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Enhanced conservation action planning: Assessing landscape condition and predicting benefits of conservation strategies

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ABSTRACT: We used remote sensing, predictive ecological models, and cost-benefit assessments to develop a landscape-scale conservation action plan. The methods provided quantitative measurements of current and predicted future ecological conditions and evaluated the benefits and costs of alternative management strategies. The approach built upon The Nature Conservancy's conservation action planning (CAP) methodology and tools developed by the national interagency LANDFIRE program. Our approach, which we call "Enhanced CAP," was designed to inform proposed management actions for the Bureau of Land Management and private land managers for a 76,464 ha (188,946 acre) project area in California's Bodie Hills and northern Mono Lake Basin. Five of the area's 15 ecological systems were found to be highly departed from their reference conditions. Using computer-based modeling and collaborative stakeholder participation, varied management scenarios were simulated for 20 years and 50 years. A combination of ecologically-based and wildfire protection management was found to meet the conservation objectives for the least cost for seven of the eight systems selected for management attention. The key to enhanced planning was our ability to use remote sensing to calculate current landscape ecological condition and use computer models to isolate management strategies with the greatest ecological payoff for the least cost.

Keywords: conservation planning, cost-benefit, ecological condition, LANDFIRE, predictive ecological models, strategies, threats

INTRODUCTION

"If you had a dollar to spend on restoring and conserving a landscape, where would you spend it first?" This question is either implicitly or explicitly being asked, with great frequency, by public and private land managers, especially across the vast public lands of the western United States. Federal agencies of the U.S. Department of Interior, Department of Agriculture, and Department of Defense must develop natural resource management plans for their respective parks, refuges, field offices, districts, forests, and installations (Council on Environmental Quality Regulations 2005). The question arises again with every management plan update and revision, and yet again with the development or revision of every land management budget. Moreover, the development of every Environmental Impact Statement or Environmental Assessment for a resource management activity requires an evaluation of alternative management actions (National Environmental Policy Act 1969). Given the limited and even shrinking budgets for natural resource management and legal requirements, the question becomes even more acute.

To help address this question, a variety of site-based conservation planning approaches and methodologies have been developed and applied over the years by public agencies and non-profit conservation organizations (Poiani et al. 1998). They range from high level planning assessments to detailed action plans. While the existing approaches have many elements in common, they invariably have idiosyncratic and sometimes substantive differences in methodologies. Each federal land management agency has its own planning approach and methods. For example, the Bureau of Land Management (BLM) uses its four-phased Rangeland Health Standards Handbook H-4180-1 (BLM 2001) for watershed assessments (Table 1). The U.S. Forest Service (USFS) watershed assessment is a six-step process (Table 1; Jensen and Bourgeron 2001). The National Park Service prepares Resource Management Plans at park units, but

TABLE 1 Conservation planning methodologies and the major steps employed by the Bureau of Land Management (BLM), U.S. Forest Service (USFS) and The Nature Conservancy (TNC).

Planning Element	Rangeland Health Standards Handbook 4180-1 (BLM)	Six-Step Watershed Assessment Process (USFS)	Conservation Action Planning (TNC)
Landscape Definition		Characterization of watershed	Define project scope
			Identify focal conservation targets
Assessment of Current Condition	Assessment: Gather, synthesize, and interpret existing inventory information on indicators to ascertain their status; Evaluation: Evaluate status of indicators in relation to standards	Description of current conditions; Description of reference conditions	Assess each target's viability (via key ecological attributes)
Assessment of Causes/Issues/ Threats	Determination: Identify causal factors if rangeland health standards not met	Identification of issues and key questions	Determine critical future threats
			Situation analysis
Strategy Development & Implementation	Implementation: Design appropriate actions to address causal factors causing standards not to be met	Synthesis and interpretation of information; Recommendations	Develop and prioritize strategies to abate critical threats and restore the viability of the targets
			Implement strategies
Measures			Measure strategy effectiveness and viability status

the existing planning process at most national parks is not rigorously structured (Schmoldt and Peterson 2001). Non-governmental conservation organizations, such as The Nature Conservancy (TNC), have also developed methodologies, and even software, to support conservation planning (Table 1; TNC 2003, 2007). The different planning approaches can often be reconciled. The BLM, USFS, and TNC landscape planning approaches are quite similar in their goals and outcomes with the main differences being in terminology. TNC and other non-governmental organizations have developed a set of common standards to increase transparency - *Open Standards for the Practice of Conservation* (Conservation Measures Partnership 2004) — for designing, implementing, and monitoring their conservation projects.

TNC has a 30-year history of site-based conservation planning that started in the late 1970s with planning conducted on flip charts. TNC and its partners are now using version 6 of a comprehensive software program, the *Conservation Action Planning Workbook.* TNC has adopted "Conservation Action Planning" (CAP; TNC 2003, 2007) as its nomenclature for site-based planning, made extensive information available on a CAP website, built a network of 172 trained CAP "coaches" in 26 countries and 12 organizations to assist project teams with conservation planning, and has completed over 900 CAPs.

CAP, watershed assessments, and other site-based planning approaches can all lead to a conservation plan with measurable objectives to abate critical threats and restore the condition of targeted ecological systems and species at a site or landscape. Detailed action steps, budgets, scorecards and monitoring plans can be developed and captured in planning software. These site-based conservation planning approaches and tools almost certainly add value to land managers; The Nature Conservancy and its partners have developed over 1000 conservation action plans (The Nature Conservancy 2009). They require a logical thought process while documenting assumptions and decisions. While these and other planning methodologies provide a valuable, transparent and iterative approach, they also have some significant shortcomings, especially at the landscape-scale:

⇒ <u>Conservation action planning methodologies lack a rigorous, consistent, empirical assessment of current ecological conditions at a landscape scale.</u> For example, CAP established a set of measures for the integrity of ecological systems based upon key ecological attributes and indicators (Parrish et al. 2003; Low 2003). These key ecological attributes measure specific elements of size, condition, and landscape processes for a targeted ecological system or species; measures can be adjusted with new information. However, their selection, indicator rating scales, and ratings of current condition typically are based upon local expert opinion, and they typically are not uniformly applied for ecological systems across multiple sites. BLM's rangeland health attributes and indicators similarly require a qualitative, expert assessment, although years of forage productivity assessments have been collected by BLM to inform their process. GIS-based landscape suitability assessments are sometimes performed to quantify the human footprint, using datasets on roads, development, mines, and dams, for example, (Nachlinger et al. 2001), but these assessments rarely reflect the key ecological attributes related to a given ecological system's integrity or its on-the-ground condition. Only recently have conservation planners had access to interpreted satellite imagery that could be used to describe the condition of ecological systems or attributes of species over whole landscapes, even in remote areas (e.g., LANDFIRE data layers, Rollins 2009). Moreover, there has not been a unified metric of landscape condition with practical properties until the recent development of the concept of Fire Regime Condition Class (Hann and Bunnell 2001).

⇒ Conservation action planning methodologies lack a rigorous assessment of likely future impairment. Similarly, the assessment of threats or likely future conditions has been based largely on expert opinion. CAP employs a transparent and robust threat ranking methodology in the CAP software, which allows for revised rankings as circumstances change or knowledge advances, but ultimately each threat ranking decision is based upon the projections and judgments of the planning team. GIS-based threat projections present the same issue for GIS landscape suitability assessments described above. A reliable and quantitative methodology for estimating future conditions is clearly needed.

⇒ Conservation action planning methodologies lack a rigorous system for evaluating the effectiveness of alternative management strategies. CAP utilizes probing questions and/or situation analysis to arrive at conservation strategies that are intended to provide measurable enhanced viability of an ecological system or species and/or abatement of a future threat. CAP practitioners can use results chains (World Wildlife Fund 2005) to test and refine strategies. However, CAP lacks a methodology for actually optimizing and quantitatively testing alternative strategies to see if they will achieve their intended effect. While federal land management agencies such as BLM and USFS are required to consider alternatives in the development of plans, the comparison of alternatives often is based upon the judgment of agency officials (Forbis et al. 2006). Quantitative evaluation of alternative management or conservation strategies has received little attention (Forbis et al. 2006; Provencher et al. 2007).

⇒ Conservation action planning methodologies lack a rigorous system for assessing the benefits vs. the costs of alternative management strategies. For agencies, cost-benefit analysis receives attention as a way for land managers to eliminate expensive management options, but cost is not connected to benefit other than acres reported and expectations about meeting area objectives, such as fuel reduction treatments. CAP offers an approach to benefit-cost assessment (Low 2003); however, this methodology provides only a coarse assessment and requires a number of subjective ranking decisions.

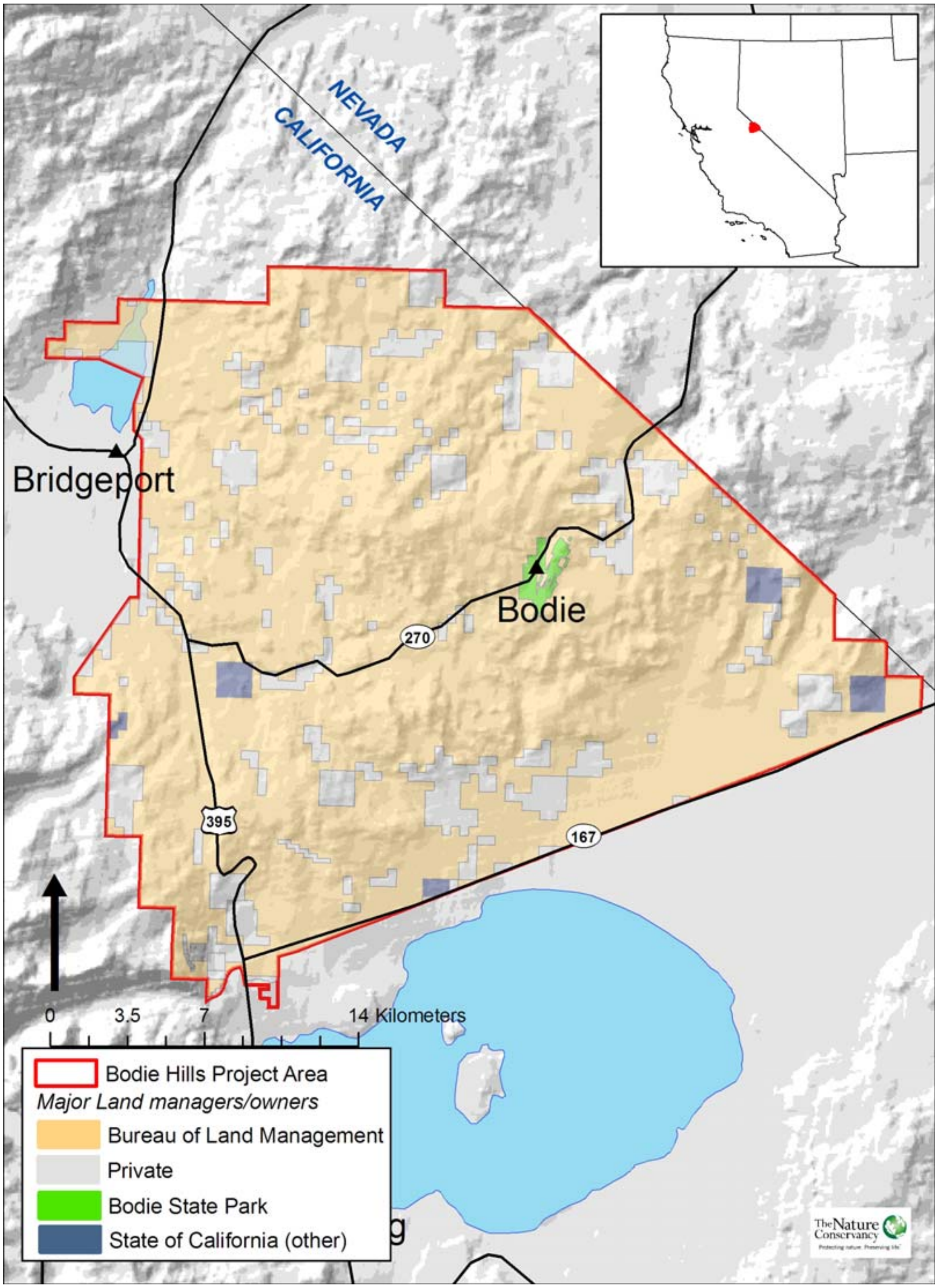
To address these deficiencies, we assembled and expanded a set of tools and methods to use with public agencies, private land mangers, and other stakeholders for landscape-scale conservation planning. Some of the tools had been developed under the auspices of the U.S. interagency LANDFIRE program (Hutter et al. 2007; Rollins 2009). We adapted or developed additional tools. The Enhanced CAP tools include remote sensing interpretation of satellite imagery, predictive ecological models, customized analytical spreadsheets, and cost-benefit assessments.

METHODS

Study Area

The Enhanced CAP was developed for a 76,464 ha (188,946 acre) project area in California's Bodie Hills and northern Mono Lake Basin (Figure1, page 40). The Bodie Hills and Mono Lake Basin, along with the White Mountains and other nearby landscapes, were identified by TNC as priority areas for conservation in the western Great Basin (Nachlinger et al. 2001). The Bodie Hills-northern Mono Basin (hereafter, Bodie Hills) project area is a largely unfragmented landscape that includes a representative diversity of Great Basin ecological systems, as well as important habitat for Greater sage

FIGURE 1 Map of Bodie Hills-Northern Mono Lake Basin Project Area



grouse. It has no major development other than remnant buildings in Bodie State Historic Park. Moreover, major fires and invasive species have not yet overtaken the dominant sagebrush ecological systems, as they have done elsewhere in the Great Basin (Young et al. 1987; Anderson and Inouye 2001; Bradley 2009).

Overview

Enhanced CAP was a scientific process that also engaged stakeholders. During 2008, TNC facilitated a series of three 2½-day workshops with a diverse group of stakeholders in the study area to help develop project objectives, review mapping products, provide input on ecological models, and identify and refine conservation and restoration management strategies. Participants in the workshops included private ranchers and ranch managers, representatives of TNC and other conservation organizations, natural resource advisers, and staff from BLM and other public agencies. We quantitatively assessed current condition of ecological systems in the project area using remote sensing to map ecological systems and GIS to calculate a measure of ecological departure for each system. We developed alternative management scenarios for priority ecological systems using the Vegetation Dynamics and Development Tool software (VDDT by ESSA Technologies, Ltd; Barrett, T.M. 2001; Beukema et al. 2003; Forbis et al. 2006). We evaluated predictive modeling results statistically to determine confidence in the predicted outcomes. Finally, we prioritized on-the-ground conservation actions utilizing a cost-benefit analysis. Figure 2, page 42, provides a flow chart overview of the Enhanced CAP process.

Evaluating Current Ecological Condition

Prior to the first stakeholder workshop, we assessed the condition of each major ecological system by mapping Fire Regime Condition Class (FRCC) using the methodology developed under the U.S. interagency LANDFIRE program (Rollins 2009 and Shlisky and Hann 2003; and adapted by Provencher et al. 2008). The fundamental elements of FRCC analysis include mapping the distribution of ecological systems prior to European settlement (hereafter, pre-settlement), mapping current vegetation and succession classes, and calculating ecological departure between current and pre-settlement conditions. The details of FRCC mapping are described in Provencher et al. (2008) and are not repeated here; however, updates to the methodology are presented.

Although called “fire regime” condition class, FRCC is actually an integrated, landscape-level measure of ecological condition. The FRCC metric incorporates species composition, vegetation structure, and all significant disturbances (not simply fire) for terrestrial and riparian ecological systems that would have occurred pre-settlement or in naturally functioning landscapes. This methodology determines the dissimilarity (called Fire Regime Condition or FRC) between an ecological system’s current condition and its natural range of variability (NRV). NRV reflects the distribution of vegetation classes that would be found under naturally functioning ecological processes, as predicted by field studies, expert opinion, and computer simulations.

The LANDFIRE program has developed maps of potential vegetation and current vegetation succession classes for the entire United States (Rollins 2009). To refine this map data for the purpose of developing detailed land management recommendations at the project area, we mapped FRCC using remote sensing analysis of 5 August 2005 LandSat V Thematic Mapper imagery (25-30m resolution). The remote sensing was supplemented by field training plots (July 10-12, 2007), field verification plots (October 18-21, 2007), hundreds of geo-referenced observations from roads, the Natural Resource Conservation Service (NRCS) Benton-Owens Valley soil survey, and the U.S. Geological Survey 10m Digital Elevation Models.

FIGURE 2 Enhanced CAP Project Workflow

Pre-Workshops: Mapping & Assessment of Ecological Condition
October 2007-February 2008 -- by TNC, prior to 1st workshop
- Obtained satellite imagery; conducted remote sensing
- Obtained and refined state-and-transition ecological models
- Mapped biophysical settings
- Compared current vegetation classes with biophysical settings and calculated departure from natural range of variability

Stakeholder Workshop I – Current Condition & Ecological Models
March 2008
- Reviewed ecological systems and refined vegetation classes
- Reviewed each ecosystem's current condition using ecological departure metric
- Reviewed and further refined state-and-transition ecological models

Stakeholder Workshop II –Future Threats & Initial Strategies
May 2008
- Determined key conservation and restoration objectives
- Used computer simulations to identify ecosystems likely to suffer future impairment
- Selected focal ecosystems for treatment
- Developed initial conservation strategies and estimated costs
- Developed management scenarios to be tested for each ecosystem

Stakeholder Workshop III – Outcomes of Management Scenarios
June 2008
- Reviewed 20-year outcomes of computer simulations for each management scenario
- Refined management scenarios, emphasizing high ecological returns for low cost

Post Workshops: Statistical and Cost-Benefit Analyses
Fall 2008
- Statistically evaluated modeling results
- Applied return-on-investment metrics to evaluate scenarios

Mapping Pre-settlement Vegetation

Preferably, pre-settlement ecological systems are mapped by interpreting ecological sites from NRCS soil surveys to major vegetation types. However, soil surveys were not available for most of the project area. Instead, we used current satellite imagery to derive the pre-settlement size and distribution of ecological systems (Figure 3) by modifying current vegetation types using landform-soil-vegetation correlation rules proposed by NRCS (Provencher et al. 2008). To determine the NRV, either we directly used LANDFIRE descriptions and models (www.landfire.gov) or we modified existing descriptions and models originally developed for northwestern Utah (York et al. 2008) and eastern Nevada, using standard LANDFIRE methodology (Hann et al. 2004; Rollins 2009) to reflect local conditions of the Bodie Hills (Table 2, page 44).

FIGURE 3 Ecological Systems of Bodie Hills Project Area Based on Mapping Biophysical Settings

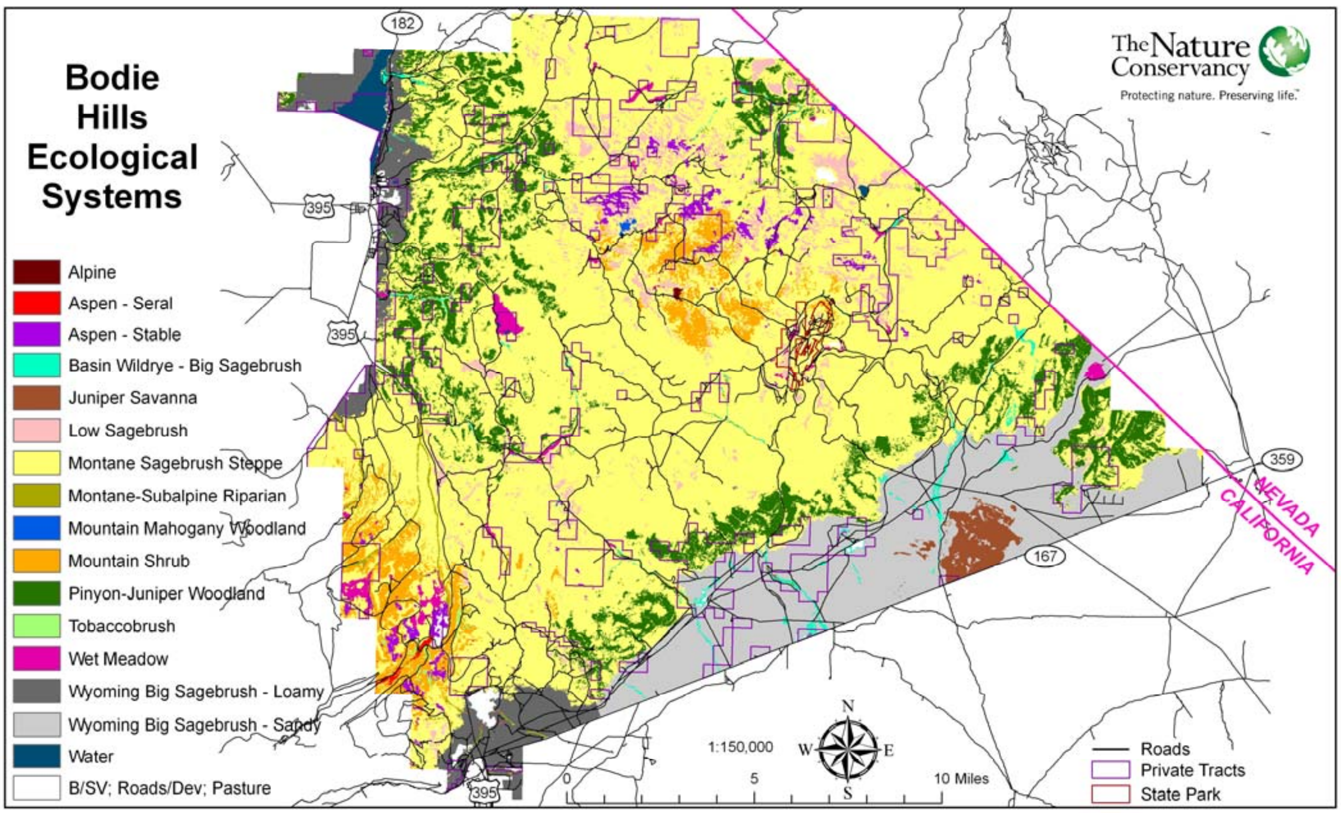


TABLE 2 Natural range of variability for Bodie Hills ecological systems.

Biophysical Setting/Ecological System		Natural Range of Variability (%)					
Code[@]	Name	A[&]	B	C	D	E	U
1011	Stable Aspen	15	40	0	5	40	0
1019	Pinyon-Juniper Woodland	5	10	30	55	0	0
1061	Seral Aspen	14	40	35	10	1	0
1062	Mountain Mahogany	5	15	10	20	50	0
1079	Low Sagebrush	10	40	0	0	50	0
1080loamy	Wyoming Big Sagebrush-loamy	15	45	25	10	5	0
1080sandy[#]	Wyoming Big Sagebrush-sandy	15	45	25	10	5	0
1080bw[#]	Basin Wildrye-Big Sagebrush	20	70	0	10	0	0
1086[#]	Mountain Shrub	10	40	45	5	0	0
1103	Tobacco Brush	15	85	0	0	0	0
1115	Juniper Savanna	2	3	10	40	45	0
1126	Montane Sagebrush Steppe	20	50	15	10	5	0
1144	Alpine	5	95	0	0	0	0
1145wm[#]	Wet Meadow	5	45	0	50	0	0
1154	Montane-Subalpine Riparian	25	0	40	0	35	0

[@] LANDFIRE core code that is not preceded by the two-digit map zone identification.

[&] Standard LANDFIRE coding for the 5-box vegetation model succession classes: A = early-development; B = mid-development, open; C = mid-development, closed; D = late-development, open; E = late-development, closed; and U = uncharacteristic. This terminology was sometimes modified for biophysical settings with <5 boxes.

Mapping Current Vegetation

For each ecological system, current vegetation was mapped as the natural succession classes and any uncharacteristic classes. Natural succession classes typically were based on the standard LANDFIRE model of up to five classes ranging from early- to mid- to late-development; mid- and late-development classes may be expressed as open or closed canopy. However, because many ecological systems across the Great Basin have been degraded by the emergence of uncharacteristic classes, it was critical to identify and map well-known uncharacteristic classes as well as the natural succession classes. Some of the more problematic uncharacteristic classes were created by the invasion of cheatgrass (*Bromus tectorum*) into shrublands and woodlands, encroachment of pinyon (*Pinus monophylla*) or juniper (*Juniperus osteosperma*) into shrublands and wet meadows, invasion of exotic forbs (e.g. tall whitetop, *Lepidium latifolium*) in wet meadows and riparian systems, loss of the herbaceous understory of shrublands, loss of aspen (*Populus tremuloides*) regeneration, loss of aspen clones, dominance of exotic forbs in wet meadows and riparian systems, and entrenchment and drop of the water table in riparian systems and wet meadows. A description of the vegetation succession classes for montane sagebrush steppe is shown in Table 3.

TABLE 3 Vegetation classes for montane sagebrush steppe.

	Montane Sagebrush Steppe
Reference Classes	
A	*Early*: 0-10% canopy of mountain sage/mountain brush; >50% grass/forb cover
B	*Mid--open*: 11-30% cover of mountain sage/mountain shrub; >50% herbaceous cover
C	*Mid--closed*; 31-50% cover of mountain sage/mountain brush; 25-50% herbaceous cover, <10% conifer sapling cover
D	*Late-open*: 10-30% cover conifer <10m; 25-40% cover of mountain sage/mountain brush; <30% herbaceous cover
E	*Late-closed*: 31-80% conifer cover 10-25m; 6-20% shrub cover; <20% herbaceous cover
Uncharacteristic Classes	
ESH:	Early-Shrub; 0-40% cover rabbitbrush species
TrEnc:	Tree-Encroached; 31-80% conifer cover 10-25m; <5% shrub cover; <5% herbaceous cover
DPL:	Depleted; 31-50% cover of mountain sage/mountain brush; <5% herbaceous cover; <10% conifer sapling cover
ShAG:	Shrub-Annual-Grass; 31-50% cover of mountain sage/mountain brush; 5-40% cheatgrass cover; <10% conifer sapling cover
ShAP:	Shrub-Annual-Grass-Perennial-Grass; 31-50% cover of mountain sage/mountain brush; 5-30% cover of native grass; 5-10% cheatgrass cover; <10% conifer sapling cover
AG:	Annual-Grass; 10-30% cover of cheatgrass

Calculating Ecological Departure

We calculated FRC for each ecological system using the GIS-based FRCC Mapping Tool (Hutter et al. 2007) on the grid data obtained from remote sensing. FRC is scored on a scale of 0% to 100% departure from NRV: 0% represents NRV while 100% represents total departure from NRV. Fire Regime Condition Class (FRCC) is a coarser-scale U.S. interagency metric that groups FRC scores into three classes: FRCC 1 represents ecological systems with low (≤33%) departure; FRCC 2 indicates ecological systems with moderate (34 to 66%) departure; and FRCC 3 indicates ecological systems with high (>66%) departure (Hann et al. 2004). An example of FRC and FRCC calculation is shown in Table 4.

TABLE 4 Example of calculation of FRC/FRCC using Bodie Hills montane sagebrush steppe.

	Current Vegetation Class						
	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 from remote sensing	182	7,950	58,718	6,659	264	46,123	119,894
Current percentage of classes	0.2	6.6	49.0	5.6	0.2	37.4	
Fire Regime Condition[@] (%)	0.2	6.6	15	5.6	0.2	0	72.4
Fire Regime Condition Class[#]							3

[&] Legend: A = early-development; B = mid-development, open; C = mid-development, closed; D = late-development, open; E = late-development, closed; and U = uncharacteristic.

[@] Fire Regime condition = 100% - $\sum_{i=1}^{n} \min\{Current_i, NRV_i\}$

[#] FRCC: 1 for 0% ≤ Fire Regime Condition ≤ 33%; 2 for 34% ≤ Fire Regime Condition ≤ 66%; 3 for 67% ≤ Fire Regime Condition ≤ 100%.

Assessing Future Condition

Predictive Ecological Models

In order to predict effects of potential future threats and alternative conservation strategies on FRC, state-and-transition models were developed using VDDT software as described in Forbis et al. (2006) and Provencher et al. (2007). All ecological system models had at their core the LANDFIRE reference condition represented by some variation around the A-B-C-D-E succession classes (Table 2, page 44). The A-E class models typically represented succession from usually herbaceous vegetation (class A) to increasing woody species dominance where the dominant woody vegetation might be shrubs (class C) or trees (class E). The state-and-transition models for these ecological systems were modified by workshop participants to reflect local ecological dynamics and management constraints. The modified models had a history of development and refinement by Great Basin ecologists and land managers (York et al. 2008).

High-Risk Vegetation Classes

The adapted models for most ecological systems included "uncharacteristic" (U) classes (Table 3, page 45). Uncharacteristic classes are classes outside of reference conditions, such as invasion by annual grasses or weeds, tree-encroached shrublands, and entrenched riparian areas. FRC calculations do not differentiate among the classes that are uncharacteristic. Since the cost and management urgency to address different uncharacteristic classes varies greatly, we determined that FRC should not be the only metric used to assess future conditions. We therefore developed a separate designation and calculation of "high-risk" vegetation classes. A high-risk class was defined as an uncharacteristic vegetation class that met at least two out of three criteria: 1) greater than 5% cover of invasive non-native species, 2) very expensive to restore, or a 3) direct pathway to one of these classes (invaded or very expensive to restore).

Testing Alternative Management Strategies and Scenarios

Conservation and Restoration Strategies

CAP focuses on developing conservation strategies that: (1) enhance or restore ecological systems that are currently in an undesirable condition and/or (2) abate the most serious future threats to ecological systems. Eight ecological systems were selected for management attention, based upon their current condition, likely future departure from NRV, and/or potential for increased high-risk classes, as well as feasibility of management action.

Working with workshop participants, a comprehensive list of potential conservation and restoration strategies (hereafter, management strategies) was developed for all of the targeted ecological systems. Examples of management strategies included controlled burning, lopping, canopy thinning, mowing, drilling and seeding, weed inventory and spot herbicides, livestock herd management, early-season grazing of cheatgrass, establishing and maintaining fuel breaks, and fencing. A cost-per-area budget and potential yearly application rate were then determined for each management strategy, using varied published sources as well as the experience of local managers and stakeholders. Each strategy generally was designed to reduce an over-represented characteristic or uncharacteristic class. All management strategies were incorporated into the VDDT ecological models, showing the predicted shift of class. The models also included a failure rate for many management strategies since management efforts sometimes only partially succeed.

An initial "strawman" set of management strategies for each ecological system was developed by TNC and workshop participants. For a quick but static assessment of alternative strategies, we used an internally developed, Microsoft Excel-based "FRC Change Worksheet" to reduce over-represented classes and recalculate FRC achieved by the changes. We then conducted VDDT model runs to test and refine a suite of strategies for each of the targeted ecological systems over a 20-year time horizon, which was the time frame desired by the land managers (we also used a 50-year period to explore longer-term trends). We used a trial-and-error process to create a robust set of strategies that reduced ecological departure and cover of high-risk classes to the desired levels for the lowest cost. The tentative strategies and budgets were refined after stakeholder review at the second workshop.

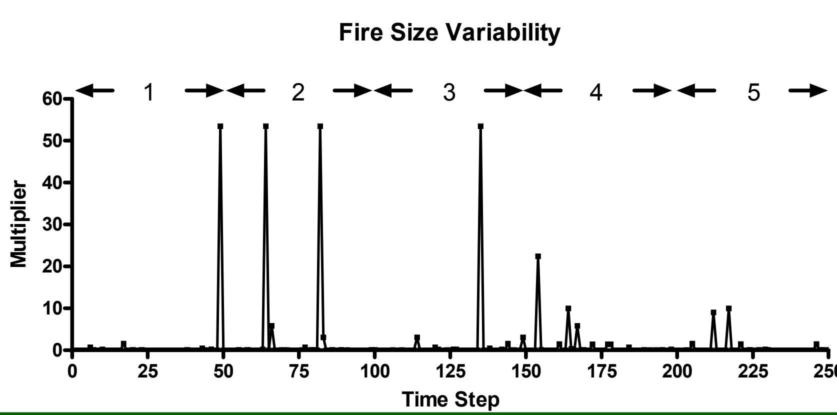
Management Scenarios

Whereas optimal strategies can be developed for conserving and restoring each ecological system using the VDDT simulations, land managers face "real world" constraints and mandates that must be considered. Constraints include limited budget and/or personnel resources, legal limitations of applications of some strategies (e.g., widespread application of the herbicide Plateau, which can be effective in controlling cheatgrass, is prohibited in California), and legal or *de facto* constraints on use of some strategies in some areas (e.g., mechanized treatments in Wilderness Study Areas). Mandates include fire management plans and policies that require application of resources to protect human settlements. Moreover, federal agencies are required to consider alternatives in their environmental assessments prior to taking major management actions. Accordingly, we developed and tested a set of alternative management "scenarios", including a scenario for minimum management of the landscape (e.g., no treatment of exotic forbs, no controlled burning, no active management of livestock) that would act as a control for cost-benefit analyses. Each scenario incorporated multiple management strategies that reflected "real world" constraints across the targeted ecological systems.

Accounting for Variability in Disturbances

The basic VDDT models incorporate a stochastic disturbance rate that varies around a mean value (e.g., fire return interval) associated with each succession class for each ecological system. However, in most landscapes the disturbance rates are likely to vary appreciably over time. To simulate strong yearly variability for fire activity, drought-induced mortality, and species invasion and encroachment rates, we incorporated temporal multipliers in the model run replicates. A temporal multiplier is a number in a yearly time series that multiplies the base parameter rate specified in the VDDT models: for a given year, a temporal multiplier of 1 implies no change, whereas a multiplier of 0 is a complete suppression of the disturbance rate and a multiplier of 3 triples the disturbance rate. Temporal data from 1980 and 2006 were available for fire activity in the Bodie Hills and four nearby areas each totaling 76,464 ha (Federal Fire Occurrence Website). The predicted level of fire activity for the Bodie Hills ranged from *no* large fires over a 50 year period in one replicate (i.e., effective fire suppression) to two large fires over the same time frame in another replicate (i.e., fires that escaped suppression) (Figure 4).

FIGURE 4 Predicted levels and variability of fire over time, using five replicates of temporal probability multipliers for fire size. Each replicate is numbered at the top of the figure and represented a 50-year period. The multiplier on the vertical axis multiplied the base fire probability for a given ecological system in a given year.



Cost-Benefit Analysis of Management Scenarios

The last step of Enhanced CAP is the calculation of benefits as compared to costs. We developed and tested three return on investment (ROI) metrics to determine which of the selected scenarios produced the greatest ecological benefits per dollar invested across the eight targeted ecological systems, as compared to minimum management.

The three ROI metrics calculated were:

(1) Area Treated ROI. Area treated divided by total cost over 20 years;

(2) Ecological ROI. The change of fire regime condition and high risk vegetation classes between the Minimum Management and another management scenario in year 20, divided by total cost over 20 years; and

(3) Ecological System-wide ROI. The change of fire regime condition and high risk vegetation classes between the Minimum Management and another management scenario in year 20, multiplied by total area of the ecological system, divided by total cost over 20 years.

Correction factors were used to bring all measures to a common order of magnitude.

RESULTS

Ecological Systems

Of the 15 ecological systems mapped (Figure 3, page 43), montane sagebrush steppe accounted for 48,443 ha (119,705 acres), over 63% of the project area (Table 5). This widespread system was followed in decreasing order by Wyoming big sagebrush on sandy soils (~12%), pinyon-juniper woodland (~9%), and Wyoming big sagebrush on loamy soils (~4%). Basin wildrye-basin big sagebrush (*Leymus cinereus-A. tridentata* spp*. tridentata*) and wet meadows were constrained to depressions and washes. Stable aspen (i.e., aspen stands which cannot become dominated by conifers), was scattered in mesic sites near springs and creeks, or in snow pockets. Several ecological systems, including alpine, tobacco brush (*Ceanothus velutinus*), seral aspen (i.e., mixed *aspen*-lodgepole pine [*Pinus contorta*] woodland), and mountain mahogany (*Cercocarpus ledifolius* var. *intermontanus*), were highly localized and had better representations outside of the project area.

Current Ecological Condition

The current condition of the Bodie Hills ecological systems varied widely in terms of departure from their NRV. Of the 15 ecological systems, five were FRCC 1 (slightly departed), five were FRCC 2 (moderately departed), and five were FRCC 3 (highly departed) (Table 5, page 50). The primary cause of high departure was the paucity of early and mid-succession classes in sagebrush and aspen systems. In the widespread montane sagebrush steppe system, which was 72% departed from its NRV, a substantial portion was depleted of native grasses and forbs, cheatgrass had invaded (but not yet replaced) the existing perennial grasses in some areas, and conifer tree species had encroached native sagebrush at middle elevations.

Six ecological systems - including all of the sagebrush ecosystems - had substantial percentages of their cover in high-risk vegetation classes (Table 5). The montane sagebrush steppe had 27% of its 2007 cover in high-risk classes (depleted condition and conifer encroachment). Wyoming big sagebrush on sandy soils was almost entirely (99%) in depleted condition.

Assessment of Future Condition

In the absence of active management over the next 20 years, eleven ecological systems were predicted to become increasingly departed from NRV and/or to experience high levels of high-risk vegetation classes (Table 6). Model runs indicated that three ecological

TABLE 5 Size and current condition of ecological systems of the Bodie Hills project area. Size was for the biophysical settings.

Name	Area (Ha)	Area (%)	FRC	FRCC	HRVC (%)*
Alpine	15	<0.1	5.0	1	na[&]
Basin Wildrye-Big Sagebrush	581	0.8	72.6	3	na
Juniper Savanna	692	0.9	35.4	2	na
Low Sagebrush	2,788	3.6	40.9	2	1
Montane Sagebrush Steppe	48,443	63.4	72.4	3	27
Montane-Subalpine Riparian	393	0.5	21.5	1	0
Mountain Mahogany	35	<0.1	23.1	1	0
Mountain Shrub	2,794	3.7	39.3	2	0
Pinyon-Juniper Woodland	6,743	8.8	28.5	1	29
Seral Aspen	43	0.1	77.5	3	9
Stable Aspen	760	1.0	41.4	2	41
Tobacco Brush	70	0.1	9.3	1	na
Wet Meadow	696	0.9	33.3	2	0
Wyoming Big Sagebrush-loamy	3,073	4.0	74.3	3	57
Wyoming Big Sagebrush-sandy	9,336	12.2	99.1	3	99
Total	76,464				

* HRVC = high risk vegetation classes

& na = not applicable

systems would become further departed from NRV. In some cases, including montane sagebrush steppe, FRC scores actually improved over time. This counter-intuitive outcome was explained by the escape of wildfire into the system in some model runs. In contrast, without thoughtful active management, 11 of the 15 Bodie Hills ecological systems were predicted to have increases or continued high stress levels in high-risk vegetation classes. For example, montane sagebrush steppe system witnessed increased cheatgrass and conifer encroachment among its high-risk vegetation classes and seral aspen showed a dramatic loss of aspen clones over 20 years.

Management Strategies and Scenarios

Participants at the second stakeholder workshop developed a set of management goals; these goals served to guide the development of conservation strategies:

- Restore ecological systems to their natural range of variability or to an "acceptable range" if NRV is not feasible;
- Reduce high-risk classes, such as cheatgrass or exotic forbs;
- Avoid threshold conversions to high risk classes;

TABLE 6 Two metrics of Bodie Hills ecological systems' condition after 20 years of simulation under the MINIMUM MANAGEMENT scenario: (1) departure from NRV (FRC) and (2) percent cover of high risk vegetation classes.

Ecological System	FRC after 20 years of simulation (%)	Cover of High Risk Vegetation Class after 20 years of simulation (%)
Alpine	5	*n/a*
Tobacco Brush	26	*n/a*
Montane-Subalpine Riparian	23	9
Mountain Mahogany	20	3
Pinyon-Juniper Woodland	32	31
Juniper Savanna	27	*n/a*
Low Sagebrush	33	10
Mountain Shrub	38	0
Stable Aspen	41	28
Wet Meadow	18	4
Basin Wildrye-Big Sagebrush	72	62
Montane Sagebrush Steppe	58	25
Seral Aspen	71	80
Wyoming Big Sagebrush-loamy	67	49
Wyoming Big Sagebrush-sandy	99	80

- Conserve high value ecological systems (e.g. habitat for special status species);
- Maintain mosaic of communities and classes, with special attention to early succession classes and requirements of special status species; and
- Protect human settlements, Bodie Historical State Park and cultural resources from wildfire.

Scenarios for the Bodie Hills were also developed by stakeholders at the second workshop. Three basic scenarios were designed: (1) minimum management; (2) ecological management; and (3) combined ecologically-based and wildfire protection management (Table 7). In addition, a modified version of the third scenario was developed that "front-loaded" in years 2-3 about 20 years worth of some management strategies to achieve economies of scale.

Table 7 Brief Descriptions of Management Scenarios for the Bodie Hills

BASIC SCENARIOS
MINIMUM MANAGEMENT
A control scenario that only included natural disturbances, including unmanaged non-native species invasion, unmanaged livestock grazing, and fire suppression. Fire suppression by agencies was simulated by reducing natural, reference fire return intervals using time series that reflected current fire events from the immediate surrounding area. In essence, this scenario was considered a no-treatment control, but not reflecting current management.
ECOLOGICAL MANAGEMENT
This scenario allocated funds with the goal of reducing ecological departure (FRC) and high risk vegetation classes. Management actions were applied only if they meaningfully improved FRC scores and maintained/reduced high risk vegetation classes below 10% of the area of the ecological system.
SELECTED ECOLOGICAL MANAGEMENT & FIRE MANAGEMENT
The purpose of this scenario was to implement a wildland-urban interface (WUI) fuel break to protect human settlements and Bodie State Park and implement, as funding allowed, selected cost-effective actions that had a disproportionate effect (highest return-on-the-investment) on reducing ecological departure and high risk vegetation classes.
FRONT-LOADED MANAGEMENT
This was similar to SELECTED ECOLOGICAL MANAGEMENT & FIRE MANAGEMENT, except a few actions with high unit prices and widespread use were implemented during three early years of simulations. The assumption was that financial economies of scale could be realized that would be reinvested in more acres treated if contractors were awarded large-area contracts by the BLM.

Multiple management strategies were required to achieve conservation and restoration objectives for each of the eight targeted ecological systems. Using montane sagebrush steppe as an example, Table 8, page 54, shows strategy worksheets with selected strategies and their respective levels of application for two scenarios, ecological management and combined ecologically-based and wildfire protection management.

The combined ecologically-based and wildfire protection scenario for montane sagebrush steppe after 20 years achieved a mean FRC of ~45% departure (down from the current 72% departure) and also showed a relatively low variance. In comparison, the ecological management scenario and the minimum management scenario achieved ~55% FRC (Figure 5, page 55). However, the combined ecological-wildfire management scenario was less effective than the ecological management scenario in reducing high-risk vegetation classes (~25% vs. ~18%; Figure 5, page 55).

Overall, the combined ecologically-based and wildfire protection scenario met conservation and restoration objectives for the least cost for six of the eight targeted ecological systems – montane sagebrush steppe, low sagebrush, both Wyoming big sagebrush systems, wet meadows, and montane riparian. The same combined management scenario with expensive strategy costs front-loaded in early years performed best for the basin wildrye-big sagebrush system. For stable aspen, the ecological management scenario performed slightly better than the combined management scenario for slightly less cost (however, that both scenarios were technically similar for this system). In a few cases, the least expensive scenario, minimum management, achieved similar results in reducing ecological departure, but did not achieve other management goals, such as habitat requirements for special status species. In general, the implementation costs for the best performing scenarios were within anticipated BLM budgets.

Cost-Benefit Analysis of Management Scenarios

There were two results of our cost-benefit analysis: (1) assessment of benefits vs. costs of alternative management scenarios *for a given ecological system* and (2) assessment of benefits vs. costs for the optimal scenarios *across ecological systems*.

The former cost-benefit analysis was determined by trial and error testing of varied management strategies and levels of application, which were then combined into scenarios. The use of the simulations allowed us to incorporate measures of both probability of success and ecological improvement. The differing scenario results for the montane sagebrush steppe system were dramatic (Table 8, page 54). The ecological management scenario for montane sagebrush steppe included expensive and extensive treatments for the depleted sagebrush class (sagebrush canopy with <10% cover of native perennial grasses). Alternatively, the combined ecological and wildfire management scenario treated far fewer acres of depleted sagebrush in conjunction with a strategy to establish a fuel break around Bodie Historical State Park. The average cost of the ecological management scenario was approximately $250,000 per year greater than the combined ecological and wildfire management, or almost $5,000,000 more expensive over 20 years. This additional cost for achieving no predicted improvement in FRC departure and some important but marginal reduction in high-risk classes was deemed prohibitive.

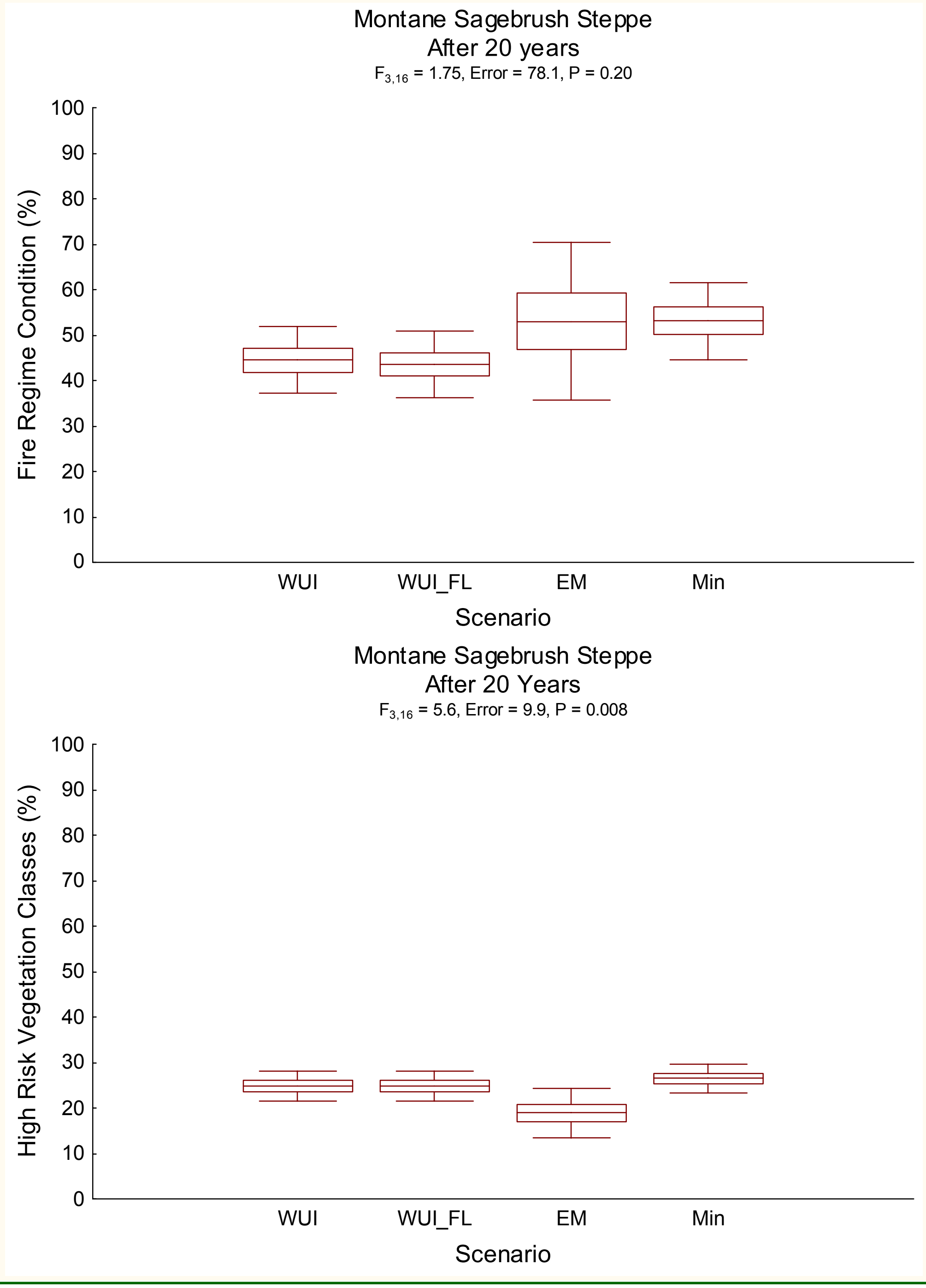
The second result was a comparison of benefits relative to the costs of selected scenarios across the eight targeted ecological systems. The three different ROI metrics tested produced different results. The first measure (area treated) clearly favored larger ecological systems that received low per-area investments, such as low sagebrush and montane sagebrush steppe (Table 9, page 56). The second ROI metric (reduction of FRC and high-risk classes) captured the improvement in an ecological system independent of its area. As a result, smaller-size ecosystems such as basin wildrye-big sagebrush, stable aspen and montane riparian were more likely to benefit, whereas low sagebrush and montane

Table 8 Ecological management and combined ecological and wildfire management scenarios and associated strategies for montane sagebrush steppe.

Scenario: Ecological Management -- Montane Sagebrush Steppe				
Objective	Improve ecological condition of ~120,000 acres of montane sagebrush steppe from 72% departure from NRV to ~55% departure and prevent increase in highest-risk classes to 10% or less… over 20 years			
Strategy	Treat ~1000 acres/yr of montane sagebrush steppe -- with prescribed fire, mowing/burning/ drilling/seeding, lopping & canopy thinning -- and managing with early cheatgrass grazing			
Management Actions	***One Time Costs***	***Acres/ Year***	***Cost/ Acre***	***Cost/ Year***
Lop late seral class, depleted class and shrubs with perennial & annual grasses to prevent conversion to Tree Encroached Class; make available for firewood; explain fire risk		140	$ 300	$ 42,000
Conduct early spring burns of shrubs with perennial & annual grasses to convert to early succession class		500	$ 40	$ 20,000
Mow & burn, drill and seed depleted class to early succession classes		350	$ 545	$190,750
Conduct early cheatgrass grazing of shrubs with perennial & annual grasses to prevent conversion to shrubs with annual grasses		1,000	$ 40	$ 40,000
Canopy thinning of mid succession class as needed for WUI objectives		30	$ 300	$ 9,000
Archeological & plant surveys		1,000	$ 50	$ 50,000
Total Cost/Yr				**$351,750**

Scenario: Combined Ecological & Wildfire Management -- Montane Sagebrush Steppe				
Objective	Improve ecological condition of ~120,000 acres of Bodie Hills montane sagebrush steppe from 72% departure from NRV to ~55% departure, prevent increase in highest-risk classes to 30% or less… over 20 years, and establish fuel break around Bodie State Park providing ecological benefits by increasing early succession classes			
Strategy	Treat ~1000 acres/yr of montane sagebrush steppe -- with prescribed fire, mowing/burning/ drilling/seeding, lopping & canopy thinning			
Management Actions	***One Time Costs***	***Acres/ Year***	***Cost/ Acre***	***Cost/ Year***
Lop late seral class, depleted class and shrubs with perennial & annual grasses to prevent conversion to Tree Encroached Class; make available for firewood; explain fire risk		50	$ 300	$ 15,000
Conduct early spring burns of shrubs with perennial & annual grasses to convert to early succession class		500	$ 40	$ 20,000
Restoration of depleted class & 300 ft. fuel break around 7 miles of State Park (280 acres over 3 years @$207/acre)	$112,000	-	$ 400	$ -
Regular prescribed fire in middle and late succession classes		400	$ 50	$ 20,000
Canopy thinning of mid succession class as needed for WUI objectives		25	$ 400	$ 10,000
Archeological & plant surveys	$ 9,800	900	$ 35	$ 31,500
Total Cost/Yr *including one time costs averaged over 20 yrs*				**$102,590**

Figure 5 Effects of scenarios on Fire Regime Condition (top) and High Risk Vegetation Classes (bottom) in montane sagebrush steppe after 20 years of simulation. Overall multivariate test: Wilks' $\lambda_{12,54}$ = 0.48, P = 0.45. N = 5 replicates. The middle line in the box plot was the mean, the edges of the box were the mean ± SDE, and the error bars were the 95% C.I. Legend: CC = CLIMATE CHANGE included; NoCC = without CLIMATE CHANGE; Min = MINIMUM MANAGE-MENT scenario; EM = ECOLOGICAL MANAGEMENT scenario; WUI = COMBINED ECOLOGICAL-FIRE MANAGEMENT scenario; and WUI_FL = FRONT-LOADED COMBINED ECOLOGICAL-FIRE MANAGEMENT scenario.



sagebrush steppe, received less relative gain. The third ROI metric captured both the area of an ecological system and its ecological improvement. Based on this metric of area-weighted ecological improvement, the basin wildrye – big sagebrush, stable aspen, montane sagebrush steppe, wet meadows, and montane riparian ecological systems – accrued the highest ecological "return on investment," in descending order for their best performing scenario. In other words, using the area-weighted ecological benefits metric, these five ecological systems achieved the greatest predicted ecological benefits per dollar invested in the recommended management scenario.

TABLE 9 Return-On-Investment (ROI) for Selected Scenarios by Ecological System

Ecological System	Preferred Scenario#	Return-On-Investment		
		Area Treated&	Ecological	Ecological System Wide
Basin Wildrye-Big Sagebrush	FL WUI-ROI	**29.8**	**23.5**	**33.8**
Low Sagebrush	WUI-ROI	**117.6**	**0.0**	**-0.3**
Montane-Subalpine Riparian	WUI-ROI	**8.8**	**3.6**	**3.5**
Montane Sagebrush Steppe	WUI-ROI	**96.4**	**0.1**	**9.9**
Stable Aspen	EM	**27.1**	**9.6**	**18.0**
Wet Meadow	WUI-ROI	**7.8**	**2.7**	**4.6**
Wyoming Big sagebrush-loamy	WUI-ROI	**27.2**	**-2.1**	**-15.9**
Wyoming Big sagebrush-sandy	WUI-ROI	**24.7**	**-3.0**	**-69.6**

&:1) Area treated ROI: area treated divided by total cost over 20 years,

2) Ecological system wide ROI: the change of fire regime condition and high risk vegetation classes between the Minimum Management and another scenario on year 20, multiplied by total area of the ecological system, divided by total cost over 20 years; and

3) Ecological ROI: the change of fire regime condition and high risk vegetation classes between the Minimum Management and another scenario on year 20, divided by total cost over 20 years.

DISCUSSION

Enhanced CAP

The Enhanced Conservation Action Planning methodology addressed four shortcomings of most site-based conservation planning approaches while respecting the fundamental conceptual planning framework of TNC's CAP methodology. Enhanced CAP:

1. Provided a rigorous, empirical assessment of current ecological conditions at a landscape level, using FRCC assessment as an integrated metric of ecological condition that encompasses species composition, vegetation structure, and natural disturbance regimes.

2. Used predictive ecological models to provide a rigorous, quantitative assessment of likely future impairment.

3. Used predictive ecological models to evaluate the effectiveness of alternative management strategies.

4. Used cost-benefit assessment to select management strategies and scenarios that achieve the highest ecological returns per dollar invested.

These outcomes were well received by BLM land managers and many stakeholders. Although much of the planning process was highly technical, the participation of varied local stakeholders in the series of three workshops captured the benefit of their knowledge and experience. Since TNC completed most of the data preparation and simulations outside of the workshops, the ambitious project objectives that involved stakeholders were achieved in a limited amount of time (i.e., three workshops). Good workshop design and facilitation is required to bridge the communication gap between lay persons and technical experts.

Limitations of Enhanced CAP

The Enhanced CAP methodology has some constraints. The FRC metric works well for large, relatively unfragmented landscapes (i.e., ~100,000 to 1,000,000+ acres). However, the FRC departure scores of ecological systems become increasingly uncertain as landscape size decreases, as well as when system size decreases, especially for systems with longer return intervals of stand replacing disturbances (Provencher et al. 2008). Moreover, the FRC assessment is only as good as the field data used to train the interpretation of satellite imagery (Provencher et al. 2009). Land managers already have access to the freely-downloadable LANDFIRE geodata with national coverage. However, land managers may be reluctant to rely upon this data if they do not understand them or believe the data do not represent the actual vegetation and succession classes in the field. Distinguishing among closely related biophysical settings and various succession classes is frequently challenging, particularly when types occupy closely similar terrain (Barrett, S.W. et al. 2006). More importantly, LANDFIRE's method does not distinguish among different uncharacteristic classes (Barrett, S.W. et al. 2006), which is critically needed for Enhanced CAP in many landscapes. As a result, we chose to invest moderate funding (i.e., ~$60,000) in remote sensing to interpret satellite imagery to remedy these shortcomings.

While the FRC metric is a powerful, unified measure of ecological departure, it does not fully account for all impairments to ecosystems. The biggest gap for the Bodie Hills project and many other landscapes – distinguishing and accounting for high-risk vegetation classes – was addressed by developing this additional metric within the FRC framework. However, FRC does not currently account for the actual amount of habitat, or minimum dynamic area required for an ecosystem to withstand severe disturbances and accommodate characteristic wildlife species. Addressing habitat heterogeneity and habitat fragmentation requires the addition of compatible, affordable and user-friendly spatial modeling tools and metrics. We believe these gaps can be resolved through research, development and testing in future applications.

In general, VDDT was found to be an excellent tool for assessing current and future ecological condition and for testing alternative management strategies and the scale of their implementation for terrestrial and riparian ecosystems. However, aquatic systems require assessment using traditional CAP methods. VDDT state-and-transition models exist for reference conditions for most terrestrial and riparian ecosystems of the United States from www.landfire.gov. Some VDDT reference condition models have not been sufficiently peer-reviewed; additional external review can reduce the inherent error in all models. We recommend that attention be invested in modifying “off-the-shelf” LANDFIRE models to reflect local conditions and the latest interagency definitions of surface, mixed severity, and replacement fire. Effort also is needed to incorporate specific uncharacteristic vegetation classes and management actions and into the models (e.g., Provencher et al. 2007). Incorporating management actions into models is as much an art as a science; securing help from experienced modelers and reviewing existing models that incorporate management actions for comparable ecological systems is recommended. A well-developed predictive model can provide a reasonable approximation of reality.

The cost of completing an Enhanced CAP for a large landscape is moderately, but not prohibitively, expensive for the intended purpose - to inform and guide cost-effective management strategies over a period of years. The typical cost for a 100,000 to 1,000,000 acre landscape ranges from approximately $130,000 to $150,000 – of which about half is devoted to remote sensing expenses. If off-the-shelf LANDFIRE maps can be used, the expense is greatly reduced. A substantial amount of the remaining cost reflects the staff time required to do laborious model runs to test alternative management strategies; these costs can be reduced by the development of an optimizer for the VDDT software, which is currently under consideration. The total time required – including remote sensing during the summer season as well as two or three workshops with stakeholders – is typically around one year.

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