E	CL	115	999	0	9999	0.0056	0.9	5	FALSE
ReplacementFire	MSm-E	CL	MSm-A	AL	115	999	0	9999	0.013	1	0	FALSE
RxFire	MSm-E	CL	MSm-A	AL	115	999	0	9999	0.01	0.7	0	FALSE
RxFire	MSm-E	CL	MSm-E	CL	115	999	0	9999	0.01	0.3	0	FALSE
Tree-Encroachment	MSm-E	CL	MSm-U	TE	140	999	0	9999	0.1	1	0	TRUE
CC-Conversion	MSm-U	AG	MSu-U	AG	0	1	0	9999	0.03	1	2	TRUE
Herbicide+Seed	MSm-U	AG	MSm-A	AL	0	999	0	9999	0.01	1	0	FALSE
ReplacementFire	MSm-U	AG	MSm-U	AG	0	999	0	9999	0.02	1	-999	FALSE
AG-Invasion	MSm-U	DP	MSm-U	SAP	50	999	0	9999	0.0001	1	0	TRUE
Chainsaw-Lopping	MSm-U	DP	MSm-U	DP	50	999	0	9999	0.01	1	-999	FALSE
Drought	MSm-U	DP	MSm-U	ES	50	999	0	9999	0.006	0.1	0	FALSE
Drought	MSm-U	DP	MSm-U	DP	50	999	0	9999	0.0056	0.9	0	FALSE
ReplacementFire	MSm-U	DP	MSm-U	ES	50	999	0	9999	0.02	1	0	FALSE
Tree-Invasion	MSm-U	DP	MSm-U	TE	100	999	0	9999	0.01	1	0	FALSE
CC-Conversion	MSm-U	ES	MSu-U	ES	0	1	0	9999	0.03	1	2	TRUE
Natural-Recovery	MSm-U	ES	MSm-B	OP	12	49	0	9999	0.001	1	0	TRUE
Natural-Recovery	MSm-U	ES	MSm-C	CL	50	999	0	9999	0.001	1	0	TRUE
ReplacementFire	MSm-U	ES	MSm-U	ES	0	999	0	9999	0.02	0.95	-999	FALSE
ReplacementFire	MSm-U	ES	MSm-A	AL	0	999	0	9999	0.02	0.05	0	FALSE
Natural-Recovery	MSm-U	SAP	MSm-A	AL	5	11	0	9999	0.01	1	0	FALSE
Natural-Recovery	MSm-U	SAP	MSm-B	OP	12	49	0	9999	0.01	1	0	FALSE
Natural-Recovery	MSm-U	SAP	MSm-D	OP	5	999	0	9999	0.01	1	0	FALSE
ReplacementFire	MSm-U	SAP	MSm-U	AG	5	999	0	9999	0.04	0.5	0	FALSE
ReplacementFire	MSm-U	SAP	MSm-A	AL	5	999	0	9999	0.04	0.5	0	FALSE
Tree-Invasion	MSm-U	SAP	MSu-U	TEA	100	999	0	9999	0.01	1	0	FALSE
Drought	MSm-U	TE	MSm-U	ES	100	999	0	9999	0.0056	1	0	FALSE
ReplacementFire	MSm-U	TE	MSm-U	ES	100	999	0	9999	0.0084	1	0	FALSE
CC-Conversion	MSu-A	AL	WS-A	AL	0	1	0	9999	0.03	1	2	TRUE

ReplacementFire	MSu-A	AL	MSu-A	AL	0	11	0	9999	0.0125	1	-999	FALSE
ReplacementFire	MSu-B	OP	MSu-A	AL	12	49	0	9999	0.025	1	0	FALSE
Tree-Invasion	MSu-B	OP	MSu-D	OP	40	49	0	9999	0.01	1	0	FALSE
AG-Invasion	MSu-C	CL	MSu-U	SAP	50	999	0	9999	0.005	1	0	TRUE
Drought	MSu-C	CL	MSu-C	CL	50	999	0	9999	0.0056	0.9	-999	FALSE
Drought	MSu-C	CL	MSu-B	OP	50	999	0	9999	0.006	0.1	0	FALSE
ReplacementFire	MSu-C	CL	MSu-A	AL	50	999	0	9999	0.02	1	0	FALSE
RxFire	MSu-C	CL	MSu-A	AL	50	999	0	9999	0.01	0.7	0	FALSE
RxFire	MSu-C	CL	MSu-C	CL	50	999	0	9999	0.01	0.3	0	FALSE
Tree-Invasion	MSu-C	CL	MSu-D	OP	50	999	0	9999	0.01	1	0	FALSE
AG-Invasion	MSu-D	OP	MSu-U	SAP	40	114	0	9999	0.005	1	0	FALSE
Chainsaw-Lopping	MSu-D	OP	MSu-C	CL	40	114	0	9999	0.01	1	0	FALSE
Drought	MSu-D	OP	MSu-C	CL	40	114	0	9999	0.0057	0.6	0	FALSE
Drought	MSu-D	OP	MSu-B	OP	40	114	0	9999	0.0057	0.3	0	FALSE
Drought	MSu-D	OP	MSu-D	OP	40	114	0	9999	0.006	0.1	-999	FALSE
ReplacementFire	MSu-D	OP	MSu-A	AL	40	114	0	9999	0.02	1	0	FALSE
RxFire	MSu-D	OP	MSu-A	AL	40	114	0	9999	0.01	0.7	0	FALSE
RxFire	MSu-D	OP	MSu-D	OP	40	114	0	9999	0.01	0.3	0	FALSE
Chainsaw-Thinning	MSu-E	CL	MSu-A	AL	115	999	0	9999	0.01	1	0	FALSE
Drought	MSu-E	CL	MSu-B	OP	115	999	0	9999	0.006	0.1	0	FALSE
Drought	MSu-E	CL	MSu-E	CL	115	999	0	9999	0.0056	0.9	5	FALSE
Mastication	MSu-E	CL	MSu-A	AL	115	999	0	9999	0.01	1	0	FALSE
ReplacementFire	MSu-E	CL	MSu-A	AL	115	999	0	9999	0.013	1	0	FALSE
RxFire	MSu-E	CL	MSu-A	AL	115	999	0	9999	0.01	0.7	0	FALSE
RxFire	MSu-E	CL	MSu-E	CL	115	999	0	9999	0.01	0.3	0	FALSE
Tree-Encroachment	MSu-E	CL	MSu-U	TEA	140	999	0	9999	0.2	1	0	TRUE
CC-Conversion	MSu-U	AG	WS-U	AG	0	1	0	9999	0.03	1	2	TRUE
Herbicide+Seed	MSu-U	AG	MSu-A	AL	0	999	0	9999	0.01	0.8	0	FALSE
Herbicide+Seed	MSu-U	AG	MSu-U	ES	0	999	0	9999	0.01	0.2	0	FALSE
ReplacementFire	MSu-U	AG	MSu-U	AG	0	999	0	9999	0.1	1	-999	FALSE
AG-Invasion	MSu-U	DP	MSu-U	SA	50	999	0	9999	0.005	1	0	TRUE
Chainsaw-Lopping	MSu-U	DP	MSu-U	DP	50	999	0	9999	0.01	1	-999	FALSE
Drought	MSu-U	DP	MSu-U	DP	50	999	0	9999	0.0056	0.9	-1	FALSE

Drought	MSu-U	DP	MSu-U	ES	50	999	0	9999	0.006	0.1	0	FALSE
ReplacementFire	MSu-U	DP	MSu-U	ES	50	999	0	9999	0.02	1	0	FALSE
Tree-Invasion	MSu-U	DP	MSu-U	TEA	100	999	0	9999	0.01	1	0	FALSE
CC-Conversion	MSu-U	ES	WS-U	ES	0	1	0	9999	0.03	1	2	TRUE
Natural-Recovery	MSu-U	ES	MSu-B	OP	12	49	0	9999	0.0001	1	0	FALSE
Natural-Recovery	MSu-U	ES	MSu-C	CL	50	999	0	9999	0.0001	1	0	FALSE
ReplacementFire	MSu-U	ES	MSu-U	ES	0	999	0	9999	0.02	0.95	0	FALSE
ReplacementFire	MSu-U	ES	MSu-A	AL	0	999	0	9999	0.02	0.05	0	FALSE
Drought	MSu-U	SA	MSu-U	SA	50	999	0	9999	0.0056	0.9	-999	FALSE
Drought	MSu-U	SA	MSu-U	AG	50	999	0	9999	0.006	0.1	0	FALSE
Herbicide+Seed	MSu-U	SA	MSu-C	CL	50	999	0	9999	0.01	0.8	0	TRUE
Herbicide+Seed	MSu-U	SA	MSu-U	SA	50	999	0	9999	0.01	0.2	0	FALSE
ReplacementFire	MSu-U	SA	MSu-U	AG	50	999	0	9999	0.04	1	0	FALSE
Tree-Invasion	MSu-U	SA	MSu-U	TEA	50	999	0	9999	0.01	1	0	FALSE
Chainsaw-Lopping	MSu-U	SAP	MSu-U	SAP	50	999	0	9999	0.01	1	-999	FALSE
Drought	MSu-U	SAP	MSu-U	SAP	50	999	0	9999	0.0056	0.9	-999	FALSE
Drought	MSu-U	SAP	MSu-U	AG	50	999	0	9999	0.006	0.05	0	FALSE
Drought	MSu-U	SAP	MSu-A	AL	50	999	0	9999	0.006	0.05	0	FALSE
Herbicide	MSu-U	SAP	MSu-C	CL	50	999	0	9999	0.01	0.8	0	TRUE
Herbicide	MSu-U	SAP	MSu-U	SAP	50	999	0	9999	0.01	0.2	0	FALSE
Natural-Recovery	MSu-U	SAP	MSu-C	CL	50	999	0	9999	0.001	1	0	TRUE
ReplacementFire	MSu-U	SAP	MSu-U	AG	50	999	0	9999	0.04	0.5	0	FALSE
ReplacementFire	MSu-U	SAP	MSu-A	AL	50	999	0	9999	0.04	0.5	0	FALSE
RxFire	MSu-U	SAP	MSu-U	AG	50	999	0	9999	0.01	0.5	0	FALSE
RxFire	MSu-U	SAP	MSu-A	AL	50	999	0	9999	0.01	0.5	0	FALSE
Tree-Invasion	MSu-U	SAP	MSu-U	TEA	100	999	0	9999	0.01	1	0	FALSE
AG-Invasion	MSu-U	SD	MSu-U	SAP	50	999	0	9999	0.001	1	0	TRUE
CC-Conversion	MSu-U	SD	WS-U	SD	0	1	0	9999	0.03	1	2	TRUE
Natural-Recovery	MSu-U	SD	MSu-A	AL	5	11	0	9999	0.001	1	0	FALSE
Natural-Recovery	MSu-U	SD	MSu-B	OP	12	49	0	9999	0.005	1	0	FALSE
Natural-Recovery	MSu-U	SD	MSu-C	CL	50	999	0	9999	0.01	1	0	FALSE
ReplacementFire	MSu-U	SD	MSu-U	SD	0	999	0	9999	0.005	1	-999	FALSE
Drought	MSu-U	TEA	MSu-U	TEA	100	999	0	9999	0.0056	0.9	-999	FALSE

Drought	MSu-U	TEA	MSu-U	ES	100	999	0	9999	0.006	0.05	0	FALSE
Drought	MSu-U	TEA	MSu-U	AG	100	999	0	9999	0.006	0.05	0	FALSE
ReplacementFire	MSu-U	TEA	MSu-U	ES	100	999	0	9999	0.0085	0.5	0	FALSE
ReplacementFire	MSu-U	TEA	MSu-U	AG	100	999	0	9999	0.0085	0.5	0	FALSE
Thin+Herbicide+Seed	MSu-U	TEA	MSu-A	AL	100	999	0	9999	0.01	0.8	0	FALSE
Thin+Herbicide+Seed	MSu-U	TEA	MSu-U	ES	100	999	0	9999	0.01	0.1	0	FALSE
Thin+Herbicide+Seed	MSu-U	TEA	MSu-U	AG	100	999	0	9999	0.01	0.1	0	FALSE
CC-Conversion	PJ-A	AL	BS-A	AL	0	1	0	9999	0.03	0.9	2	TRUE
CC-Conversion	PJ-A	AL	WS-A	AL	0	1	0	9999	0.03	0.1	2	TRUE
ReplacementFire	PJ-A	AL	PJ-A	AL	0	9	0	9999	0.005	1	0	FALSE
ReplacementFire	PJ-B	OP	PJ-A	AL	10	29	0	9999	0.005	1	0	FALSE
AG-Invasion	PJ-C	OP	PJ-U	TA	30	99	0	9999	0.001	1	0	TRUE
Drought	PJ-C	OP	PJ-B	OP	30	99	0	9999	0.006	0.1	0	FALSE
Drought	PJ-C	OP	PJ-C	OP	30	99	0	9999	0.0056	0.9	-999	FALSE
ReplacementFire	PJ-C	OP	PJ-A	AL	30	99	0	9999	0.005	1	0	FALSE
AG-Invasion	PJ-D	OP	PJ-U	TA	100	999	0	9999	0.001	1	0	TRUE
Drought	PJ-D	OP	PJ-D	OP	100	999	0	9999	0.0168	0.9	-999	FALSE
Drought	PJ-D	OP	PJ-C	OP	100	999	0	9999	0.0171	0.07	0	FALSE
Drought	PJ-D	OP	PJ-B	OP	100	999	0	9999	0.0167	0.03	0	FALSE
ReplacementFire	PJ-D	OP	PJ-A	AL	100	999	0	9999	0.002	1	0	FALSE
SurfaceFire	PJ-D	OP	PJ-D	OP	100	999	0	9999	0.001	1	0	FALSE
CC-Conversion	PJ-U	AG	BS-U	AG	0	1	0	9999	0.03	0.9	2	TRUE
CC-Conversion	PJ-U	AG	WS-U	AG	0	1	0	9999	0.03	0.1	2	TRUE
Herbicide+Seed	PJ-U	AG	PJ-A	AL	0	3	0	9999	0.01	0.6	0	FALSE
Herbicide+Seed	PJ-U	AG	PJ-U	AG	0	3	0	9999	0.01	0.4	0	FALSE
ReplacementFire	PJ-U	AG	PJ-U	AG	0	999	0	9999	0.1	1	-999	FALSE
Drought	PJ-U	TA	PJ-U	TA	100	999	0	9999	0.0056	0.9	-999	FALSE
Drought	PJ-U	TA	PJ-U	AG	100	999	0	9999	0.006	0.1	0	FALSE
ReplacementFire	PJ-U	TA	PJ-U	AG	100	999	0	9999	0.005	1	0	FALSE
AltSuccession	PP-A	AL	PP-B	CL	0	39	38	9999	0.33	1	0	FALSE
CC-Conversion	PP-A	AL	PJ-A	AL	0	1	0	9999	0.03	0.5	2	TRUE
CC-Conversion	PP-A	AL	MM-A	AL	0	1	0	9999	0.03	0.5	2	TRUE
ReplacementFire-Forest	PP-A	AL	PP-A	AL	0	39	0	9999	0.01	1	-999	FALSE

AG-Invasion	PP-B	CL	PP-U	TA	40	159	0	9999	0.001	1	0	FALSE
Insect/Disease	PP-B	CL	PP-C	OP	40	159	0	9999	0.04	1	0	FALSE
MixedFire-Forest	PP-B	CL	PP-C	OP	40	159	0	9999	0.04	1	0	TRUE
ReplacementFire-Forest	PP-B	CL	PP-A	AL	40	159	0	9999	0.0067	1	0	FALSE
RxFire	PP-B	CL	PP-C	OP	40	159	0	9999	0.01	0.7	0	TRUE
RxFire	PP-B	CL	PP-B	CL	40	159	0	9999	0.01	0.3	0	FALSE
AG-Invasion	PP-C	OP	PP-U	TA	40	159	0	9999	0.005	1	0	TRUE
AltSuccession	PP-C	OP	PP-B	CL	40	159	80	9999	0.33	1	0	TRUE
MixedFire-Forest	PP-C	OP	PP-C	OP	40	159	0	9999	0.028	1	-10	FALSE
ReplacementFire-Forest	PP-C	OP	PP-A	AL	40	159	0	9999	0.0025	1	0	FALSE
RxFire	PP-C	OP	PP-C	OP	40	159	0	9999	0.01	1	0	TRUE
SurfaceFire-Forest	PP-C	OP	PP-C	OP	40	159	0	9999	0.04	1	0	FALSE
AG-Invasion	PP-D	OP	PP-U	TA	160	999	0	9999	0.005	1	0	FALSE
AltSuccession	PP-D	OP	PP-E	CL	160	999	100	9999	0.33	1	0	TRUE
MixedFire-Forest	PP-D	OP	PP-D	OP	160	999	0	9999	0.028	1	-10	FALSE
ReplacementFire-Forest	PP-D	OP	PP-A	AL	160	999	0	9999	0.0025	1	0	FALSE
RxFire	PP-D	OP	PP-D	OP	160	999	0	9999	0.01	1	0	TRUE
SurfaceFire-Forest	PP-D	OP	PP-D	OP	160	999	0	9999	0.05	1	0	FALSE
AG-Invasion	PP-E	CL	PP-U	TA	160	999	0	9999	0.001	1	0	FALSE
Insect/Disease	PP-E	CL	PP-D	OP	160	999	0	9999	0.02	1	0	FALSE
MixedFire-Forest	PP-E	CL	PP-D	OP	160	999	0	9999	0.05	1	0	TRUE
ReplacementFire-Forest	PP-E	CL	PP-A	AL	160	999	0	9999	0.0067	1	0	FALSE
RxFire	PP-E	CL	PP-D	OP	160	999	0	9999	0.01	0.7	0	TRUE
RxFire	PP-E	CL	PP-E	CL	160	999	0	9999	0.01	0.3	0	TRUE
CC-Conversion	PP-U	AG	PJ-U	AG	0	1	0	9999	0.03	0.5	2	TRUE
CC-Conversion	PP-U	AG	MM-B	OP	0	1	0	9999	0.03	0.5	2	TRUE
ReplacementFire	PP-U	AG	PP-U	AG	0	39	0	9999	0.1	1	-999	FALSE
Insect/Disease	PP-U	TA	PP-U	TA	40	999	0	9999	0.04	0.9	0	FALSE
Insect/Disease	PP-U	TA	PP-U	AG	40	999	0	9999	0.04	0.1	0	FALSE
MixedFire-Forest	PP-U	TA	PP-U	TA	40	999	0	9999	0.04	0.75	0	FALSE
MixedFire-Forest	PP-U	TA	PP-U	AG	40	999	0	9999	0.04	0.25	0	FALSE
Natural-Recovery	PP-U	TA	PP-B	CL	40	159	30	9999	0.01	1	0	TRUE
Natural-Recovery	PP-U	TA	PP-E	CL	160	999	30	9999	0.01	1	0	TRUE

ReplacementFire-Forest	PP-U	TA	PP-U	AG	40	999	0	9999	0.0067	1	0	FALSE
AltSuccession	RPP-A	AL	RPP-B	CL	0	19	18	9999	1	1	0	FALSE
Drought	RPP-A	AL	RPP-A	AL	0	19	0	9999	0.0056	1	-999	FALSE
Flooding-20yr	RPP-A	AL	RPP-A	AL	0	19	0	9999	0.05	1	-999	FALSE
ReplacementFire-Forest	RPP-A	AL	RPP-A	AL	0	19	0	9999	0.01	1	-999	FALSE
SurfaceFire	RPP-A	AL	RPP-B	CL	0	19	0	9999	0.001	1	0	FALSE
Drought	RPP-B	CL	RPP-C	OP	20	99	0	9999	0.0056	0.7	-999	FALSE
Drought	RPP-B	CL	RPP-A	AL	20	99	0	9999	0.0056	0.3	0	FALSE
Flooding-100yr	RPP-B	CL	RPP-A	AL	20	99	0	9999	0.01	1	0	FALSE
Insect/Disease	RPP-B	CL	RPP-C	OP	20	99	0	9999	0.04	1	0	FALSE
MixedFire-Forest	RPP-B	CL	RPP-C	OP	0	99	0	9999	0.04	1	0	FALSE
ReplacementFire-Forest	RPP-B	CL	RPP-A	AL	0	99	0	9999	0.0067	1	0	FALSE
RxFire	RPP-B	CL	RPP-B	CL	20	99	0	9999	0.01	0.3	0	FALSE
RxFire	RPP-B	CL	RPP-C	OP	20	99	0	9999	0.01	0.7	0	TRUE
AltSuccession	RPP-C	OP	RPP-B	CL	20	99	80	9999	1	1	0	TRUE
Drought	RPP-C	OP	RPP-C	OP	20	99	0	9999	0.0056	0.9	-999	FALSE
Drought	RPP-C	OP	RPP-A	AL	20	99	0	9999	0.0056	0.1	0	FALSE
Flooding-100yr	RPP-C	OP	RPP-A	AL	20	99	0	9999	0.01	1	0	FALSE
MixedFire-Forest	RPP-C	OP	RPP-C	OP	0	99	0	9999	0.025	1	-999	FALSE
ReplacementFire-Forest	RPP-C	OP	RPP-A	AL	0	99	0	9999	0.0025	1	0	FALSE
RxFire	RPP-C	OP	RPP-C	OP	20	99	0	9999	0.01	1	0	FALSE
SurfaceFire	RPP-C	OP	RPP-C	OP	0	99	0	9999	0.04	1	0	FALSE
AltSuccession	RPP-D	OP	RPP-E	CL	100	1098	50	9999	1	1	0	FALSE
Drought	RPP-D	OP	RPP-D	OP	100	1098	0	9999	0.0056	0.9	-999	FALSE
Drought	RPP-D	OP	RPP-A	AL	100	1098	0	9999	0.0056	0.1	0	FALSE
Flooding-100yr	RPP-D	OP	RPP-D	OP	100	1098	0	9999	0.01	0.9	0	FALSE
Flooding-100yr	RPP-D	OP	RPP-A	AL	100	1098	0	9999	0.01	0.1	0	FALSE
MixedFire-Forest	RPP-D	OP	RPP-D	OP	100	1098	0	9999	0.025	1	-999	FALSE
ReplacementFire-Forest	RPP-D	OP	RPP-A	AL	0	1098	0	9999	0.0025	1	0	FALSE
RxFire	RPP-D	OP	RPP-D	OP	100	1098	0	9999	0.01	1	0	FALSE
SurfaceFire	RPP-D	OP	RPP-D	OP	0	1098	0	9999	0.05	1	0	FALSE
Drought	RPP-E	CL	RPP-D	OP	100	1098	0	9999	0.0056	0.7	-999	FALSE
Drought	RPP-E	CL	RPP-A	AL	100	1098	0	9999	0.0056	0.3	0	FALSE

Flooding-100yr	RPP-E	CL	RPP-D	OP	100	1098	0	9999	0.01	0.8	-999	FALSE
Flooding-100yr	RPP-E	CL	RPP-A	AL	100	1098	0	9999	0.01	0.2	0	FALSE
MixedFire-Forest	RPP-E	CL	RPP-D	OP	100	1098	0	9999	0.05	1	0	FALSE
ReplacementFire-Forest	RPP-E	CL	RPP-A	AL	100	1098	0	9999	0.0067	1	0	FALSE
RxFire	RPP-E	CL	RPP-E	CL	100	1098	0	9999	0.01	0.3	0	FALSE
RxFire	RPP-E	CL	RPP-D	OP	100	1098	0	9999	0.01	0.7	0	FALSE
CC-Conversion	SP-A	AL	MC-A	AL	0	1	0	9999	0.03	1	2	TRUE
Competition/Maintenance	SP-A	AL	SP-A	AL	0	39	0	9999	0.002	1	-10	FALSE
ReplacementFire-Forest	SP-A	AL	SP-A	AL	0	10	0	9999	0.0133	1	-999	FALSE
ReplacementFire-Forest	SP-A	AL	SP-A	AL	11	39	0	9999	0.005	1	-999	FALSE
Competition/Maintenance	SP-B	CL	SP-B	CL	40	129	0	9999	0.001	1	-10	FALSE
Insect/Disease	SP-B	CL	SP-C	OP	40	129	0	9999	0.007	1	0	FALSE
ReplacementFire-Forest	SP-B	CL	SP-A	AL	40	69	0	9999	0.005	1	0	FALSE
ReplacementFire-Forest	SP-B	CL	SP-A	AL	70	129	0	9999	0.0025	1	0	FALSE
SurfaceFire	SP-B	CL	SP-B	CL	40	129	0	9999	0.0025	1	0	FALSE
AltSuccession	SP-C	OP	SP-B	CL	40	129	60	9999	1	0.33	0	TRUE
Insect/Disease	SP-C	OP	SP-A	AL	40	129	0	9999	0.002	1	0	FALSE
ReplacementFire-Forest	SP-C	OP	SP-A	AL	40	129	0	9999	0.008	1	0	FALSE
SurfaceFire-Forest	SP-C	OP	SP-C	OP	40	129	0	9999	0.008	1	0	FALSE
Drought	SP-D	CL	SP-D	CL	130	999	0	9999	0.0056	1	0	FALSE
Insect/Disease	SP-D	CL	SP-A	AL	130	999	0	9999	0.002	1	0	FALSE
ReplacementFire-Forest	SP-D	CL	SP-A	AL	130	999	0	9999	0.004	1	0	FALSE
SurfaceFire	SP-D	CL	SP-D	CL	130	999	0	9999	0.0014	1	0	FALSE
CC-Conversion	SR-A	AL	MR-A	AL	0	1	0	9999	0.03	1	2	TRUE
Flooding-7yr	SR-A	AL	SR-A	AL	0	2	0	9999	0.13	1	-999	FALSE
ReplacementFire	SR-A	AL	SR-A	AL	0	2	0	9999	0.02	1	-999	FALSE
Flooding-20yr	SR-B	CL	SR-A	AL	3	22	0	9999	0.05	1	0	FALSE
ReplacementFire	SR-B	CL	SR-A	AL	3	22	0	9999	0.02	1	0	FALSE
Flooding-100yr	SR-C	OP	SR-A	AL	23	999	0	9999	0.01	1	0	FALSE
MixedFire	SR-C	OP	SR-B	CL	23	999	0	9999	0.013	1	0	FALSE
ReplacementFire	SR-C	OP	SR-A	AL	23	999	0	9999	0.02	1	0	FALSE
CC-Conversion	WM-A	OP	BW-A	OP	0	1	0	9999	0.03	1	2	TRUE
Drought	WM-A	OP	WM-A	OP	0	2	0	9999	0.0056	1	-999	FALSE

Native-Grazing	WM-A	OP	WM-A	OP	0	2	0	9999	0.001	1	-999	FALSE
RoadLateralFlow	WM-A	OP	WM-U	DE	0	2	20	9999	0.04	0.01	0	FALSE
Weed-Inventory	WM-A	OP	WM-A	OP	0	2	0	9999	0.25	1	0	FALSE
Drought	WM-B	CL	WM-B	CL	3	22	0	9999	0.0056	1	2	FALSE
Exotic-Invasion	WM-B	CL	WM-U	EF	3	22	5	9999	0.01	1	0	FALSE
ReplacementFire	WM-B	CL	WM-A	OP	3	22	0	9999	0.025	1	0	FALSE
RoadLateralFlow	WM-B	CL	WM-U	DE	3	22	20	9999	0.04	0.01	0	FALSE
RxFire	WM-B	CL	WM-A	OP	3	22	0	9999	0.01	1	0	FALSE
Weed-Inventory	WM-B	CL	WM-B	CL	3	22	0	9999	0.25	1	0	FALSE
Chainsaw-Lopping	WM-C	OP	WM-B	CL	50	999	10	9999	0.01	1	-999	FALSE
Exotic-Invasion	WM-C	OP	WM-U	EF	23	999	5	9999	0.01	1	0	FALSE
ReplacementFire	WM-C	OP	WM-A	OP	23	999	0	9999	0.025	1	0	FALSE
RoadLateralFlow	WM-C	OP	WM-U	DE	23	999	20	9999	0.04	0.01	0	FALSE
RxFire	WM-C	OP	WM-A	OP	23	999	0	9999	0.01	1	0	FALSE
Weed-Inventory	WM-C	OP	WM-C	OP	23	999	0	9999	0.25	1	0	FALSE
Floodplain-Restoration	WM-U	AG	WM-A	OP	0	999	0	9999	0.01	1	0	FALSE
ReplacementFire	WM-U	AG	WM-U	AG	0	999	0	9999	0.1	1	-999	FALSE
AG-Invasion	WM-U	DE	WM-U	SA	0	999	0	9999	0.005	1	0	TRUE
Drought	WM-U	DE	WM-U	DE	0	999	0	9999	0.0056	1	-10	FALSE
Floodplain-Restoration	WM-U	DE	WM-A	OP	0	999	0	9999	0.01	1	0	FALSE
ReplacementFire	WM-U	DE	WM-U	DE	0	999	0	9999	0.025	1	-999	FALSE
Tree-Invasion	WM-U	DE	WM-U	TE	50	999	0	9999	0.01	1	0	FALSE
CC-Conversion	WM-U	EF	BW-U	EF	1	999	0	9999	0.03	1	0	FALSE
Exotic-Control	WM-U	EF	WM-A	OP	1	999	0	20	1	0.6	0	FALSE
Exotic-Control	WM-U	EF	WM-U	EF	1	999	0	20	1	0.4	0	FALSE
ReplacementFire	WM-U	EF	WM-U	EF	1	999	0	9999	0.025	1	-9999	FALSE
Drought	WM-U	SA	WM-U	SA	0	999	0	9999	0.0056	0.9	-10	FALSE
Drought	WM-U	SA	WM-U	AG	0	999	0	9999	0.0056	0.1	0	FALSE
Floodplain-Restoration	WM-U	SA	WM-A	OP	0	999	0	9999	0.01	1	0	FALSE
ReplacementFire	WM-U	SA	WM-U	AG	0	999	0	9999	0.025	1	0	FALSE
Tree-Invasion	WM-U	SA	WM-U	TE	50	999	0	9999	0.01	1	0	FALSE
Exotic-Invasion	WM-U	SFE	WM-U	EF	1	999	5	9999	0.01	1	0	FALSE
ReplacementFire	WM-U	SFE	WM-U	SFE	1	999	0	9999	0.025	1	-999	FALSE

RoadLateralFlow	WM-U	SFE	WM-U	DE	1	999	20	9999	0.04	0.01	0	TRUE
RxFire+Herbicide	WM-U	SFE	WM-A	OP	1	999	0	9999	0.01	0.8	0	FALSE
RxFire+Herbicide	WM-U	SFE	WM-U	SFE	1	999	0	9999	0.01	0.2	0	FALSE
Weed-Inventory	WM-U	SFE	WM-U	SFE	1	999	0	9999	0.25	1	0	FALSE
Drought	WM-U	TE	WM-U	TE	50	999	0	9999	0.0056	0.9	-999	FALSE
Drought	WM-U	TE	WM-U	DE	50	999	0	9999	0.0056	0.1	0	FALSE
Floodplain-Restoration	WM-U	TE	WM-A	OP	50	999	0	9999	0.01	1	0	FALSE
ReplacementFire	WM-U	TE	WM-U	DE	50	999	0	9999	0.0068	1	0	FALSE
RxFire	WM-U	TE	WM-U	DE	50	999	0	9999	0.01	0.7	0	FALSE
RxFire	WM-U	TE	WM-U	TE	50	999	0	9999	0.01	0.3	0	FALSE

Appendix 4. Management actions and cost by biophysical settings.

Ecological System	Management Action in Model	Management Action Description	From Class	To Class	Cost/ Acre	Project	Success Rate	Comment
Antelope Bitterbrush	RxFire	Prescribed fire to restore early succession class	C,D,E	A	$400	GBNP	70%	Only used in Max mgmt scenario
Antelope Bitterbrush	Chainsaw Lopping	Lop conifer trees with chainsaw in various classes to prevent conversion to tree encroached class	D,DP,SAP	Same	$200	GBNP		
Antelope Bitterbrush	Chainsaw Thinning	Hand thin conifer trees in late succession class	E	B	$600	GBNP		
Antelope Bitterbrush	Thin+Herbicide+Seed	Mechanically thin tree-encroached sagebrush and apply spot herbicide and native seed to restore early succession class	TE	A	$750	GBNP	80%	
Antelope Bitterbrush	Spot Herbicide+Seed	Spot application of Plateau followed by hand seeding among shrubs	SA,DP	A	$300	GBNP	70%	treatment unique to GBNP
Antelope Bitterbrush	Herbicide+Seed	Broadcast application of Plateau followed by seeding	AG	A	$350	GBNP	70%	
Antelope Bitterbrush	Herbicide-Plateau	Apply Plateau herbicide but not aerially to treat cheatgrass under shrubs	SAP	A	$100	GBNP	90%	
Aspen-Mixed Conifer	RxFire	Prescribed fire to restore early succession class	D,E	A	$250	GBNP		
Aspen-Mixed Conifer	Chainsaw Thinning	Hand thin conifer trees in late succession classes	C,D,E	E to C & A, D to C, C to C	$800	GBNP		Age 200-300 yr trees in Class D; 25% from Class E to class A, remainder stays in class
Aspen-Subalpine Conifer	RxFire	Prescribed fire via helicopter to restore early succession class	C,D	A	$50	GBNP		80% from class D to class A, remainder stays in class D; lower cost than aspen-mixed conifer due to helicopter and natural fire breaks above

Basin Wildrye	RxFire	Prescribed fire to restore early succession class	C	A	$400	GBNP		Higher cost than larger shrub systems due to much smaller fires; averaged cost of BWRye & Antelope bitterbrush
Basin Wildrye	Thin+Herbicide+Seed	Mechanically thin sagebrush invaded with annual grass, and apply herbicide and native seed to restore early succession class	SA	A	$600	GBNP	80%	Cost is higher than black sagebrush due to very small acres treated under contract; remainder stays in SA
Basin Wildrye	Masticate+Herb+Seed	Masticate conifers in tree encroached classes and apply herbicide and native seed to restore early succession class	TE,TA	A	$600	GBNP	80%	20% of TE to ES; 20% of TA to AG
Basin Wildrye	Thin+Seed	Mechanically thin depleted sagebrush and apply native seed to restore early succession class	DP	A	$340	GBNP	80%	20% to ES
Basin Wildrye	Weed Inventory	Periodic inventory of invasive weeds	Many	n/a	$50	GBNP		
Basin Wildrye	Exotic Control	Spot treatment of invasive weeds	EF	A	$260	GBNP	50%	Remainder stays in EF
Black sagebrush	RxFire	Prescribed fire to restore early succession class	C,D	A	$250	GBNP	70%	Remainder stays in class
Black sagebrush	Chainsaw-Chip-Herb-Seed	Chainsaw and chip conifer trees in tree-encroached classes, apply herbicide and native seed to restore early succession class	TE,TA	A	$500	GBNP	60-70%	30% TE to ES; 40% TA to AG
Black sagebrush	Thin+Herbicide+Seed	Mechanically thin sagebrush invaded with annual grass, and apply herbicide and native seed to restore early succession class	SA	A	$325	GBNP	70%	30% to AG
Black sagebrush	Chainsaw Lopping	Lop conifer trees with chainsaw to prevent conversion to tree encroached class	C	C	$200	GBNP		
Black sagebrush	Seed	Apply native seed to depleted sagebrush to restore herbaceous understory	DP	B,C	$200	GBNP	50%	Age 26-119 to class B, over 120 yrs to class C, remainder stays in class

Limber-Bristlecone Pine - mesic	RxFire	Prescribed fire via helicopter to restore early succession class	C	A	$50	GBNP	80%	Remainder stays in class; see aspen-subalpine cost comment
Low Sagebrush Steppe	RxFire	Prescribed fire to restore early succession class	C	A	$250	GBNP	60%	Remainder stays in class
Montane Riparian	Weed Inventory	Periodic inventory of invasive weeds	Many	n/a	$50	GBNP		
Montane Riparian	Exotic Control	Spot treatment of invasive weeds	EF	B	$260	GBNP	60%	Remainder stays in class
Montane Riparian	Floodplain Restoration	Restoration of entrenched stream channels	DE	A	$2,000	GBNP	90%	Need to explore less expensive alternatives
Montane Sagebrush Steppe -upland	RxFire	Prescribed fire to restore early succession class	C,D,E	A	$250	GBNP	70%	Remainder stays in class
Montane Sagebrush Steppe -upland	Herbicide	Apply herbicide (Plateau) but not aerially to treat cheatgrass under shrubs	SAP	C	$100	GBNP	80%	Remainder stays in class
Montane Sagebrush Steppe -upland	Chainsaw-Chip-Herb-Seed	Chainsaw and chip conifer trees in tree-encroached classes, apply herbicide and native seed to restore early succession class	TE,TA,E	A	$500	GBNP	80%-100%	From TE-TA 10% to ES and 10% to AG
Montane Sagebrush Steppe -upland	Chainsaw-Chip-Herb-Seed	Chainsaw and **chip or pile** conifer trees in tree-encroached classes, apply herbicide and native seed to restore early succession class	TE,TA	A	$450	GBNP	80%	10% to ES and 10% to AG; slightly lower cost for piling
Montane Sagebrush Steppe -upland	Chainsaw Lopping	Lop conifer trees with chainsaw in late succession class to prevent conversion to tree encroached class	D	C	$200	GBNP		
Wet Meadow	Weed Inventory	Periodic inventory of invasive weeds	Many	n/a	$50	GBNP		
Wet Meadow	Exotic Control	Spot treatment of invasive weeds	EF	A	$260	GBNP	60%	Remainder stays in EF

Appendix 5. Current acres by vegetation class, natural range of variability (NRV) and ecological departure (ED) calculations for biophysical settings on Great Basin National Park.

Alpine

Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	13	1,676	-	-	-	-	-	-	-	-	-	-	-	-	-	1,689
NRV	1	99	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	1	99	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																0

Antelope Bitterbrush

Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	0	2	36	56	23	-	17	-	-	121	-	-	-	59	22	336
NRV	21	44	21	7	7	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	0	1	11	17	7	0	5	0	0	36	0	0	0	17	6	100
Ecological Departure																75

Aspen Woodland

Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	39	263	82	91	-	-	92	0	-	-	-	-	-	-	-	567
NRV	16	41	33	10	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	7	46	15	16	0	0	16	0	0	0	0	0	0	0	0	100
Ecological Departure																27

Aspen-Mixed Conifer

Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	133	321	1,149	2,439	3,580	-	-	492	-	-	-	-	-	-	-	8,114
NRV	19	43	24	9	5	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	2	4	14	30	44	0	0	6	0	0	0	0	0	0	0	100
Ecological Departure																66

Aspen-Subalpine Conifer

Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	1,161	1,207	1,294	6,917	-	-	-	737	-	-	-	-	-	-	-	11,316
NRV	12	33	47	8	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	10	11	11	61	0	0	0	7	0	0	0	0	0	0	0	100

Ecological Departure																59
Basin Wildrye																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	6	30	117	0	0	0	61	-	18	0	0	-	-	35	0	268
NRV	18	63	19	0	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	2	11	44	0	0	0	23	0	7	0	0	0	0	13	0	100
Ecological Departure																68
Black Sagebrush																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	-	118	715	307	-	-	54	-	332	7	-	-	-	239	105	1,877
NRV	17	47	24	10	2	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	0	6	38	16	0	0	3	0	18	0	0	0	0	13	6	100
Ecological Departure																60
Limber-Bristlecone Pine																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	64	61	1,866	-	-	-	-	-	-	-	-	-	-	-	-	1,991
NRV	9	12	78	0	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	3	3	94	0	0	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																16
Limber-Bristlecone Pine-mesic																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	425	298	3,778	-	-	-	-	-	-	-	-	-	-	-	-	4,502
NRV	17	47	36	0	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	9	7	84	0	0	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																48
Low Sagebrush Steppe																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	0	85	337	-	-	-	-	-	-	-	-	-	-	-	-	422
NRV	25	56	19	0	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																61
Mixed Conifer																

Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	192	49	42	200	110	-	-	-	-	-	-	-	-	-	-	594
NRV	11	19	24	23	23	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	32	8	7	34	19	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																32
Montane Riparian																
Class	A	B	C	D	E	AG	DP	DE	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	25	111	298	-	-	1	-	11	-	0	1	4	-	-	-	452
NRV	21	36	43	0	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	6	25	66	0	0	0	0	2	0	0	0	1	0	0	0	100
Ecological Departure																27
Montane Sagebrush Steppe-mountain																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	9	416	470	27	1	10	-	-	10	-	-	-	-	-	-	943
NRV	21	44	22	10	3	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	1	44	50	3	0	1	0	0	1	0	0	0	0	0	0	100
Ecological Departure																30
Montane Sagebrush Steppe-upland																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	66	963	4,857	2,283	840	5	8	-	-	974	26	-	-	2,574	116	12,711
NRV	21	44	22	10	3	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	1	8	38	18	7	0	0	0	0	8	0	0	0	20	1	100
Ecological Departure																57
Montane-Subalpine Grassland																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	2	47	221	-	-	-	-	-	-	-	-	-	-	-	-	271
NRV	4	30	66	0	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	1	17	82	0	0	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																16
Mountain Mahogany																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	92	686	1,090	3,775	8,409	-	-	-	-	-	-	-	1	-	-	14,053

NRV	8	13	15	23	41	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	1	5	8	27	60	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																22
Mountain Shrub																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	0	2	16	0	0	-	-	-	-	-	-	-	-	0	-	19
NRV	7	23	41	29	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	0	12	85	1	2	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																46
Pinyon-Juniper Woodland																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	0	15	1,694	4,545	-	0	-	-	-	0	0	-	692	-	-	6,947
NRV	2	6	26	65	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	0	0	24	65	0	0	0	0	0	0	0	0	10	0	0	100
Ecological Departure																10
Ponderosa Pine																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	1	0	70	40	141	-	-	-	-	-	-	-	-	-	-	253
NRV	11	2	29	57	1	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	1	0	28	16	56	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																55
Riparian Ponderosa Pine																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	27	9	46	37	52	-	-	-	-	-	-	-	-	-	-	171
NRV	26	9	47	17	1	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	16	5	27	22	30	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																34
Spruce																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	1,377	31	123	4,237	-	-	-	-	-	-	-	-	-	-	-	5,768
NRV	18	36	2	43	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	24	1	2	73	0	0	0	0	0	0	0	0	0	0	0	100

Ecological Departure																36
Subalpine Riparian																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	1	0	0	-	-	-	-	-	-	-	-	-	-	-	-	1
NRV	13	58	29	0	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	60	29	11	0	0	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																48
Wet Meadow																
Class	A	B	C	D	E	AG	DP	NAS	SA	SAP	SD	SFE	TA	TE	TE/SA/SAP	Total
Acres in Class	0	76	11	-	-	-	-	-	-	-	-	0	-	0	-	87
NRV	5	38	58	0	0	0	0	0	0	0	0	0	0	0	0	100
Current % in Class	0	87	13	0	0	0	0	0	0	0	0	0	0	0	0	100
Ecological Departure																50

Appendix 6. Minimum Management scenario areas (acre) by vegetation class for biophysical settings on Great Basin National Park.

	Replicate				
BpS × Class	1	2	3	4	5
AB-A	56.6	5.7	0.0	46.4	38.5
AB-B	55.4	89.4	116.5	71.3	49.8
AB-C	12.4	13.6	6.8	5.7	10.2
AB-D	5.7	5.7	0.0	3.4	5.7
AB-E	3.4	7.9	5.7	4.5	10.2
AG	75.8	69.0	90.5	87.1	80.3
DP	3.4	4.5	2.3	3.4	5.7
ES	57.7	55.4	61.1	54.3	50.9
SA	0.0	2.3	0.0	0.0	1.1
SAP	13.6	13.6	0.0	1.1	11.3
TA	11.3	20.4	12.4	10.2	21.5
TE	40.7	48.6	40.7	48.6	50.9
ASC-A	758.5	713.2	713.2	1437.8	1324.6
ASC-B	2932.1	3283.1	3769.9	3090.6	2524.6
ASC-C	2400.1	2309.5	1709.5	1947.2	2332.1
ASC-D	2864.2	2626.5	2875.5	2490.6	2954.8
ASM-A	462.7	560.1	434.7	1704.6	1416.9
ASM-B	3145.8	2516.3	3490.3	2256.5	2078.0
ASM-C	284.1	402.2	316.6	491.5	422.1
ASM-D	827.9	1095.8	568.2	568.2	787.3
ASM-E	2435.1	2573.1	2215.9	2086.1	2459.5
BS-A	138.9	150.2	167.1	264.7	170.8
BS-B	199.0	187.7	208.3	172.7	187.7
BS-C	328.5	382.9	322.8	270.3	330.4
BS-D	161.4	146.4	144.5	133.3	182.1
BS-E	0.0	1.9	0.0	0.0	0.0
AG	272.2	200.8	315.3	332.2	223.4
DP	31.9	41.3	28.2	31.9	33.8
ES	142.7	125.8	195.2	214.0	150.2
SA	172.7	212.1	146.4	144.5	200.8
SAP	129.5	90.1	99.5	101.4	103.2
TA	123.9	144.5	108.9	67.6	108.9
TE	176.4	193.3	140.8	144.5	185.8
BW-A	1.3	3.8	1.3	26.3	23.6
BW-B	56.3	45.0	57.1	46.1	26.3
BW-C	23.0	28.4	18.5	17.2	26.8
AG	12.9	11.5	15.0	13.7	11.5
DP	35.4	33.8	31.4	32.4	31.1

EF	68.3	71.0	74.0	62.2	70.2
ES	16.9	10.5	17.7	20.9	17.4
SA	6.2	8.0	2.7	3.2	4.8
TA	13.1	16.6	12.1	11.5	9.9
TE	34.6	39.4	38.3	34.6	46.4
LBm-A	400.9	400.9	373.8	468.4	346.8
LBm-B	603.5	630.6	594.5	603.5	617.0
LBm-C	3495.1	3468.1	3531.1	3427.5	3535.6
LSS-A	86.0	135.0	141.0	230.0	132.0
LSS-B	169.0	103.0	159.0	86.0	120.0
LSS-C	154.0	177.0	117.0	103.0	162.0
DP	2.0	1.0	1.0	1.0	1.0
ES	1.0	0.0	1.0	0.0	1.0
TE	10.0	6.0	3.0	2.0	6.0
MR-A	15.4	9.0	11.8	85.0	71.9
MR-B	120.7	58.8	156.4	110.7	38.9
MR-C	149.6	201.6	101.2	85.4	151.9
AG	2.3	1.4	2.7	2.3	4.1
DE	6.8	6.3	17.6	6.8	19.0
DEP	0.0	0.0	0.0	0.0	
DW	0.0	0.9	0.9	0.9	0.5
EF	146.0	163.6	148.7	151.0	151.9
EFD	2.3	2.3	2.7	2.7	3.2
PD	3.6	3.6	2.7	2.7	3.6
SAP	0.5	0.5	0.9	0.5	1.8
SD	0.9	0.5	0.9	0.5	1.4
SDA	0.0	0.0	0.0	0.0	0.0
SFE	3.2	2.3	2.3	2.3	2.3
TE	0.9	1.4	3.2	1.4	1.8
MSu-A	3222.7	392.2	31.8	2883.4	2406.4
MSu-B	2766.8	4855.2	6911.7	3996.5	3010.6
MSu-C	964.7	1558.3	614.8	731.5	1187.3
MSu-D	583.0	720.9	360.4	392.2	816.3
MSu-E	180.2	296.8	148.4	180.2	243.8
AG	1643.1	1219.1	1727.9	1632.5	1547.7
DP	0.0	0.0	0.0	0.0	0.0
ES	720.9	498.2	784.5	720.9	752.7
SA	0.0	0.0	0.0	0.0	0.0
SAP	307.4	445.2	116.6	180.2	360.4
SD	0.0	0.0	0.0	0.0	
TEA	2332.2	2735.0	2024.8	2003.6	2395.8
WM-A	0.9	0.0	0.9	0.9	2.6
WM-B	27.0	25.2	38.3	47.0	28.7
WM-C	24.4	31.3	15.7	12.2	23.5

AG	0.0	0.0	0.0	0.0	
DE	0.9	0.9	2.6	1.7	
EF	33.9	29.6	29.6	25.2	32.2
SA	0.0	0.0	0.0	0.0	
SFE	0.0	0.0	0.0	0.0	0.0
TE	0.0	0.0	0.0	0.0	

Appendix 7. (A) Maximum Management scenario strategy details (acres/years of implementation) and (B) 50-year area results (acre) by vegetation class for biophysical settings on Great Basin National Park.

A. Strategies, treatment rates, and cost.

	Biophysical Setting[#]									
Strategy	AB	AMC	ASC	BS	BW	LBm	LSS	MR	MSu	WM
Chainsaw+Chip+Herbicide+Seed				140ac-3yr				1,050ac-3yr		
Chainsaw+Chip/Pile+Herbicide+Seed										
Chainsaw Lopping	16ac-5yr			10ac-3yr						
Chainsaw Thinning	8ac-5yr	400ac-10yr								
Exotic Control					2ac-50yr			8ac-50yr		4ac-3yr
Floodplain Restoration								5ac-3yr		
Herbicide	25ac-5yr								400ac-3yr	
Masticate+Herbicide+Seed					13ac-3yr					
Rx Fire	7ac-5yr	250ac-10yr	2,000ac-5yr	350ac-3yr	10ac-3yr	750ac-3yr	40ac-3yr		1,000ac-3yr	
Seed				20ac-3yr						
Spot herbicide+ Seed for SA/DP/AG	10ac-5yr									
Thin+ Seed					20ac-3yr					
Thin+Spot Herbicide+Seed	15ac-5yr			130ac-3yr	7ac-3yr					
Weed Inventory					30ac-50yr			10ac-50yr		8ac-3yr

[#]Biophysical setting legend: AB = Antelope Bitterbrush, AMC = Aspen-Mixed Conifer, ASC = Aspen-Subalpine Conifer, BS = Black Sagebrush, BW = Basin Wildrye, LBm = Limber-Bristlecone Pine-mesic, LSS = Low Sagebrush Steppe, MR = Montane Riparian, MSu = Montane Sagebrush Steppe-upland, WM = Wet Meadow.

B. 50-year area results by biophysical setting and vegetation classes.

	Replicate				
BpS × Class	1	2	3	4	5
AB-A	150	11	6	94	91
AB-B	124	264	286	190	170
AB-C	18	27	10	12	24
AB-D	8	18	6	11	18
AB-E	3	1	2	1	2
AG	6	0	8	1	6
DP	0	0	0	0	0
ES	18	12	16	25	21
SA	0	0	0	0	0
SAP	3	2	1	0	3
TA	1	0	0	1	0
TE	3	0	1	0	1
ASC-A	759	962	521	1879	1528
ASC-B	4460	3623	5117	3679	3238
ASC-C	5162	5728	4630	4766	5547
ASC-D	91	125	91	91	91
ASM-A	552	593	451	2370	2042
ASM-B	4112	3563	5373	3279	2792
ASM-C	1112	1441	609	1019	1437
ASM-D	966	1063	536	390	584
ASM-E	869	893	560	503	731
BS-A	270	298	353	556	315
BS-B	950	837	888	715	908
BS-C	139	158	107	98	90
BS-D	45	60	54	43	38
BS-E	2	9	6	2	4
AG	163	141	148	143	169
DP	11	13	9	13	21
ES	111	114	124	98	99

SA	2	0	0	2	0
SAP	137	156	148	173	141
TA	24	28	11	6	19
TE	23	62	28	30	73
BW-A	16	17	7	83	72
BW-B	185	181	199	123	123
BW-C	22	26	19	15	26
AG	3	2	3	2	3
DP	0	1	1	1	1
EF	2	2	2	1	2
ES	24	23	22	28	24
SA	1	2	1	2	2
TA	3	5	4	3	4
TE	11	11	10	10	12
LBm-A	1594	1513	1621	1793	1603
LBm-B	1045	991	1036	977	1054
LBm-C	1860	1995	1842	1730	1842
LSS-A	93	131	121	209	117
LSS-B	209	143	207	128	170
LSS-C	112	144	92	82	122
DP	0	2	0	1	4
ES	0	1	1	0	0
TE	8	1	1	2	9
MR-A	16	20	20	115	102
MR-B	189	134	253	170	105
MR-C	203	280	150	136	214
AG	0	0	1	0	0
DE	0	0	11	0	16
DEP	0	0	0	0	0
DW	9	2	1	7	3
EF	6	6	9	5	3
EFD	1	1	0	1	0
PD	24	7	3	15	5

SAP	0	0	0	0	0
SD	0	0	0	0	0
SDA	0	0	0	0	0
SFE	3	2	2	2	3
TE	0	0	1	0	0
MSu-A	4686	572	127	3869	3435
MSu-B	4495	7739	9901	6191	4866
MSu-C	1219	2099	742	837	1993
MSu-D	509	774	424	371	827
MSu-E	191	170	127	106	148
AG	731	551	795	784	710
DP	0	0	0	0	0
ES	403	244	318	307	318
SA	0	0	0	0	0
SAP	191	307	32	74	233
SD	0	0	0	0	
TEA	297	265	254	180	191
WM-A	1	3	1	0	7
WM-B	41	44	58	61	37
WM-C	42	38	27	24	41
AG	0	0	0	0	0
DE	3	2	1	1	1
EF	1	0	0	1	1
SA	0	0	0	0	0
SFE	0	0	0	0	0
TE	0	0	0	0	0

Appendix 8. Preferred Management scenario areas (acre) by vegetation class for biophysical settings on Great Basin National Park.

	Replicate				
BpS × Class	1.0	2.0	3.0	4.0	5.0
AB-A	105.2	11.3	6.8	83.7	84.8
AB-B	110.9	211.6	246.6	174.2	136.9
AB-C	18.1	33.9	9.1	14.7	28.3
AB-D	13.6	12.4	6.8	3.4	12.4
AB-E	3.4	0.0	2.3	1.1	9.1
AG	20.4	11.3	14.7	13.6	7.9
DP	2.3	2.3	0.0	0.0	0.0
ES	41.9	31.7	31.7	29.4	26.0
SA	0.0	2.3	0.0	0.0	2.3
SAP	5.7	5.7	1.1	0.0	4.5
TA	1.1	4.5	0.0	2.3	3.4
TE	13.6	9.1	17.0	13.6	20.4
ASC-A	701.9	724.5	713.2	1675.5	1630.2
ASC-B	4437.8	4052.9	5117.1	3645.4	3441.6
ASC-C	5151.1	5513.3	4347.3	4969.9	5230.3
ASC-D	158.5	101.9	158.5	90.6	169.8
ASM-A	454.6	665.6	434.7	2053.6	1684.7
ASM-B	4111.7	3603.9	4829.6	2873.4	2573.1
ASM-C	949.7	1287.0	600.7	1181.5	1241.9
ASM-D	600.7	649.4	267.9	332.8	535.7
ASM-E	1217.6	1136.4	1225.7	892.9	1290.6
BS-A	244.0	272.2	285.3	459.9	225.2
BS-B	747.0	604.4	672.0	504.9	572.5
BS-C	212.1	266.5	225.2	206.5	281.6
BS-D	110.7	116.4	105.1	73.2	105.1
BS-E	1.9	3.8	3.8	0.0	3.8
AG	167.1	161.4	191.5	187.7	176.4
DP	18.8	22.5	13.1	15.0	16.9
ES	123.9	103.2	137.0	142.7	112.6
SA	30.0	61.9	16.9	24.4	52.6
SAP	142.7	120.1	123.9	142.7	142.7
TA	48.8	33.8	35.7	30.0	71.3
TE	30.0	110.7	67.6	90.1	116.4
BW-A	17.2	22.8	12.6	79.6	68.6
BW-B	145.8	129.2	150.9	101.0	89.2
BW-C	25.7	29.5	21.2	12.1	23.9
AG	9.4	7.8	11.3	12.1	8.3
DP	16.1	17.2	14.5	14.5	14.5

EF	7.2	9.1	2.7	2.4	2.9
ES	15.5	16.9	22.2	20.1	16.3
SA	4.3	3.2	3.5	3.2	2.7
TA	10.2	11.3	7.2	5.4	11.3
TE	16.6	21.2	22.0	17.7	30.3
LBm-A	1594.4	1513.3	1621.4	1792.6	1603.4
LBm-B	1044.9	990.9	1035.9	977.4	1053.9
LBm-C	1860.2	1995.3	1842.1	1729.5	1842.1
LSS-A	93.0	131.0	121.0	209.0	117.0
LSS-B	209.0	143.0	207.0	128.0	170.0
LSS-C	112.0	144.0	92.0	82.0	122.0
DP	0.0	2.0	0.0	1.0	4.0
ES	0.0	1.0	1.0	0.0	0.0
TE	8.0	1.0	1.0	2.0	9.0
MR-A	15.4	16.3	21.2	120.2	102.2
MR-B	189.4	130.6	257.2	162.7	93.1
MR-C	195.3	277.5	130.6	133.3	204.3
AG	3.2	2.3	4.1	1.8	2.3
DE	5.0	5.9	16.3	5.4	24.4
DEP	0.0	0.0	0.0	0.0	0.0
DW	3.6	0.5	1.8	1.8	0.0
EF	17.2	12.2	9.5	13.6	13.6
EFD	3.2	0.5	0.5	0.0	0.0
PD	13.1	2.3	3.6	6.8	3.6
SAP	1.4	0.0	0.9	0.0	0.5
SD	0.9	0.9	0.0	0.9	0.0
SDA	0.0	0.0	0.0	0.0	0.5
SFE	2.3	1.4	3.2	3.6	4.1
TE	2.3	1.8	3.2	1.8	3.6
MSu-A	4600.8	922.3	498.2	3879.9	3402.9
MSu-B	3826.9	6540.7	8523.1	5374.6	4091.9
MSu-C	2109.6	3031.8	1441.7	1537.1	2618.4
MSu-D	21.2	275.6	0.0	10.6	201.4
MSu-E	31.8	63.6	42.4	0.0	42.4
AG	1155.5	901.1	1272.1	964.7	996.5
DP	0.0	0.0	0.0	0.0	0.0
ES	625.4	487.6	742.1	848.1	508.8
SA	0.0	0.0	0.0	0.0	0.0
SAP	0.0	31.8	0.0	21.2	21.2
SD	0.0	0.0	0.0	0.0	
TEA	349.8	466.4	201.4	84.8	837.5
WM-A	0.0	2.6	0.9	1.7	6.1
WM-B	27.0	44.4	57.4	63.5	47.9
WM-C	46.1	30.5	23.5	16.5	27.8

AG	0.0	0.0	0.0	0.0	0.0
DE	2.6	0.0	3.5	0.9	1.7
EF	10.4	9.6	1.7	4.4	3.5
SA	0.9	0.0	0.0	0.0	0.0
SFE	0.0	0.0	0.0	0.0	0.0
TE	0.0	0.0	0.0	0.0	0.0