Landscape conservation forecasting™ for Great Basin National Park

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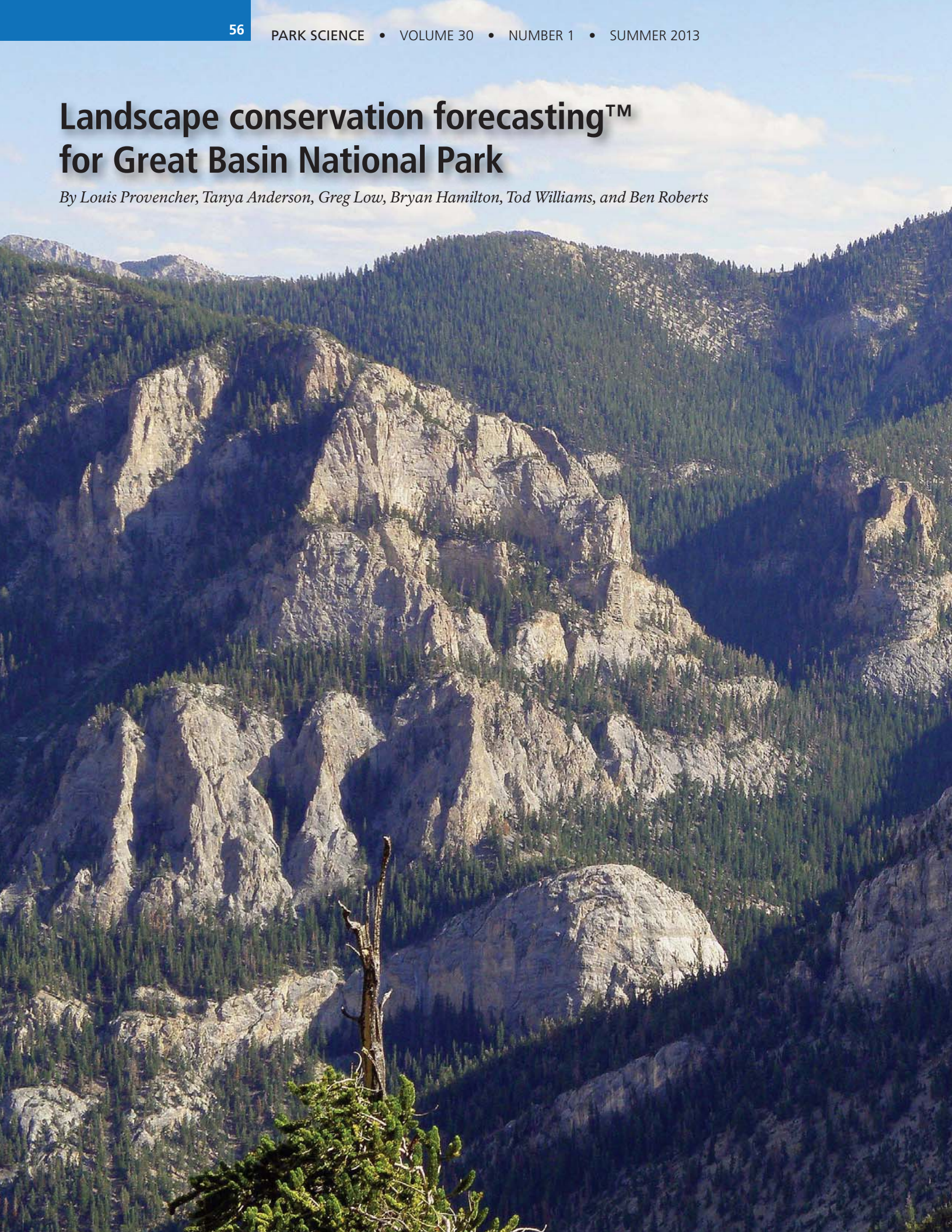

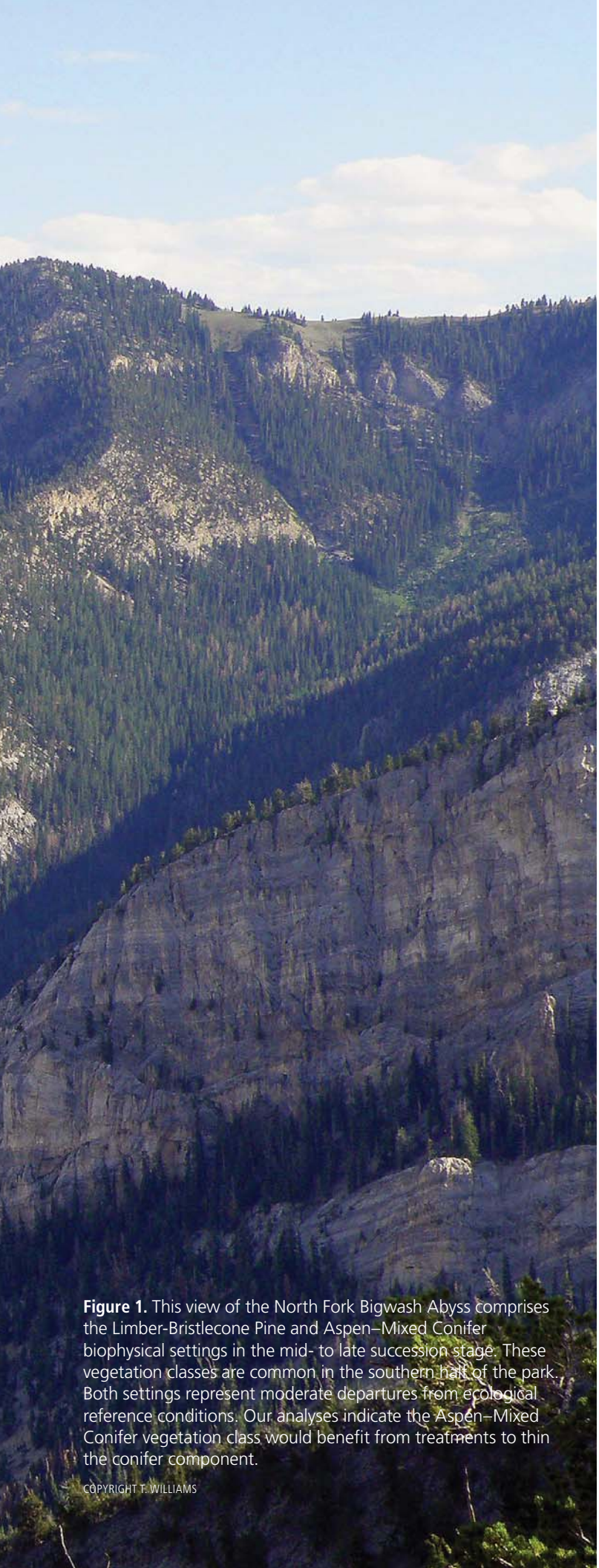

Figure 1. This view of the North Fork Bigwash Abyss comprises the Limber-Bristlecone Pine and Aspen–Mixed Conifer biophysical settings in the mid- to late succession stage. These vegetation classes are common in the southern half of the park. Both settings represent moderate departures from ecological reference conditions. Our analyses indicate the Aspen–Mixed Conifer vegetation class would benefit from treatments to thin the conifer component.

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Abstract

Great Basin National Park and The Nature Conservancy collaboratively mapped the park's biophysical settings (potential natural communities), calculated ecological departure from reference conditions (pre-European settlement), and simulated management actions to restore and prevent future degradation of natural communities. Among 21 mapped biophysical settings, 9 were slightly departed from reference conditions, 10 were moderately departed, and only 2 smaller biophysical settings were highly departed. The primary causes of ecological departure were lack of the earliest succession classes, overrepresentation by late succession classes, conifer encroachment in shrublands, and invasion of nonnative cheatgrass. Fifty-year simulations with no active management revealed that 10 of 22 biophysical settings required active management. Two active management scenarios were simulated for 50 years: maximum management causing reduction of ecological departure without fiscal budget constraints and preferred management causing reduction of ecological departure within the constraints of a realistic budget. Simulations of cost-effective management actions achieved lower ecological departure for all 10 focal biophysical settings at a total cost of approximately $3.6 million over 50 years. Many actions were implemented fully in the first years of simulation. The aspen–subalpine conifer and limber-bristlecone pine–mesic biophysical settings achieved the greatest improvement relative to dollars invested.

Key words

biophysical setting, desired future condition, ecological departure, Fire Regime Condition Class (FRCC), management scenarios, remote sensing, return on investment, state-and-transition modeling, treatment areas

THE FUNDAMENTAL PURPOSE OF THE NATIONAL Park Service is to maintain, conserve, and restore park resources and the processes that sustain them, to the greatest extent practicable, to a condition minimally influenced by human actions, and to provide for visitor enjoyment of the same. Great Basin National Park was established to preserve unimpaired a representative segment of the Great Basin (described below). The park is to be managed so as to maintain the greatest degree of biological diversity and ecosystem integrity.

A century of fire exclusion combined with livestock grazing, nonnative plant species invasion, and stream diversions has resulted in large-scale conversion of many native vegetative ecosystems across the Great Basin and in the national park (Blackburn and Tueller 1970; Pyne 2004). Although livestock grazing permits were progressively retired and most water diversions were eliminated and restored since the park's creation in 1986, nonnative annual grass invasion persists at lower elevations, whereas fire-sensitive conifers dominate in sagebrush shrublands and aspen forests as

a legacy of fire exclusion. Occurrence of the majority of wildlife classified as species of management concern relates to habitat loss and degradation by conifer encroachment historically caused by fire exclusion, altered flows from former water diversions, and livestock grazing. Maintenance, protection, and restoration of sagebrush, aspen, riparian, and ponderosa pine vegetation community types and their dependent wildlife populations are of high priority for park management (fig. 1, previous pages, and fig. 2, right).

Identification of desired future conditions, which can be difficult for parks to define, and scenario modeling to achieve them are important steps in implementing restoration actions. Desired future conditions may be based on enabling legislation but more often are derived from some conceptualization of "pre-Columbian" condition. This conceptualization is often biased and difficult to quantify at a landscape scale.

In 2005 natural resources staff mapped the Fire Regime Condition Class (FRCC) of all the park's major vegetation types using existing data, soil surveys, and GIS (geographic information system) software. Fire Regime Condition Class is a categorical measure of ecological departure from the reference condition (Hann and Bunnell 2001). Our initial work quantified desired future conditions in conjunction with fuels planning, complied with federal fire management guidelines, and produced a science-based fire management plan.

At this time, The Nature Conservancy (TNC) approached the park to collaboratively achieve the following goals: (1) map more accurately the park's vegetation based on field-interpreted high-resolution satellite imagery; (2) develop computer models of all major potential natural communities that would allow characterization of their reference conditions (i.e., the pre-European settlement condition of the landscape); (3) evaluate current and projected future departure from reference conditions, including FRCC; and (4) simulate cost-effective management scenarios that would reduce future departure from reference conditions. We highlight mapping and management results from this collaborative effort.

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Figure 2. This aspen riparian vegetation represents the Montane Riparian biophysical setting and occurs in the park's drainages with perennial streams. Typical dominant woody species are aspen, cottonwood, willows, white fir, and wood rose. Overall this system exhibits low ecological departure, but the analysis found numerous areas in the park with higher ecological departure values because of conifer encroachment.

Study methods

The national park is located within the central Great Basin physiographic region of alternating north-south–trending mountains and valleys on the southern Snake Range in eastern Nevada close to the Utah border (Wheeler Peak's 3,982 m [13,063 ft] summit: 38° 59′ 9″ N; 114° 18′ 50″ W). The park is about 31,161 ha (77,000 ac) in size, most of which is above the 30 cm (12 in) precipitation zone, with large expanses above 3,048 m (10,000 ft) in elevation. It encompasses a wide diversity of Great Basin ecological systems, ranging from desert upland shrublands to subalpine bristlecone pines to alpine terrain. Because the park is relatively far from the rain shadow of the Sierra Nevada and relatively close to humid atmospheric circulation from the Gulf of California, precipitation patterns combine with topographic relief and metamorphic and carbonate geology to produce an abundance of plant communities, wildlife, and aquatic habitat types from both the eastern and western Great Basin.

We implemented TNC's Landscape Conservation Forecasting™ methodology (fig. 3; Low et al. 2010), which combines remote sensing of potential natural communities (hereafter, biophysical setting), calculation of ecological departure (also known as Fire Regime Condition), computer simulations to forecast future condition of biophysical settings under minimum alternative management scenarios, and calculation of return-on-investment analysis to assess which strategies would most efficiently return park

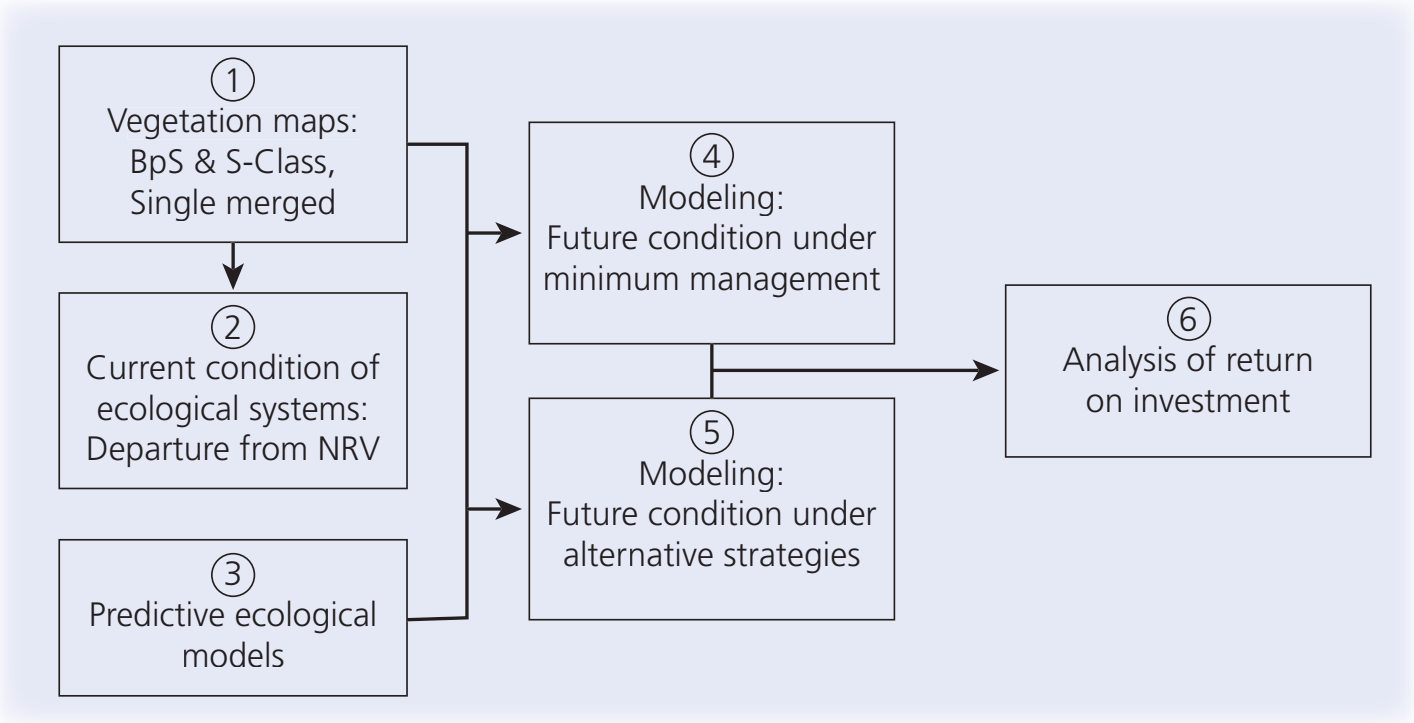

Figure 3. Diagram of the Landscape Conservation Forecasting™ method. This method was formerly called Enhanced-Conservation Action Planning in Low et al. (2010). BpS = biophysical setting, S-Class = succession class, NRV = natural range of variability.

ecosystems to reference conditions. Return-on-investment analysis was designed only to inform, but not finalize, decision making because managers might choose different priorities dictated by regulatory factors, public perception, and funding opportunities.

Remote sensing was completed using the software Imagine® from Leica Geosystems to conduct an unsupervised classification of QuickBird imagery (pixels are 2.4 m [7.9 ft] multispectral imagery) captured in 2007. The unsupervised classification of satellite imagery is described in Provencher et al. (2008) and Low et al. (2010) and is summarized here. A first unsupervised classification of the imagery was conducted to identify unique spectral classes prior to field surveys. To support interpretation of spectral classes (Lillesand and Kiefer 2000), we conducted an initial field survey to establish training plots (59) and to record rapid driving and hiking observations (around 2,000, including two photographs per observation) in July 2009. At a minimum, only the identity of the biophysical setting and vegetation class was needed at a location, although simple ground-cover and landform observations were also recorded. After the first field survey, iterative unsupervised classifications with manual editing were used to create draft maps of biophysical settings and vegetation classes, which were verified and improved during a second field trip in October 2009. Nearly every sector of the project area was visited by truck or on foot to interpret unique spectral classes. A final map of current vegetation classes was used to calculate ecological departure scores.

One state-and-transition computer model was developed for each biophysical setting using the Vegetation Dynamics Development Tool (VDDT, by ESSA Technologies, Ltd.; Beukema et al. 2003) to estimate the reference condition for ecological departure calculation and to simulate the effect of proposed management actions. 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 (Rumpff et al. 2010). Different boxes in the model belong either to different states or to different phases within a state. States are formally defined in rangeland literature (Rumpff et al. 2010) 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 are typically represented by succession classes, ranging from herbaceous vegetation to increasing woody species dominance where the dominant woody vegetation might be shrubs or trees. We included uncharacteristic vegetation classes (classes outside the reference condition) and simulated future conditions under alternative management strategies and scenarios (Low et al. 2010). State-and-transition models included each vegetation class's responses to natural and uncharacteristic disturbances, and mul-

tiple pathways and success or failure rates associated with various management actions.

Using local and regional data, temporal variability in fire activity, climate, insect and disease outbreaks, nonnative plant and native tree species invasions, and stream discharge were imported in simulations as annual time series that modified (suppressed or increased) the base parameters in each biophysical setting's model (Low et al. 2010; Provencher et al. 2010). Five replicates of each time series were imported into the VDDT database. For fire, each replicate was created by resampling 75 yearly values from a standardized time series of area burned (i.e., the annual value divided by the temporal average) obtained from 1980 to 2008 for the park and from four adjacent mountain landscapes of the same size as the park. The historical time series of the Palmer Drought Severity Index was similarly resampled five times to generate five replicates representing the variability for mortality caused by drought and insect outbreaks and for nonnative annual grass and native tree invasion. Historical discharge data from Lamoille Canyon in the Ruby Mountains were used to generate temporal variability for 7-, 20-, and 100-year flood events. Often, the introduced variability was high, especially for fire activity.

Two landscape-scale metrics were used to summarize the ecological condition of each biophysical setting: ecological departure and high-risk vegetation classes. Ecological departure incorporates species composition, vegetation structure, and disturbance regimes to estimate a biophysical setting's departure from its natural range of variability (also known as reference condition and Historic Range of Variation) over the whole landscape. The natural range of variability is the relative amount (%) of each vegetation class in a landscape expected to occur in a biophysical setting under natural disturbance regimes and actual climate. The natural range of variability is determined by simulating a natural disturbance regime for each biophysical setting until the proportion of each reference vegetation class reaches equilibrium, or 1,000 years if equilibrium is not reached (Hann and Bunnell 2001; Provencher et al. 2008). In this project, ecological departure was based only on vegetation responses to reference and current disturbance regimes and not on departure from historical fire regimes. The park also has a paucity of data on historical fire regimes.[1] Ecological departure is scored on a scale of 0–100%, where 0% represents the natural range of variability and 100% represents total departure. Further, Fire Regime Condition Class is used by federal agencies to group ecological departure scores into three classes: FRCC 1 represents biophysical settings with low (<34%) departure; FRCC 2 indicates moderate (34–66%) departure; and FRCC 3 indicates high (>66%) departure (Hann and Bunnell 2001).

Table 1. Descriptions of management scenarios for Great Basin National Park

Management Scenarios
Minimum Management
A control scenario that included only natural disturbances, unmanaged nonnative 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 Web site. 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 or to 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 stakeholders. 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 that produced the highest return on investment were sought.

Ecological departure assumes that all uncharacteristic classes are equal to managers. We developed a separate designation and calculation of high-risk vegetation classes because it is possible to reduce ecological departure while increasing the percentage of undesirable classes (for example, nonnative annual grassland). A high-risk class was defined as an uncharacteristic vegetation class that met at least two of the following three criteria: (1) ≥5% cover of invasive nonnative species, (2) expensive to restore, and (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 loss of aspen clones to other biophysical settings, such as mixed conifer and montane sagebrush steppe, which is vegetation conversion (Debyle et al. 1987; Mueggler 1988; Kay 1997, 2001; Bartos and Campbell 1998).

Using computer-based models, the likely future condition of the focal biophysical setting was assessed after 50 years under three primary scenarios to achieve these objectives: Minimum Management, Maximum Management, and Preferred Management (table 1). We used an ecological return-on-investment metric to determine which of the scenarios (Maximum or Preferred) produced the greatest ecological benefits per dollar invested across

[1]Technically, ecological departure is a measure of dissimilarity between the natural range of variability and the current vegetation class distribution obtained from remote sensing (Provencher et al. 2008).

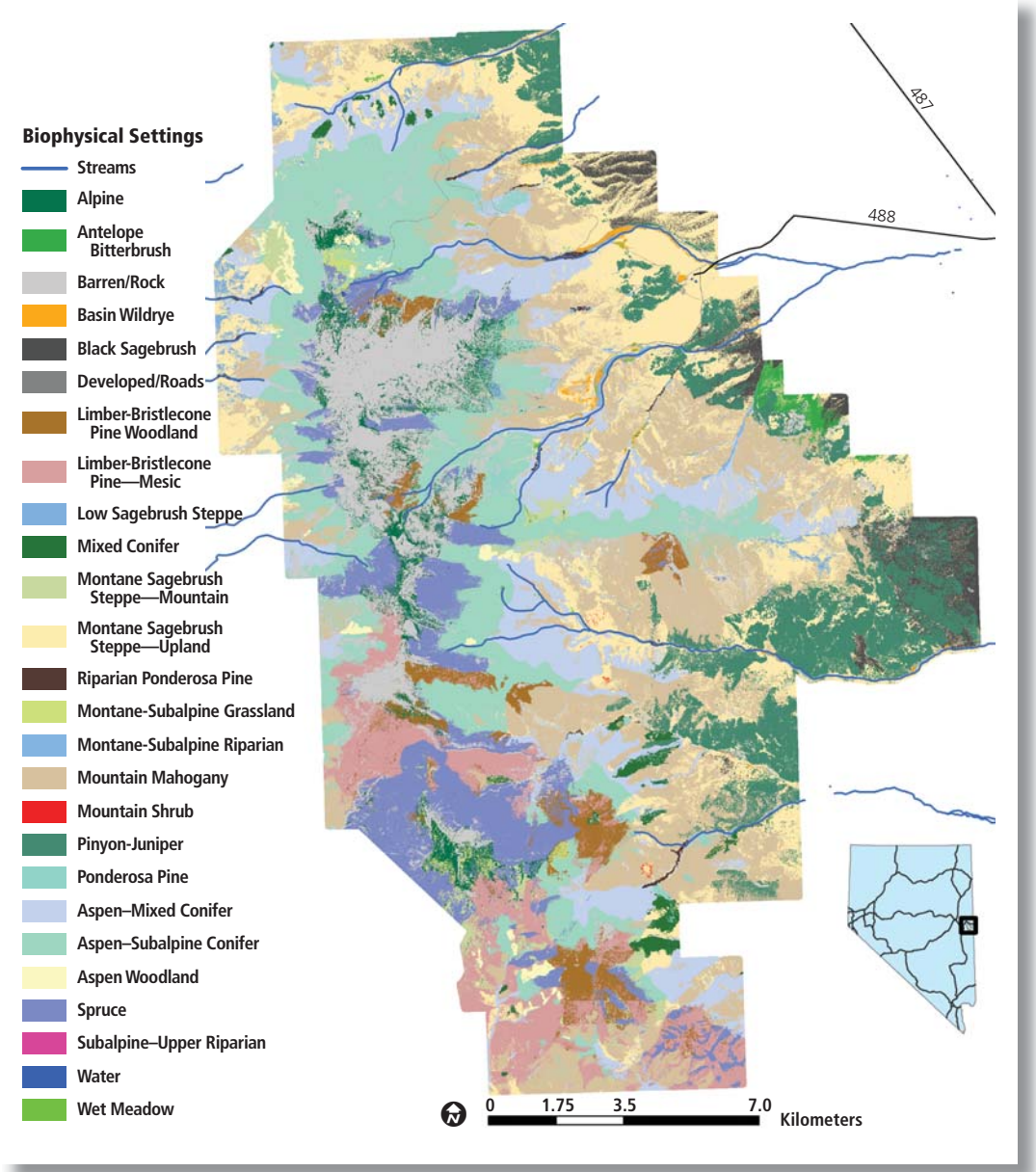

Figure 4. Map of Great Basin National Park's potential natural communities, also called biophysical settings.

SOURCE: THE NATURE CONSERVANCY

multiple scenarios within each biophysical setting, and across targeted biophysical settings in relation to Minimum Management. We first created this metric for a western Nevada project with the Bureau of Land Management (Low et al. 2010) and have since used it in about 10 landscapes in the western United States and once for eastern Tennessee's Cherokee National Forest. The ecological systemwide return-on-investment metric is the sum of change in 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; Low et al. 2010). Inflation was not included in the calculation of cost; however, this would probably not have affected the relative comparison of return-on-investment values among scenarios, as inflation would have applied equally to all management activities.

Findings

We mapped 21 biophysical settings (fig. 4). The natural range of variability of each biophysical setting is presented in table 2 (next page) based on simulations of presettlement conditions. The number of reference vegetation classes varies with the complexity of the biophysical setting.

Nine biophysical settings were slightly departed from the natural range of variability, 10 were moderately departed, and only 2 smaller biophysical settings were highly departed (table 3, next page). The primary cause of ecological departure was sagebrush biophysical settings that lacked the earliest succession classes and aspen-conifer biophysical settings that were overrepresented by late succession classes. Two small biophysical settings (antelope bitterbrush and basin wildrye) were highly departed primarily because of the presence of conifer encroachment and nonnative cheatgrass.

Twelve biophysical settings were not targeted for active management in the park because they were projected to benefit from periodic wildfires embedded in the computer simulations

Table 2. Natural range of variability (NRV) for biophysical settings of Great Basin National Park

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

Note: By definition, the "Uncharacteristic" classes are equal to zero (not shown).

[1]Standard LANDFIRE coding for the five-box vegetation model: A = early-development; B = mid-development, closed; C = mid-development, open; D = late-development, open; and E = late-development, closed. This terminology was often modified.

Table 3. Ecological departure and percentage of high-risk classes of Great Basin National Park's biophysical settings

Biophysical Setting	Area ac	Area ha	Ecological Departure (%)	High-Risk Classes (%)
Alpine-Subalpine				
Alpine	1,690	684	0.1	0
Aspen–Subalpine Conifer	11,320	4,581	60	7
Limber-Bristlecone Pine Woodland	1,991	482	16	0
Limber-Bristlecone Pine Woodland—mesic	4,500	1,821	48	0
Montane-Subalpine Grassland	269	109	16	0
Spruce	5,770	2,335	36	0
Mid-Elevation Forests				
Aspen Woodland	571	231	27	16
Aspen–Mixed Conifer	8,110	3,282	66	6
Mixed Conifer	591	239	32	0
Ponderosa Pine	250	101	54	0
Shrublands				
Antelope Bitterbrush	341	138	74	28
Basin Wildrye	269	109	68	43
Black Sagebrush	1,880	761	60	39
Low Sagebrush Steppe	420	170	61	0
Montane Sagebrush Steppe—mountain	939	380	30	2
Montane Sagebrush Steppe—upland	12,711	5,144	56	21
Mountain Mahogany	14,050	5,686	23	0
Pinyon-Juniper	6,951	2,813	11	10
Riparian and Wet Meadows				
Montane Riparian	450	182	26	3
Riparian Ponderosa Pine	171	69	34	0
Wet Meadow	89	36	49	0

Note: Ecological departure scores were classified as good (0–33%, Class 1, green), fair (34–66%, Class 2, orange), and poor (>66%, Class 3, red). Levels of high-risk classes by ecological systems were ranked as low (0%, dark green), medium (1–10%, light green), high (11–30%, orange), and very high (>30%, red).

(table 4, page 63). These natural communities included curl-leaf mountain mahogany, pinyon-juniper woodland, spruce, limber-bristlecone pine, montane sagebrush steppe–subalpine sites, mixed conifer, aspen woodland, montane-subalpine grassland, ponderosa pine, riparian ponderosa pine, mountain shrub, and subalpine riparian. The subalpine riparian biophysical setting was very small and further subsumed within the montane riparian biophysical setting.

Ten biophysical settings with high departure from reference conditions were chosen for 50-year simulations of specific management actions within budgetary constraints (table 4). Key ecological issues included the following:

- Sagebrush biophysical settings (montane sagebrush–upland sites, black sagebrush, low sagebrush steppe, antelope bitterbrush, basin wildrye): lack of early succession classes, pinyon-juniper encroachment, and prediction of increased cheatgrass cover.
- Aspen-conifer biophysical settings (aspen–subalpine conifer and aspen–mixed conifer): high percentage of conversion to conifers and permanent loss of aspen clones.
- Riparian, wet meadow, and basin wildrye systems: invasion by exotic forbs.

Table 4. Current and predicted future (under minimum management) ecological departure and high-risk vegetation classes of ecological systems of Great Basin National Park

Biophysical Setting	Ecological Departure		High-Risk Classes	
	Current Condition	Minimum Management (50 years)	Current Condition	Minimum Management (50 years)
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

Note: Systems in boldface type were selected for active management analyses. Ecological departure scores were classified as good (0–33%, Class 1, green), fair (34–66%, Class 2, yellow), and poor (>66%, Class 3, red). Levels of high-risk classes to ecological systems were ranked as low (0%, dark green), medium (1–10%, light green), high (11–30%, yellow), and very high (>30%, red).

- Mesic[2] limber-bristlecone pine: high percentage of late succession classes at the expense of mostly mid-succession forests.

A variety of strategies were modeled. Multiple strategies were required for most biophysical settings, except aspen systems, in the Preferred Management scenario (table 5, page 64):

- Sagebrush management strategies included prescribed fire to restore early succession classes; chainsaw lopping of encroached conifer trees; chainsaw thinning of late succession classes of tree-encroached sagebrush, variously combined with chipping, mastication, pile burning, herbicide, and seeding of native species; and varied applications of herbicide and native seeding to uncharacteristic vegetation classes.

- Aspen-conifer management strategies included prescribed fire to prevent transition to conifers and loss of aspen clones (for example, fig. 5, page 66).

- The mesic limber-bristlecone pine forest management strategy included prescribed fire to reduce the area of late succession classes and increase that of early and mid-succession classes (fig. 5).

[2]Unlike ancient (>2,000 years old) limber and bristlecone pines growing on bedrock and skeletal soils, mesic forests show soil depth, soil moisture, and closed canopies, and generally do not exceed 1,000 years of age mainly because of death caused by heart rot.

Table 5. Treatment details (area and duration) for the preferred management scenario strategy for managed biophysical settings in Great Basin National Park

Treatment	Biophysical Setting*									
	AB	AMC	ASC	BS	BW	LBm	LSS	MR	MSu	WM
Chainsaw lopping	3.2 ha (7.9 ac) 5 yr			4.0 ha (9.9 ac) 3 yr					20.2 ha (49.9 ac) 50 yr	
Chainsaw thinning	1.6 ha (4 ac) 5 yr									
Exotic control					1.2 ha (3.0 ac) 50 yr			2.4 ha (5.9 ac) 50 yr		0.4 ha (1.0 ac) 50 yr
Herbicide	4.9 ha (12.1 ac) 5 yr								20.2 ha (49.9 ac) 50 yr	
Masticate + herbicide + seed				40.5 ha (100.1 ac) 3 yr	3.2 ha (7.9 ac) 3 yr					
Prescribed fire	1.6 ha (4 ac) 5 yr	131.5 ha (324.9 ac) 10 yr	1,194 ha (2,950 ac) 3 yr	70.8 ha (175.0 ac) 3 yr	1.2 ha (3.0 ac) 3 yr	224.6 ha (555.0 ac) 3 yr	16.2 ha (40.0 ac) 3 yr			
"Free" prescribed fire[1]			368.3 ha (910.1 ac) 3 yr			78.9 ha (195.0 ac) 3 yr				
Seed				4.0 ha (9.9 ac) 3 yr						
Spot herbicide + seed for SA/DP/AG	2.0 ha (4.9 ac) 5 yr									
Thin + seed					4.5 ha (11.1 ac) 3 yr					
Thin + spot herbicide + seed	3.2 ha (7.9 ac) 5 yr			40.5 ha (100.1 ac) 3 yr	0.8 ha (2.0 ac) 3 yr				20.2 ha (49.9 ac) 50 yr	
Weed Inventory					4.0 ha (10 ac) 50 yr			3.2 ha (8 ac) 50yr		1.62 ha (4 ac) 50 yr

**Biophysical settings:* 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.

[1]"Free" prescribed fire is prescribed fire that is allowed to spread at little cost to biophysical settings situated below alpine vegetation and rock, but above aspen–mixed conifer vegetation where ignitions are conducted.

- Riparian and wet meadow management strategies included cyclic weed inventory and spot application of herbicides.

Computer simulations of cost-effective management actions achieved lower ecological departure for all 10 focal natural communities. The total cost of implementation across all communities was around $3.6 million over 50 years (table 6, page 65). Many actions, however, were implemented fully in the first years of simulation (table 5).

The return on investment for aspen–subalpine conifer and mesic limber-bristlecone pine biophysical settings was significantly higher than that of other biophysical settings because the 95% confidence intervals between the two groups of biophysical settings did not overlap (table 6). Both biophysical settings rapidly responded to burning and recruitment into underrepresented early succession classes at very low costs that were uniquely caused by letting fire applied at full cost to lower-elevation aspen–mixed conifer to climb uphill until reaching barren cover and alpine terrain at nearly no extra cost to the park. Other biophysical settings did not benefit from such low implementation costs and the security of natural fire breaks.

Discussion

Landscape Conservation Forecasting™ is a useful science-based process for determining desired future conditions of plant com-

Table 6. Summary of ecological forecasts for management scenarios in 10 biophysical settings of Great Basin National Park

Biophysical setting	Ecological Departure (%)			High-Risk Classes			Area		Preferred Management average annual cost of implementation	Return on Investment (± 95% confidence interval)	Preferred Management average total cost (50 years)
	Current Condition	Minimum Management (50 years)	Preferred Management (50 years)	Current Condition	Minimum Management (50 years)	Preferred Management (50 years)	ac	ha			
Alpine-Subalpine											
Aspen–Subalpine Conifer	60	27	11	7	20	10	11,320	4,581	$108,918	92 ± 10	$326,755
Limber-Bristlecone Pine—mesic	48	42	24	—	—	—	4,500	1,821	$29,284	89 ± 11	$87,854
Mid-Elevation Forests											
Aspen–Mixed Conifer	66	33	22	6	12	8	8,110	3,282	$82,834	15 ± 9	$828,340
Shrublands											
Antelope Bitterbrush	74	62	35	28	44	10	341	138	$20,866	20 ± 6	$104,330
Basin Wildrye	68	70	35	43	64	24	269	109	$12,371 first 3 yr $1,192 last 47 yr	22 ± 3	$93,159
Black Sagebrush	60	55	34	39	40	19	1,880	761	$113,877	23 ± 3	$341,633
Low Sagebrush Steppe	61	27	16	0	1	1	420	170	$10,616	14 ± 2	$31,850
Montane Sagebrush Steppe—upland	56	41	29	21	30	11	12,711	5,144	$33,422	24 ± 3	$1,671,115
Riparian and Wet Meadows											
Montane Riparian	26	40	20	3	36	5	450	182	$1,806	25 ± 3	$90,301
Wet Meadow	49	40	28	0	36	9	89	36	$399	18 ± 4	$19,930
Total											**$3,595,268**

Note: Ecological departure scores were classified as good (0–33%, Class 1, green), fair (34–66%, Class 2, yellow), and poor (>66%, Class 3, red). Levels of high-risk classes to ecological systems were ranked as low (0%, dark green), medium (1–10%, light green), high (11–30%, yellow), and very high (>30%, red).

munities and their current ecological departure. The method's scenario simulations quantify the effects of current and future planning decisions into the future at landscape scale, assess the environmental costs and benefits of proposed resource restoration projects, and calculate the probability of success prior to initiation of any action. The inclusion of numerous management tools in the models allows assessment of many options and timelines for restoring plant communities to their desired future conditions. The results of this Landscape Conservation Forecasting™ effort will form the basis for the park's landscape-scale vegetation management plan and future funding proposals.

We generated detailed management prescriptions (table 5) and recommended treatment area maps for each focal biophysical setting of the park (fig. 5). Recommendations are ambitious and require more than $3 million to achieve predicted results over a 50-year period (table 6). It was determined that the park should focus first on prescribed burning of the aspen–subalpine conifer and limber-bristlecone pine mesic biophysical settings based on return-on-investment analysis alone (table 6; fig. 5). However, this represents a total cost of about $400,000 and requires time for planning. Immediate need for action to prevent loss of critical wildlife habitat in antelope bitterbrush and basin wildrye areas will allow park staff to make progress concomitantly in those biophysical settings while securing funding for aggressive restoration of the park's high elevations.

The park's fire management plan had always allowed the full range of management responses, including wildland fire use, prior to this project. Unfortunately, many areas had previously been considered FRCC 3, which required suppression. Similarly, the park had undertaken previous restoration projects based on professional knowledge on a case-by-case basis. This project provided valuable science-based and ground-verified data that enabled the park to update the FRCC map, allowing greater areas of wildland fire use as well as a better understanding of the consequences of and responses to wildland fire. Within months of updating the FRCC map, a naturally ignited fire was allowed to burn on the summit of Granite Peak until weather conditions put it out. This project also allows the park to develop a comprehensive vegetation management plan that identifies and prioritizes key management areas.

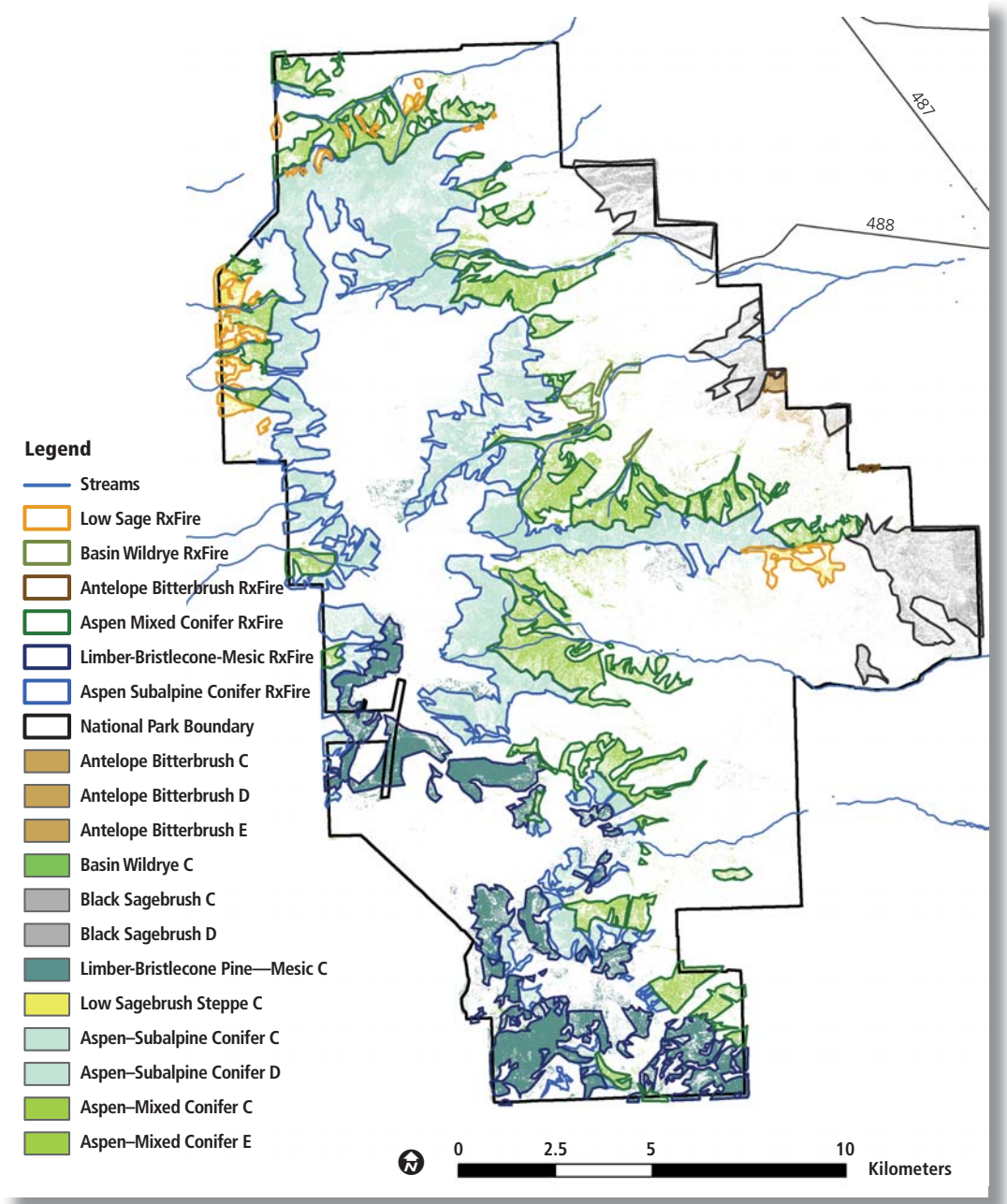

Figure 5. Map of recommended prescribed fire areas for different ecological systems. Not all areas need to be burned to reach low ecological departure from the natural range of variability.

puter models using the latest state-and-transition software platform, (3) collaboratively develop and run management scenarios with local stakeholders, and (4) produce and statistically analyze ecological departure and return-on-investment results that are understandable to managers (e.g., Provencher et al. 2010). Based on experience in the dry intermountain West, areas greater than about 20,234 ha (50,000 ac) are recommended for application of the method to ensure that ecological disturbances can create the different reference vegetation classes used to estimate ecological departure—as a rule of thumb, longer fire return intervals require larger project areas. The Nature Conservancy collaboratively implemented this method in 15 other landscapes with the Bureau of Land Management, U.S. Forest Service, and private industry.

Landscape Conservation Forecasting™ has also been implemented with climate change effects on model disturbance rates with the Bureau of Land Management in western Nevada, for the revision of Nevada's State Wildlife Action Plan, and currently as a supplemental project with Great Basin National Park.

Management implications

Application of Landscape Conservation Forecasting™ to assist natural resources management in other national parks is straightforward, although not easy, as it requires natural resource experts and contractors who can (1) conduct comprehensive high-resolution (≤5 m [16 ft] recommended) remote sensing of biophysical settings and vegetation classes (reference and all uncharacteristic classes), (2) build and run local state-and-transition com-

Climate change effects as predicted by global circulation models are incorporated through temporal time series acting as forcing factors; however, we are innovating in this field of state-and-transition modeling because (1) the climate change literature on ecological system range shifts for the intermountain West is very young and one field study does not support the predicted speed of modeled range shifts (Kelly and Goulden 2008; Rehfeldt et al. 2006); (2) field studies are mostly lacking; and (3) the literature offers no quantitative guidance on how predicted temperature,

precipitation, and greenhouse gas concentration changes will affect local ecological processes. Therefore, updated state-and-transition models incorporating local climate change effects require formulating hypotheses that local land managers accept as highly probable but not definitive.

Acknowledgments

This project was funded by the National Park Service through the Southern Nevada Public Land Management Act. Funding provided by the LongNow Foundation to TNC allowed for mapping of the Keyhole property. We thank Superintendent Andrew J. Ferguson for his support. We are grateful to the following individuals: Gretchen Baker, Beth Cristobal, and Meg Horner (Great Basin National Park); Tod Johnson and Jeanne Taylor (National Park Service); Zachary Peterson (Bureau of Land Management); and Julie Thompson (Eastern Nevada Landscape Coalition). Jeff Campbell from Spatial Solutions, Inc., conducted remote sensing with field interpretation by TNC staff. We thank Henri Bastian (Department of the Interior) for his review.

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