Fine-scale remote sensing applications to support vegetation and fire management planning and implementation

Pacific Northwest Cooperative Ecosystem Studies Unit
Task Agreement National Park Service

2012 Final Project Report

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Photo by E.K. Strand

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Abstract

This Task Agreement details the steps by which Lava Beds National Monument (LABE), and the Rangeland Ecology and Management Program at the University of Idaho will collaborate in development of fine scale remotely sensed digital data layers of vegetation and fuels for LABE. Lava Beds National Monument (LABE) recently initiated a pilot project to develop a comprehensive long-term vegetation management plan to be integrated with short-term fire and resource planning. LABE is an ideal setting for such an approach because: (a) it contains a complex mix of intact and degraded sagebrush steppe with differential response to fire, (b) juniper woodlands are expanding into sagebrush and other vegetation types, (c) exotic species, mainly cheatgrass, are present in the park with potential to spread, and (d) the park has experienced a relatively high rate of 20^{th} century burning. Thus, the decision to burn in LABE requires careful consideration of many factors due to these dynamic and altered fuels and expected response to fire. The purpose of this research is to develop state-of-the-art remote sensing techniques and high resolution spatial data layers that will complement and contribute to implementation of an integrated management plan at LABE. We investigated three different remote sensing methods: Classification of 1-m scale aerial imagery, spectral unmixing of time-series satellite images, and object extraction using wavelet analysis. Combining these remote sensing methods with field data from the park we produced high thematic resolution layers essential for vegetation and fuels management. Specifically, we developed maps of sagebrush steppe including cover of shrub, annual, and perennial grass; juniper woodland maps differentiating between four phases of woodland development and maps of lava cover. Fuel loading maps were developed via regression of vegetation cover and fuel types with correlation coefficients ranging from 0.4 to 0.8 for different fuel types.

Deliverables from the project include digital spatial data layers of the following attributes: shrub cover, functional successional stage, juniper density and crown area, exotic annual grass cover, fuel model, and fuel load. Additional deliverables include all collected field data, source code for classification of maps, a final report and a journal article submitted to a peer reviewed journal. Presentations of all work will be delivered to the NPS staff and at one professional conference.

Introduction

Burn plans typically address short- to intermediate-term objectives such as fuels reduction or "reintroducing" fire as an ecosystem process, but few park units have spatially explicit vegetation management plans that identify long-term desired future conditions. In 2008 Lava Beds National Monument (LABE) initiated a pilot project to develop a comprehensive long-term vegetation management plan that will be integrated with fire and resource planning. LABE is an ideal setting for such an approach because (a) it contains a complex mix of intact and degraded sagebrush steppe ecosystem with differential response to fire, (b) it has experienced a relatively high rate of 20th century burning relative to other parks. Thus, the decision to burn in LABE requires careful consideration of many factors. Moreover, LABE contains a rich network of fire effects monitoring data and recent research for decision support.

Importance of Research for Fire Management

This research will directly address two fire management priority areas: 1) Research that supports Fire Management Plan revisions, especially for 5 year fuels treatment plans, and 2) Research that assists in removing stumbling blocks and hurdles for implementing fuels treatment and fire use. Table 1 outlines in detail how our results will be used individually and collectively to assess ecological site conditions, establish burn units based on quantitative structural and compositional parameters, and monitor landscape dynamics following fire. Specific language in is included to describe vegetation management applications (Table 1).

The remote sensing algorithms and products are directly applicable in similar vegetation communities or in most shrub-dominated ecosystems. While this is this is restricted to a few NPS units (e.g., Great Basin, John Day Fossil Beds, Santa Monica Mountains, etc.), fire occurrence is inevitable in those units and support staffs are small, so these products would be very pertinent. These algorithms have very wide application across the western US in non NPS units, which would reinforce the importance and relevance of NPS units as unique natural laboratories for applied fire research.

Most importantly, we believe the most important contribution of this project will be to demonstrate a link between research and applied fire management planning. This spatial data will facilitate directly decisions of where, when and how to burn – or if burning is even a viable option – to achieve long-term desired future conditions.

Goals and Objectives

The purpose of this proposed research is to develop state-of-the-art remote sensing techniques and high resolution spatial data layers needed to complete and implement an integrated management plan LABE. The spatial data layers needed for planning efforts in LABE derive directly from empirical, site-specific research and fire effects data (FMH) and are not available in national databases. Moreover, the fine-scale vegetation mosaic and relatively small size of the park, combined with the detailed knowledge of successional pathways, dictate that higher resolution data be obtained than currently exists. Vegetation is highly dynamic and any data layers must therefore be developed with automated methods that can be frequently updated.

Primary remotely sensed and secondary post-classification processing data layers produce from this research are listed in Table 1, including information about the ecological basis and justification, direct management application(s), remote sensing approach, field data, and spatial coverage.

In addition to facilitating current planning efforts, this research was timely because we were able to build upon data collected via other efforts including 1) intensive field data collection efforts during 2009 by Kupfer and Farris, 2) Odion et al. 2010, 3) Miller et al. 2003. These data could be used as training and validation data and this cost savings is assumed in the submitted budget.

Deliverables

Project deliverables include:

- Spatial data layers listed in Appendix A, delivered in compatible GIS format
- Field data (original data plus summary statistics).
- Source code for classification algorithms and any external software routines
- A final report and an article submitted to a peer reviewed journal
- Detailed presentation on research results to NPS staff
- One on one training to show NPS staff how to perform classifications and update products (including support of the University of Idaho Remote Sensing Lab)

Study Area

Lava Beds National Monument is located in northeastern California (Lat 41°42′50″N, Long 121°30′30″W), 77 kilometers southwest of Klamath Falls, Oregon. The monument was established by the US Forest Service in 1925 and was transferred to the National Park Service in 1933; the park encompasses an area of 18,900 ha. Elevation ranges from 1,230 m at Tule Lake in the northeast, to 1,725 m in the southwest. The climate is typical of the high elevation semi-arid desert with hot dry summers and cold winters. The average annual high temperature is 16 °C, an average annual low of 2 °C and extremes ranging from -8 °C to 39 °C. Average annual precipitation at the monument's headquarters, located at the southern end of the park, is 39 cm with the majority falling between October and June. Thunder and lightning are common during the summer months. The geology is unique and volcanic formations include lava tubes, caves, cinder cones, spatter, cones, craters, lava flows and lava fields. The lava flows in the park ranges in age from 2 million years ago to 1110 years ago while most of the lava tubes were formed 30,000-40,000 years ago. Soils in the southern portion of LABE are primarily composed of gravelly to cobbly sandy loams formed from pumice (Vitrandepts). Soils occupied by western juniper (*Juniperus occidentalis*) are typically coarser with gravely sand to stony cobbly loams, strongly influenced by pumice (Erhard 1980).

The park vegetation is characterized by mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) and bunchgrasses including bottlebrush squirrletail (*Elymus elymoides*), Sandberg's bluegrass (*Poa secunda*), Thurber's needlegrass (*Achnatherum thurberianum*), Columbia needlegrass (*Achnatherum nelsonii*), bluebunch wheatgrass (*Pseudoroegneria spicata*), and prairie Junegrass (*Maireana pyramidata*). Cheatgrass (*Bromus tectorum*) is present in the park and dominant in places recently burned in the Jack fire of 2009 in the northern end of LABE. The southern portion of the park host open ponderosa pine (*Pinus ponderosa*) woodland and western juniper (*Juniperus occidentalis*) woodlands. Western juniper is expanding into the ponderosa pine in the south and the sagebrush steppe to the north. All successional stages of juniper, as described by Miller et al. (2005) are present in the park. Curlleaf mountain-mahogany (*Cerocarpus ledifolius*) is common in continuous patches the south and southwestern end of the park. At the southern end of LABE, Millet et al. (2003) identified six plant associations that are currently occupied by old and/or young western juniper trees. Miller et al. (2003) describe that the distribution of these plant associations across LABE is a function of temperature and available moisture, which are in turn functions of slope, aspect, soil, and elevation. The plant associations they identified are common throughout the range of western juniper (Eddleman et al. 1994, Miller et al. 2000).

The Park Service's archival records of fire indicate that only 1,400 ha burned at LABE between 1910 and 1931, increasing to 7,500 ha during the 1930s. The fires of 1941 and 1949 were the most extensive during the 20th century covering approximately 24,000 ha. During the decades of 1950 and 1960 only a few small fires burned across LABE. In 1973 a 380-ha fire threatened the headquarters and visitor center. This threat prompted the beginning of a prescribed fire program at LABE to reduce fuel loads and decrease the expansion of western juniper. Since the 1973 wildfire, fires greater than one hectare have been prescribed except for the lightning started Jack Fire that burned 2,500 ha in the northern part of the park in 2009 (Figure 1 and 2).

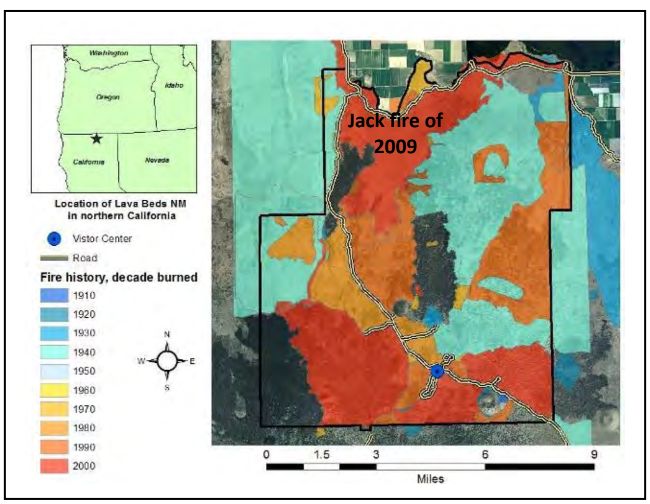

Figure 1. Fire history for Lava Beds NM.

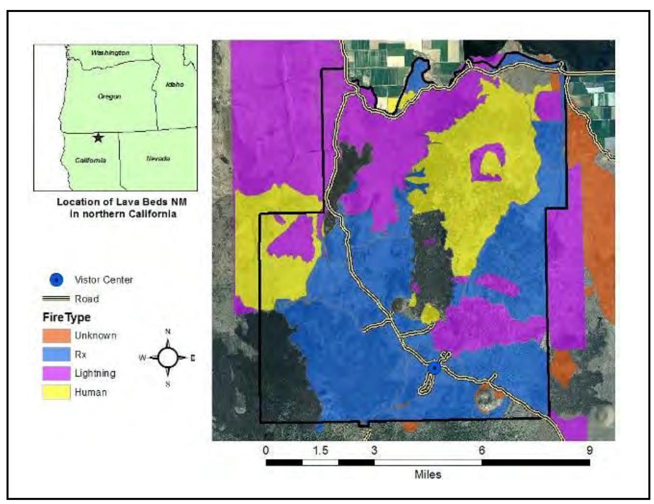

Figure 2. Fire cause in Lava Beds NM.

Methods

Ground data collection

Existing ground data was used whenever possible for training data and validation of maps and include: Fire effects data collected by the NPS LABE staff since year 2000; plots established by Miller et al. (2003) in the woodlands of LABE; plots established by the University of South Carolina (Kupfer et al. 2010); and data collected by Dennis Odion in 2010.

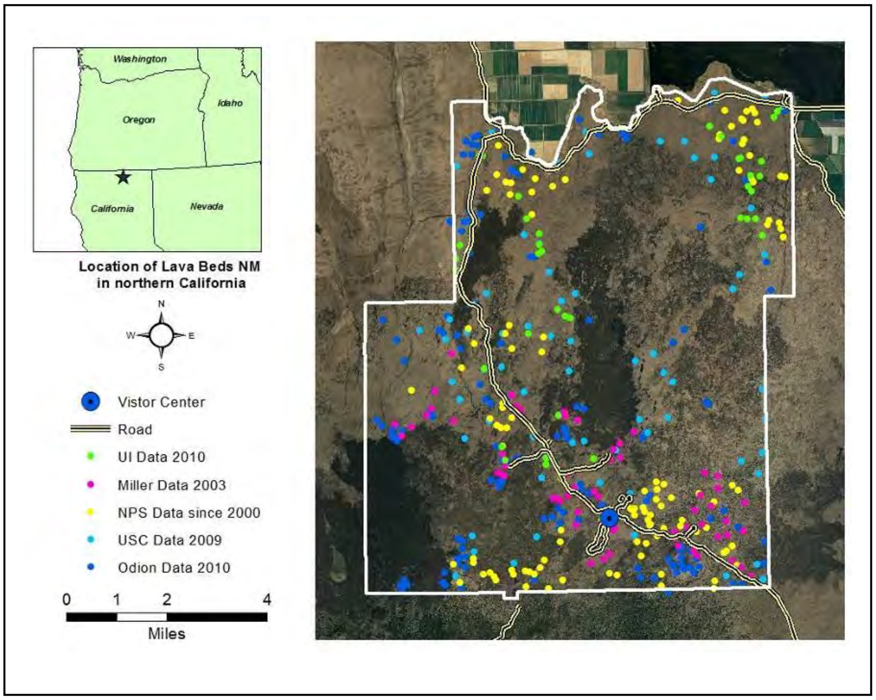

Figure 3. Field data points in LABE by this and other data collection efforts.

An additional 43 vegetation transects were established in the sagebrush steppe cover type in LABE during the summer of 2010. Plot sites were non-randomly selected with the goal to be representative of a wide range of shrub cover, perennial grass cover and annual grass cover. At each plot site, the start location of a 30-m transect was randomly selected by tossing a metal pin in a random azimuth. Vegetation data was collected according to the line-point intercept method using the USDI National Park Service Fire Monitoring Handbook (2003), data sheet FMH-16. Plants by species, litter and bare ground were recorded by dropping a pin through the vegetation to the ground in 100 locations evenly placed along the transect. Percent plant cover by species was calculated and also summarized by functional group: shrub, perennial grass, annual grass, perennial forb, and annual forb. Bare ground and litter cover was estimated similarly. Fine and woody fuel was recorded by time lag class (1 hr, 10 hr, 100 hr) according to Brown's (1974) methods, see USDI National Park Service Fire Monitoring Handbook (2003). Topographic variable slope, elevation aspect, habitat type, and GPS coordinates (UTM, zone 10, NAD83) were recorded at the center of each transect.

Classification of vegetation cover

In response to the need for fine-scale vegetation structure maps and more detailed thematic classifications we developed a fine scale vegetation map was created by classifying National Agriculture Imagery Program (NAIP) aerial photography from 2009 into six land cover classes: conifer, sagebrush, perennial grass, annual grass, bare ground, and lava. The 1-m resolution 2009 NAIP multi-spectral images included blue, green, red, and a near Infrared bands. Field data was used to train the maximum likelihood image classification algorithm in the ENVI software (Exelis 2009) to create the final map of cover type at 1-m resolution. Maps of canopy cover for each of the six land cover types were created by summarizing the number of pixels of the same cover type within 30-m grid cells.

Woodland structural stages, as defined by Miller et al. (2005) were mapped by classifying the conifer cover maps into the following classes:

1) Phase 1 (P1): Initiation of woodland development where trees are present but the sagebrush steppe vegetation is still dominating the ecological processes (juniper canopy cover < 5%).

2) Phase 2 (P2): Young woodland development where woodland and steppe vegetation are co-dominant and both are affecting ecological processes (juniper canopy cover 5-15%)

3) Phase 3 (P3): Mixed age woodlands were the woodland component is dominating ecological processes (juniper canopy cover 15-30%)

4) Mature (M): Mature woodland (> 30% juniper canopy cover)

Method for quantifying conifer density and crown area

In addition to the maximum likelihood classification described above, conifer cover was also quantified using a novel method for automatic detection of size and location of individual trees based on wavelet technology (Strand et al. 2006). The Normalized Difference Vegetation Index (NDVI), a strong indicator of green vegetation, was derived from the red and infrared band in the NAIP aerial photographs at 1 m resolution ((IR-R)/ (IR+R)). The NDVI images were then processed through a mathematical algorithm in the Matlab software and the output is a table containing the UTM coordinates and the estimated crown diameter for individual trees. The wavelet method has compared well to manual field measurements of western juniper crowns (R=0.86, see Strand et al. 2006). The output of individual tree locations was buffered with the crown diameters to create a data layer representative of conifer cover and density.

Methods for mapping fuel load

Fuel load was estimated from data collected for the SageSTEP project (Stebleton and Bunting 2009) in sagebrush steppe and juniper woodlands. We estimated the fuel load for herbaceous fuel, litter, 1 hour timelag shrub fuels and 10 hour timelag shrub fuels via linear regression with percent canopy cover of shrubs, perennial grasses, and annual grasses as the independent variables.

Results and Discussion

Cover type and canopy cover maps

The map products produced as part of this project included a fine-scale (1-m resolution) land cover map with six land cover classes: conifer, sagebrush, perennial grass, annual grass, bare ground, and lava (Figure 4). Maps of canopy cover for each of the six land cover types were created by summarizing the number of pixels of the same cover type within 30-m grid cells (Figures 5 – 10). The conifer cover type includes both ponderosa pine and western juniper (Figure 5). A post-classification correction was made for the sagebrush canopy cover map such that the maximum canopy cover was set to 60% (Figure 6). The decrease in sagebrush canopy cover in some pixels was compensated for by an increase in the cover of bare ground (Figure 9). Annual grasses were particularly predominant in the area burned by the Jack Fire in 2009, but were scattered in low concentrations across the park (Figure 8).

A summary of the collected field data and a species list is included in Appendix B. A list of all GIS data layers produced as part of this project is included in Appendix C.

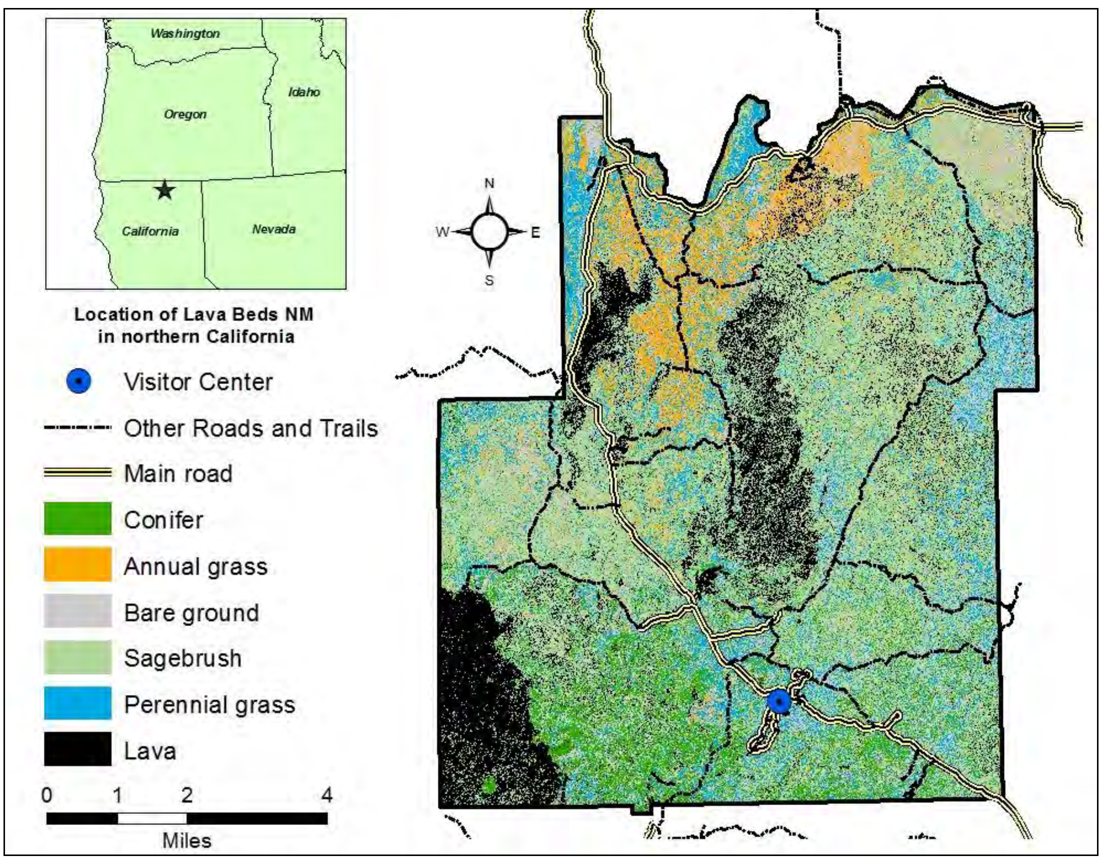

Figure 4. Land cover types at 1 m resolution classified from NAIP imagery.

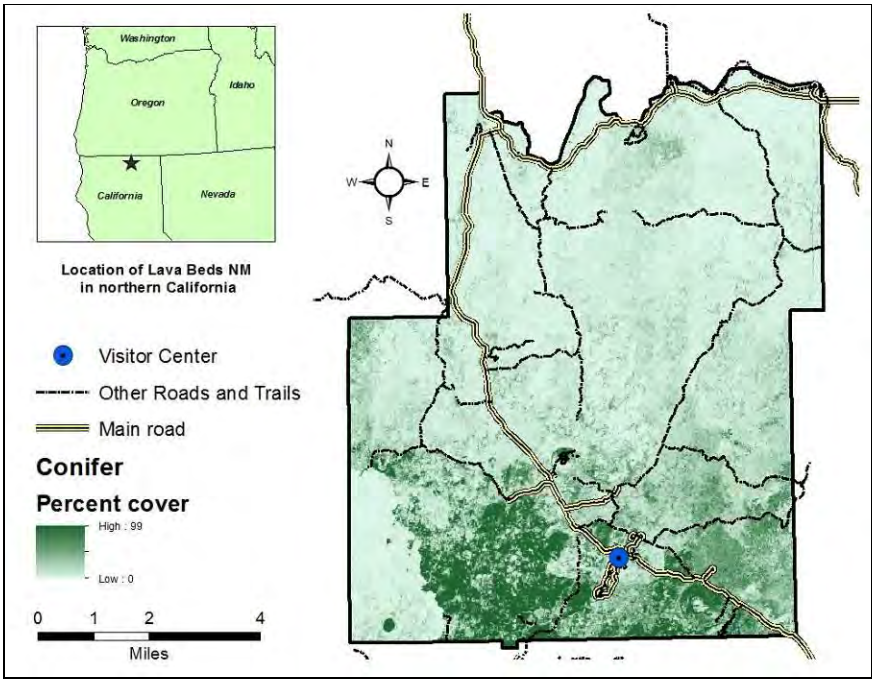

Figure 5. Map of conifer canopy cover at 30 m resolution. Conifers in LABE include western juniper and ponderosa pine.

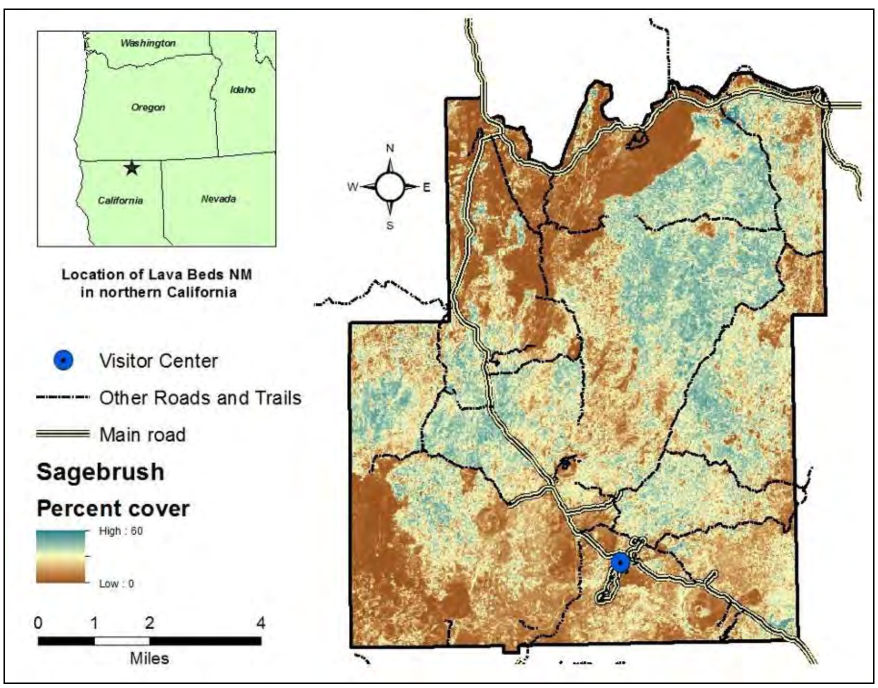

Figure 6. Map of shrub canopy cover at 30 m resolution. The dominant shrub type in LABE is mountain big sagebrush but other shrub species include rabbit brush and bitterbrush.

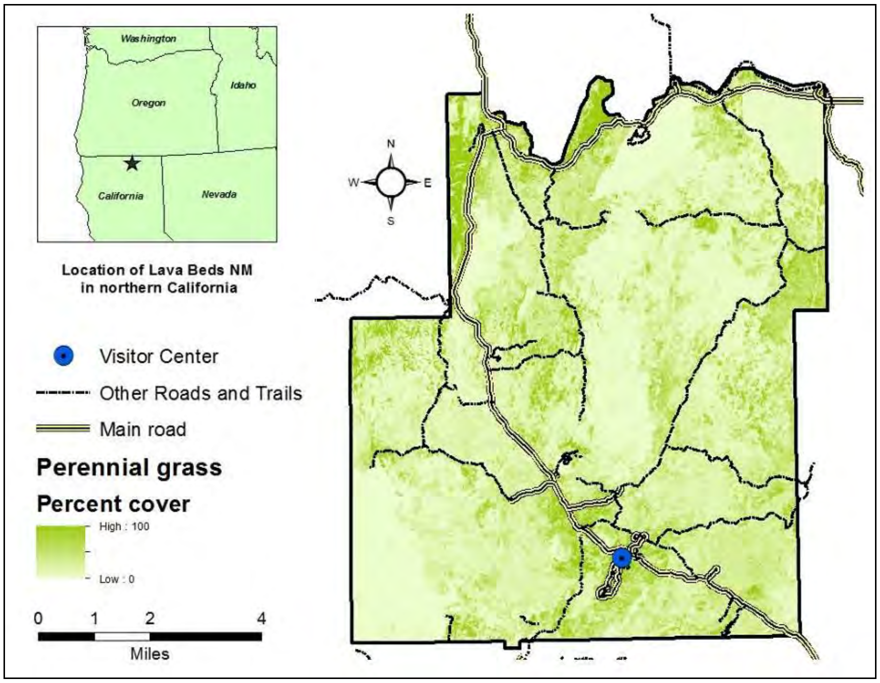

Figure 7. Map of perennial grass cover at 30 m resolution. The dominant perennial grasses in LABE include bluebunch wheatgrass, Idaho fescue, needlegrass, and bottlebrush squirreltail.

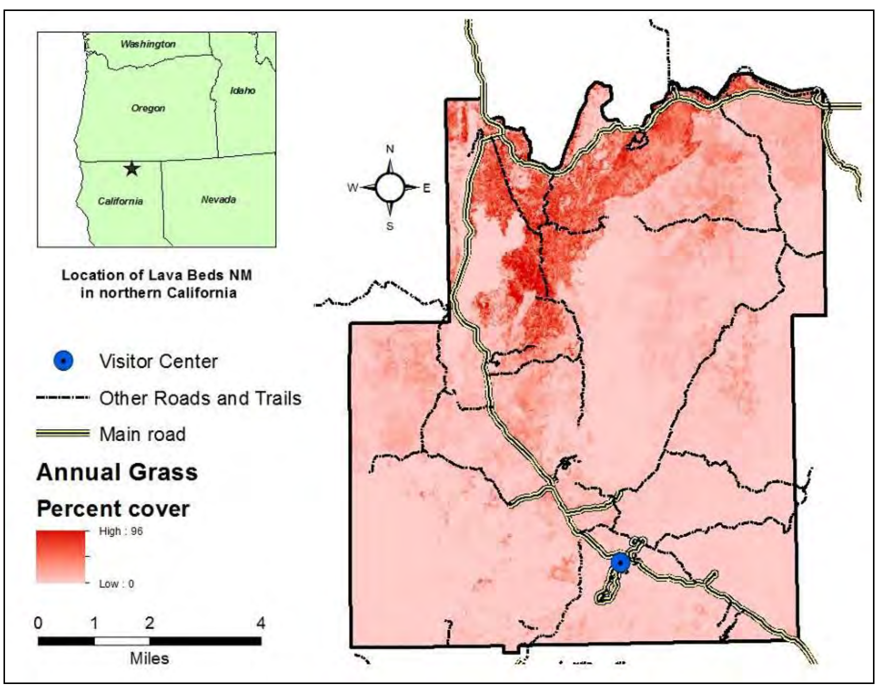

Figure 8. Map of annual grass cover at 30 m resolution. The dominant annual grass in LABE is cheatgrass.

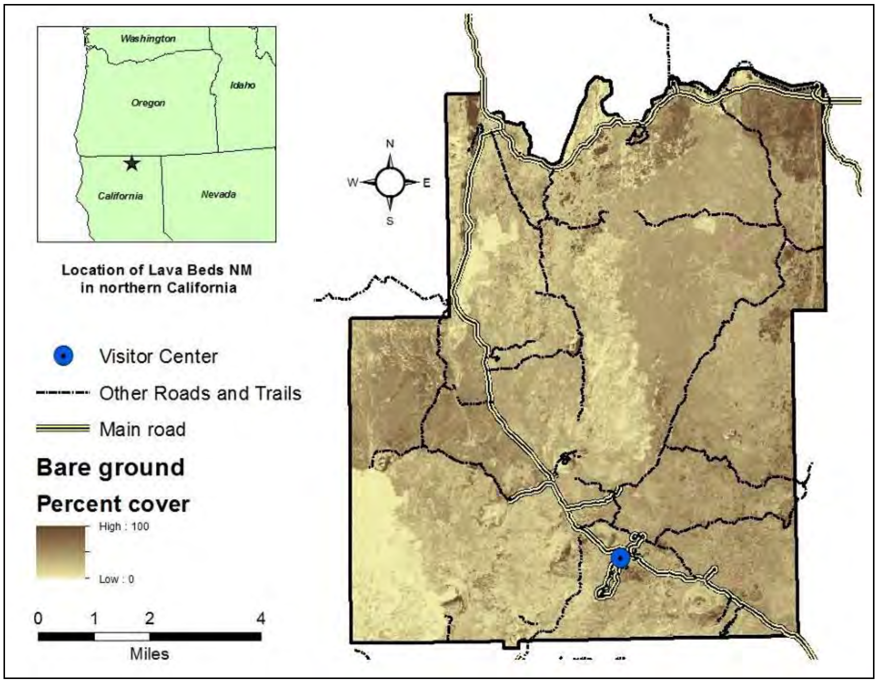

Figure 9. Map of bare ground cover at 30 m resolution.

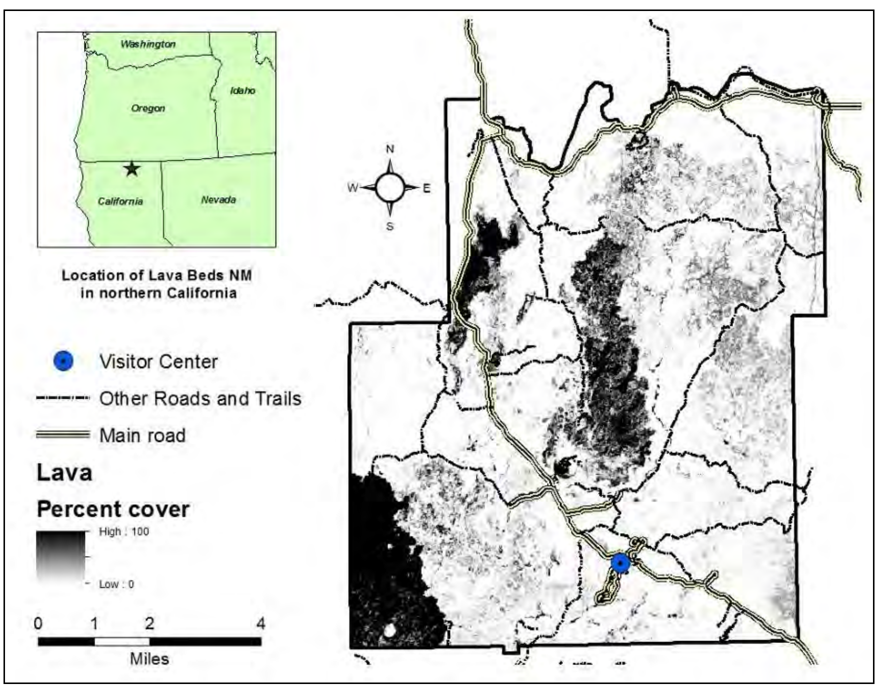

Figure 10. Map of lava cover.

Woodland structural stages, as defined by Miller et al. (2005) were mapped by classifying the conifer cover maps into the following classes:

1) Phase 1 (P1): Initiation of woodland development where trees are present but the sagebrush steppe vegetation is still dominating the ecological processes (juniper canopy cover < 5%).
2) Phase 2 (P2): Young woodland development where woodland and steppe vegetation are co-dominant and both are affecting ecological processes (juniper canopy cover 5-15%)
3) Phase 3 (P3): Mixed age woodlands were the woodland component is dominating ecological processes (juniper canopy cover 15-30%)
4) Mature (M): Mature woodland (> 30% juniper canopy cover)

Vegetation or fuel composition in the LABE woodlands was not recorded as part of this project. Fuel composition within each structural stage has however been recorded as part of the SageSTEP project on similar ecological sites, although without the lava component. This information is available to inform fuel assessments and development of burn plans (Stebleton and Bunting 2009).

Because ponderosa pine and western juniper were lumped in into a conifer cover type, the ponderosa pine portion of the park was classified into the same woodland phases as the western juniper. Ponderosa pine and western juniper could be separated by overlaying a cover type boundary.

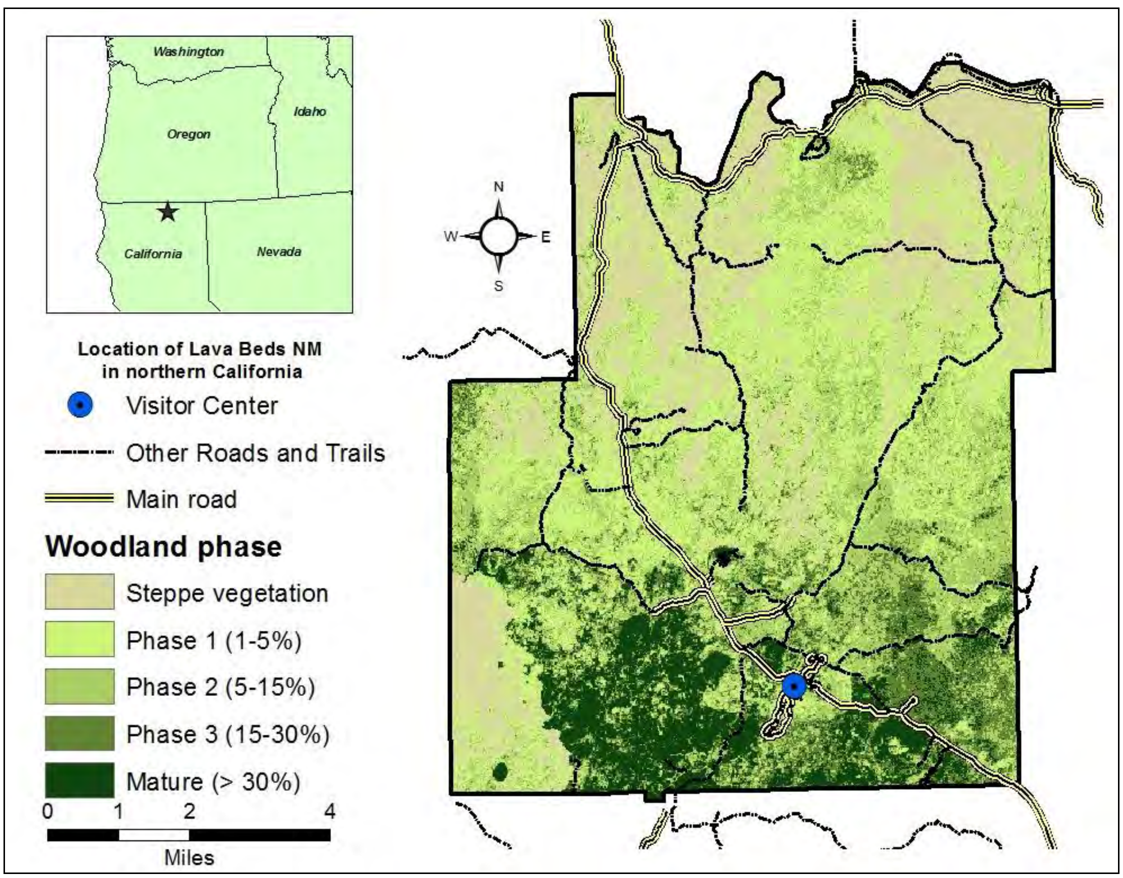

Figure 11. Map of woodland phases derived from the conifer cover maps.

Woodland tree density and crown area

Conifer density and cover was also quantified using a novel method for automatic detection of size and location of individual trees based on spatial wavelet analysis (Strand et al. 2006). The input image was a 1-m resolution NDVI image derived from a multispectral NAIP imagery. The output is a table containing the UTM coordinates and the estimated crown diameter for individual trees. The output of individual tree locations was buffered with the crown diameters to create a data layer representative of conifer cover and density. An example of how the wavelet algorighm outlines individual trees around the LABE Visitors Center is illustrated in Figure 12 below. It should be noted that identification of individual trees with the wavelet analysis works well when the tree canopy cover is below 50% (Strand et al. 2006). In areas with higher tree canopy cover the wavelet algorithm tend to miss significant expanses of woodland, this phenomenon was observed in the analysis of the LABE landscape. Output data layers are listed in Appendix C.

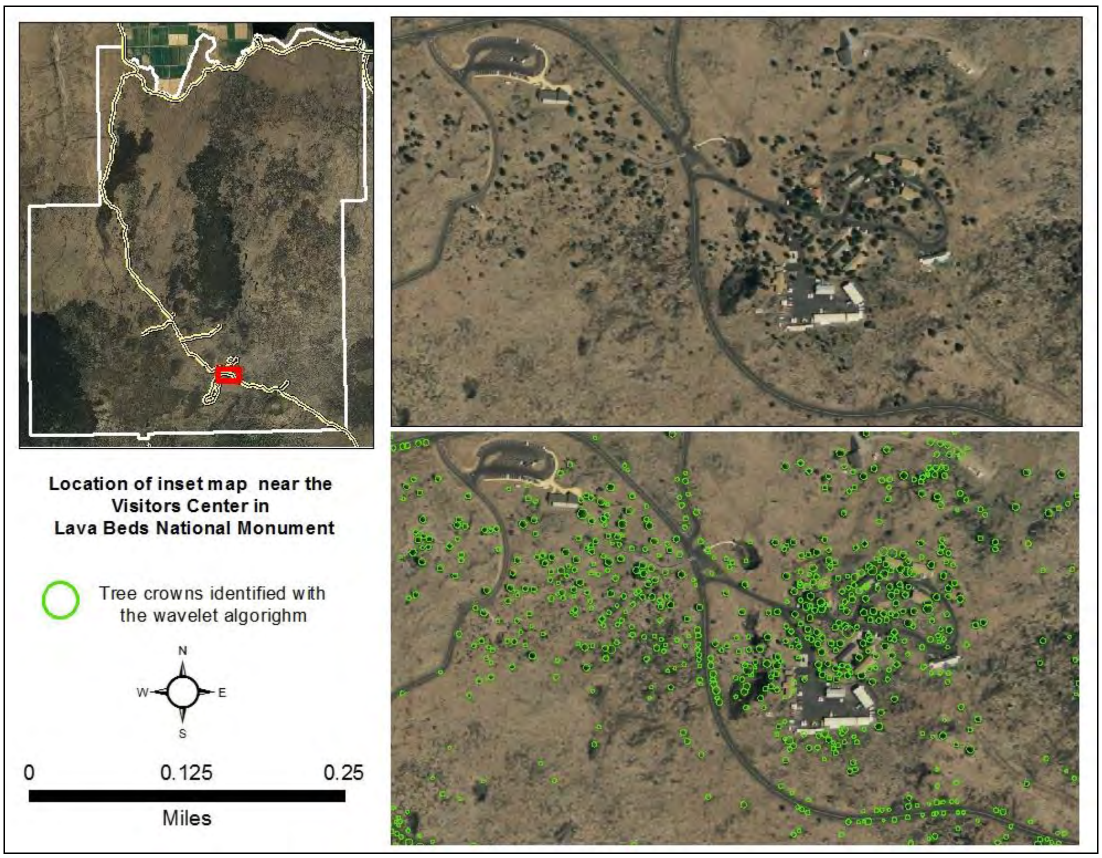

Figure 12. Individual trees were identified using a wavelet algorithm. This image shows an example near the Visitors Center.

Fuel load maps

Fuel load was estimated from data collected for the SageSTEP project (Stebleton and Bunting 2009) in sagebrush steppe and juniper woodlands. We estimated the fuel load for herbaceous fuel, litter, 1 hour timelag shrub fuels and 10 hour timelag shrub fuels via linear regression with percent canopy cover of shrubs, perennial grasses, and annual grasses as the independent variables (Figure 13 and 14). All independent variables included were significant at alpha = 0.05. The following equations were used in the estimates based on 266 SageSTEP plots in mountain big sagebrush steppe vegetation:

Shrub fuel 1 hr (kg/ha) = 219.749 * S - 55.248 * PG – 47.468 * AG (r = 0.84)

Shrub fuel 10 hr (kg/ha) = 97.2 * S - 14.408 * PG (r = 086)

Total Herbaceous Fuel (kg/ha) = 243.7799 - S * 9.2205 + PG * 10.8741 + AG * 4.0127 (r = 053)

Litter (kg/ha) = 279.3994 – 7.1864 * S + 5.05077 * PG (r = 038)

Where: S = % sagebrush canopy cover
PG = % perennial grass cover
AG = % annual grass cover
r = correlation coefficient for the relationship

A caveat in the estimate of fuel loads is the lava component present at LABE, which was not present in the SageSTEP plots used to develop these relationships. We therefore recommend that the fuel loads in areas dominated by lava is interpreted with caution.

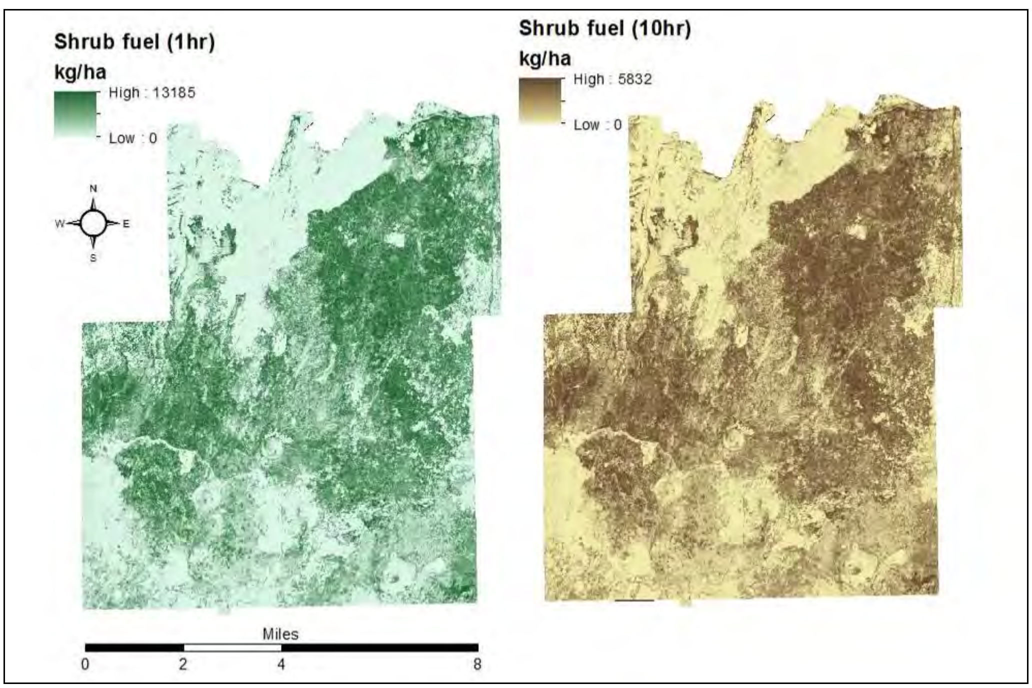

Figure 13. Map of 1 hr and 10 hr timelag shrub fuel.

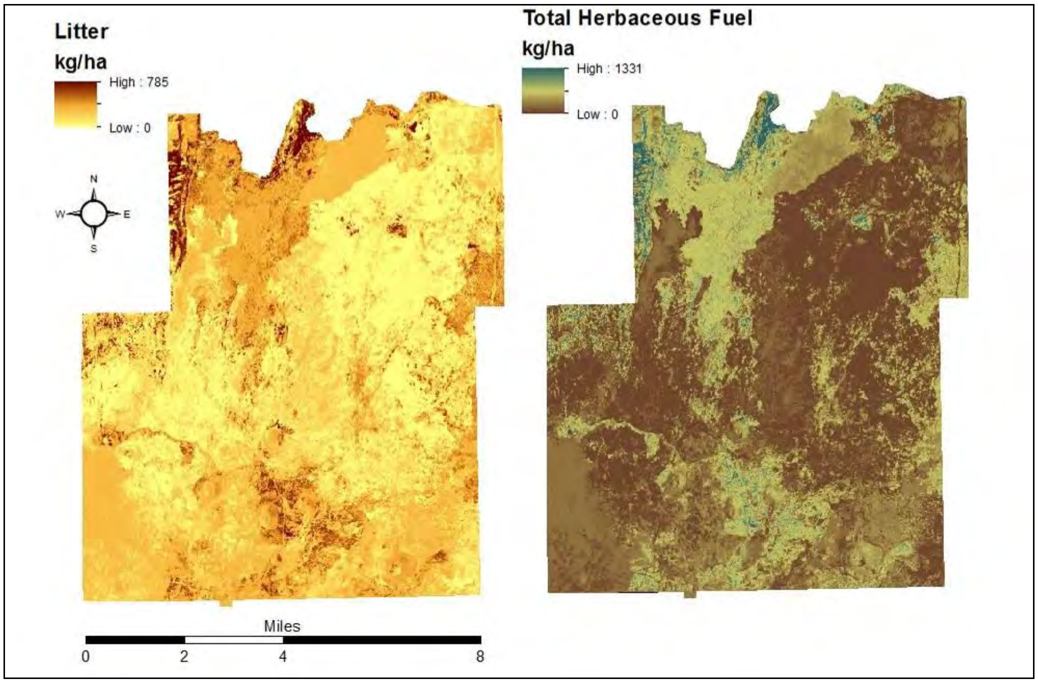

Figure 14. Map of litter and total (live and dead) herbaceous fuel.

Fulfillment of Deliverables

Project deliverables include:

- Spatial data layers delivered in compatible GIS format
    - All data layers delivered as part of this project are compatible with ArcGIS and are listed in Appendix C.
- Field data (original data plus summary statistics).
    - Field and original data is provided in Appendix B.
- Source code for classification algorithms and any external software routines
    - Source code for the wavelet algorithm is provided in Appendix D.
- A final report and an article submitted to a peer reviewed journal
    - This document is the final project report and a journal article is in progress.
- Detailed presentation on research results to NPS staff
    - A presentation to NPS staff was conducted on October 31, 2012 and a conference presentation was given at the Northwest Science meeting in Boise on March 27, 2012.
- One on one training to show NPS staff how to perform classifications and update products (including support of the University of Idaho Remote Sensing Lab)
    - This training will be provided upon request from LABE.

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Appendix A. Spatial data layers deliverables

SPATIAL DATA LAYER	ECOLOGICAL SIGNIFICANCE/ FOUNDATION	VEGETATION/FIRE MANAGEMENT APPLICATION(S)/OBJECTIVE	REM. SEN. APPROACH	FIELD DATA	SPATIAL COVERAGE
Shrub Cover	Strong inverse relationship between shrub cover and native species diversity (NPS FMH Data); Thresholds identified that predict post-fire response and steady states (Miller et al. 2000a, 2000b); Shrub strongly related to age and time-since-fire (Miller et al. 2003).	Determine spatial and temporal burn rotations using on shrub cover trigger points; Maintain mix of shrub cover to maximize native biodiversity (in "positive response zones"); Interpolate FMH cover-diversity curves for landscape monitoring.	Strand 2006 (fusion of digital aerial photo and IR satellite bands)	FMH data; Utilize Kupfer and Farris 2009 field season;	Park-wide
	Key habitat suitability variable for sage grouse (USFWS 2005)	Sage grouse habitat management in north zone; Old-growth shrub management in degraded range ("poor response zone"); monitor "patch burning" efficacy.			
Functional Successional Stage	Four woodland/shrub steppe successional stages have been developed using site-specific plot and age class data: *early, mid, late, closed* (Miller et al. 2003, Miller et al. 2000b); Major habitat types have distinctive successional stage sequences and proportions; Ecological function and structure well documented for each stage; Spatial patch structure strongly related to post-fire recovery (Strand et al. 2006)	Incorporate spatial patterns of tree cover thresholds Plan burn units to maintain spatiotemporal successional stage distributions to maximize ecosystem resilience; Maintain successional stages proportionate to habitat types; Monitor and project successional trajectories Unique pathways for each vegetation type; identify burn rotations and proportions within habitat types	Post-classification model (shrub and tree cover + texture analysis)	FMH; Kupfer and Farris 2009; Miller et al. 2003.	80% Park-wide (not applicable in PIPO zone)
Juniper density/crown area	Juniper cover strongly correlated to herbaceous and shrub production (Miller et al. 2003, Miller and Heyerdahl 2008); Direct relationship between crown width or circumference with tree age (Miller et al. 2003); Well defined density thresholds predict potential successional pathways (Miller et al. 2000)	Direct input into successional stage data layer; Identify juniper cover thresholds to improve post-fire response; Predict and monitor forest-shrubland ecotone resistance and resilience (a key climate change indicator). Determine if ecotones are expanding or contracting.	Strand et al. 2008 (Wavelet Analysis and object classification)	FMH; Kupfer and Farris 2009; Miller et al. 2003; Validation data in 2010	Partial (ecotones, encroachment zones)
Exotic Annual Grass Cover	Cheatgrass and medusahead invasion an indication of degraded range; High cover may alter fire behavior and frequency; Indirectly related to potential response of native species (FMH data); Vital sign parameter for monitoring long-term change in "control" plots	Monitor fire effects; monitor spatial pattern of controls; Quantify fire frequency/cheatgrass relationship; Spatially weighted regression to predict future cover using FMH data	New algorithm (this study) (based on Bradley and Mustard, 2005)	This proposal (collect 2010)	Partial (transition zones)
Fuel Model	Rate of spread a direct function of shrub cover and height (Brown 1982 nomograms); Better estimation of basalt cover improves fuel model estimation and and refugia for old-growth mahogany (Powell 2005)	Improved ability to predict fire behavior and effects; Validate time-series models of fuel model succession.	GIS integration of shrub cover/exotic cover/suc-cession stage	FMH data; Kupfer and Farris 2009	Park-wide
Fuel Load	Directly related to potential fire intensity and severity in woodlands, which are predictors of subsequent post-fire impacts to soils and exotic plant establishment (Ottmar et al. 1998).	Improve prediction of fire intensity and effects; Identify potential exotic species response; Target mechanical treatments in areas with potential alternate steady state from high intensity burning.	Post-classification (juniper density texture analysis)	New data collection (2010 calibration)	Partial (shrub/juniper dominated areas)

Appendix B. Plant species list and data collections in June 2010

Symbol	Plant Type	Common Name	Scientific Name (NRCS Plants Database)
Shrubs			
Artr	S	big sagebrush	*Artemisia tridentata*
ArtrD	D	Dead big sagebrush	Dead *Artemisia tridentata*
Cele	S	curl-leaf mountain mahogany	*Cercocarpus ledifolius*
Chna	S	rubber rabbitbrush	*Ericameria nauseosa*
ChnaD	D	dead rubber rabbitbrush	*Dead Ericameria nauseosa*
Chvi	S	yellow rabbitbrush	*Chrysothamnus viscidiflorus*
Prem	S	bitter cherry	*Prunus emarginata*
PutrD	S	Dead antelope bitterbrush	*Dead Purshia tridentata*
Putr	S	antelope bitterbrush	*Purshia tridentata*
Syal	S	snowberry	*Symphoricarpos albus*
Teca	S	spineless horsebrush	*Tetradymia canescens*
TecaD	D	spineless horsebrush	*Dead Tetradymia canescens*
UnkChry	S	Unknown Chrysothamus	
Perennial Grasses and Grass-like plants			
Acth	PG	Thurber's needlegrass	*Achnatherum thurberianum*
CAREX	PG	Sedge	Carex spp.
Kopy	PG	prarie Junegrass	*Maireana pyramidata*
POA	PG	bluegrass	Poa spp.
Pose	PG	Sandberg bluegrass	*Poa secunda*
Pssp	PG	bluebunch wheatgrass	*Psuedoroegnaria spicata*
Sihy	PG	squirreltail	*Elymus elymoides*
Stco	PG	Columbia needlegrass	*Achnatherum nelsonii*
Stipa	PG	stipa	*Stipa spp.*
Stth	PG	Thurber's needlegrass	*Stipa thurberiana*
Annual grasses			
Brte	AG	cheatgrass	Bromus tectorum
Perennial Forbs			
Acmi	PF	Common yarrow	Achillea millefolium
Crep	PF	tapertip hawksbeard	*Crepis acuminata*
Debi	PF	low larkspur	*Delphinium bicolor*
Erfi	PF	threadleaf fleabane	*Erigeron filifolius*
Erig	PF	fleabane	*Erigeron* spp
Lepto	PF	prickly phlox	*Leptodactylon*

Phhe	PF	varileaf phacelia	*Phacelia heterophylla*
Phho	PF	carpet phlox	*Phlox hoodii*
Phlox	PF	phlox	*Phlox* spp
Wood	PF	cliff fern	*Woodsia*

Annual forbs

AnnForb	AF	Annual Forb	
Clarkia	AF	Clarkia	*Clarkia*
Copa	AF	maiden blue eyed Mary	*Collinsia parviflora*
Drve	AF	Spring draba	*Draba verna*
Eppa	AF	tall annual willowherb	*Epilobium brachycarpum*
Gadi	AF	spreading groundsmoke	*Gayophytum diffusum*
Houm	AF	jagged chickweed	*Holosteum umbellatum*
Phli	AF	threadleaf phacelia	*Phacelia linearis*
Stel	AF	starwort	*Stellaria spp.*
Trdu	AF	yellow salsify	*Tragopogon dubius*

Lower Layer & Ground Cover

L	L	Litter
BG	BG	Bare Ground
Deadwood	DW	Deadwood
Li	L	Litter
R	R	Rock (rock fragment >5mm)

PlotID	Date	Bearing	PVT	Structural Stage	Elevation	Aspect	Slope	Easting	Northing
UI1	6/17/2010	10	Artrv	R34	1359	330	7	619857	4623727
UI2	6/17/2010	235	Artrt	R2	1246	70	12	619697	4630606
UI3	6/17/2010	130	Artr	R2	1242	300	5	619814	4630610
UI4	6/17/2010	225	Artrt	R3B	1247	50	3	629286	4632021
UI5	6/17/2010	250	Artrt	R3b	1246	100	2	629175	4631831
UI6	6/17/2010	90	Artrtr	R3B	1293	40	4	629407	4632178
UI7	6/18/2010	75	Artrt	R3B	1245	160	4	627331	4632412
UI8	6/18/2010		Artrt	R3B	1260	.	0	628428	4629952
UI9	6/18/2010	290	Artrwy	R3B	1257	290	2	628701	4629947
UI10	6/18/2010	50	Artrwy	R3A	1237	60	3	628771	4630406
UI11	6/18/2010	160	Artrwy	R3B	1254	320	4	628033	4630486
UI12	6/18/2010	70	Artrva	R3B	1255	110	2	628097	4630525
UI13	6/18/2010	330	Artrwy	R3B	1242	70	3	627478	4631231
UI14	6/19/2010	260	Artrwy	R3B	1239	140	2	627101	4631550
UI15	6/19/2010	320	Artrv	R3A	1333	10	8	621284	4624876
UI16	6/19/2010	220	Artrv	R2	1295	30	4	622627	4625386
UI17	6/19/2010	80	Artr	R3B	1295	300	8	622466	4625434
UI18	6/19/2010	130	Artrv	R1	1289	70	3	622218	4625633
UI19	6/19/2010	315	Artrv	R1	1445	60	1	622329	4620183
UI20	6/20/2010	85	Artrv	R3B	1403	160	5	623386	4620839
UI21	6/20/2010	170		R1	1447	120	4	621872	4620866
UI22	6/20/2010	340	Artrv, Juoc	R3B	1483	35	1	620533	4620796
UI23	6/21/2010	75	Artrv, Juoc	R3B	1479	150	3	620418	4621205
UI24	6/21/2010		Artrw	R1	1265	350	8	621703	4627511
UI25	6/21/2010	245	Artr	R1	1263	200	4	621604	4627433
UI26	6/21/2010	100	Artrwy	R1	1253	280	2	621632	4627742
UI27	6/21/2010	250	Artrwy	R1	1252	250	1	621620	4628087
UI28	6/21/2010	300	Artrwy	R1	1241	260	2	621224	4628564
UI29	6/21/2010	45	Artrwy	R1	1248	60	2	620972	4629290
UI30	6/21/2010	180	Artrwy	R3A	1237	340	2	626734	4632248
UI31	6/22/2010	50	Artrt	R3B	1258	60	.	628432	4629447
UI32	6/22/2010	270	Artrwy	R3B	1259	360	2	628571	4628574
UI33	6/22/2010	275		R3B	1262	30	3	628781	4628021
UI34	6/22/2010	130	Artrwy	R3B	1259	140	2	628306	4628555
UI35	6/22/2010	310	Artrwy?	R3B	1264	210	3	628086	4628606
UI36	6/22/2010	125	Artr	R3B	1261	20	1	628338	4629624
UI37	6/23/2010	230	Artr	R3B	1320	290	.	618940	4626920
UI38	6/23/2010	320	Artrv	R3A	1315	240	9	618942	4627289
UI39	6/23/2010	195	Artr	R3A	1350	230	10	619069	4627719
UI40	6/23/2010	80	Cele	R3B	1454	340	5	621835	4620655
UI41	6/23/2010	325	Artr, Putr	R3A	1438	220	3	621847	4620875
UI42	6/24/2010	330	Artrv	R3B	1442	360	1	622250	4622230
UI43	6/24/2010	95	Artrv	R3B	1491	5	5	623635	4618844

PlotID	1hr	10hr	100hr	Shrub Live	Shrub Dead	PG	AG	PF	AF	Litter	Rock	BG
UI1	46	10	2	20	4	17	2	0	0	6	27	24
UI2	24	5	2	0	0	3	85	3	0	8	1	0
UI3	0	0	0	0	0	22	34	0	0	10	24	10
UI4	287	60	2	19	3	3	13	1	0	33	5	22
UI5	154	31	3	24	0	0	1	0	0	24	1	50
UI6	579	43	0	20	0	5	20	1	0	27	17	10
UI7	566	79	16	34	7	0	7	0	0	44	0	8
UI8	212	43	13	9	4	5	29	0	0	27	1	25
UI9	171	34	2	20	5	10	10	0	0	20	16	19
UI10	311	14	1	11	3	17	36	1	0	12	9	11
UI11	218	24	0	34	1	1	2	0	0	6	8	48
UI12	206	27	0	15	4	2	2	0	0	23	20	34
UI13	129	27	1	19	1	4	4	0	0	17	10	45
UI14	198	70	3	22	1	14	3	0	0	25	12	23
UI15	57	0	0	7	1	37	16	2	0	6	2	29
UI16	0	0	0	2	0	53	3	1	1	24	0	16
UI17	88	32	1	29	3	13	1	1	0	14	17	22
UI18	85	10	1	1	2	11	24	9	1	5	27	20
UI19	49	8	0	3	0	42	20	5	1	11	0	18
UI20	194	11	0	26	5	11	8	0	2	13	3	31
UI21	39	22	5	7	0	27	9	1	0	21	3	31
UI22	195	40	4	33	0	11	3	0	3	11	6	32
UI23	307	25	1	23	7	14	6	0	3	11	5	31
UI24	0	0	0	0	0	26	9	3	0	7	20	35
UI25	16	6	0	2	0	21	8	1	0	13	13	42
UI26	2	0	0	0	0	19	27	2	2	28	3	19
UI27	0	0	0	0	0	29	21	1	0	20	0	29
UI28	5	1	0	0	0	11	43	1	1	11	14	19
UI29	0	0	0	22	0	4	43	1	3	9	5	13
UI30	59	6	0	10	2	2	43	0	1	16	11	11
UI31	70	35	8	40	11	1	15	0	0	7	5	21
UI32	102	32	11	25	6	1	9	0	1	22	9	28
UI33	300	7	2	8	4	23	12	0	9	24	0	18
UI34	494	15	0	25	15	1	8	0	0	7	9	35
UI35	331	47	1	35	8	6	5	0	0	9	11	24
UI36	148	42	1	25	11	3	11	0	0	12	6	32
UI37	187	39	0	9	14	36	8	0	0	21	1	9
UI38	339	7	0	6	0	29	10	0	0	22	5	26
UI39	305	15	3	5	11	33	22	0	0	22	4	3
UI40	36	12	7	5	0	55	5	2	3	9	8	12
UI41	36	7	2	10	0	14	28	0	3	9	3	26
UI42	71	12	1	8	0	25	4	1	0	22	5	27
UI43	71	29	4	3	3	18	11	3	1	9	10	42

Appendix C. GIS data layers produced as part of this project.

Layer name	Description	Units	Scale	Type
ag30	Annual grass canopy cover	%	30 m	raster
bare30	Bare ground canopy cover	%	30 m	raster
bare30new	Bare ground canopy cover adjusted for sagebrush cover	%	30 m	raster
confer30	Conifer canopy cover. Includes ponderosa pine and western juniper	%	30 m	raster
herbtot	Total herbaceous fuels (live + dead)	kg/ha	30 m	raster
labeveg1m	Cover types (conifer, shrub, perennial grass, annual grass, bare ground, lava)		1 m	raster
lava30	Lava cover	%	30 m	raster
litter	Litter fuels	kg/ha	30 m	raster
pg30	Perennial grass canopy cover	%	30 m	raster
sage30	Shrub canopy cover. The majority of the shrubs are mountain big sagebrush	%	30 m	raster
sage30new	Shrub canopy cover. The majority of the shrubs are mountain big sagebrush. Cover is adjusted to max 60% canopy cover	%	30 m	raster
shrub1hr	1 hr timelag shrub fuels	kg/ha	30 m	raster
shrub10hr	10 hr timelag shrub fuels	kg/ha	30 m	raster
woodlndphase	Woodland succesional phase		30 m	raster
ndvieast_buffers_ex_10	Wavelet derived canopy area, southeastern section		1 m	vector
ndvieast_points_ex_10	Wavelet derived tree center points, southeastern section		1 m	vector
ndvimid_buffers_ex_10c	Wavelet derived canopy area, southcentral section		1 m	vector
ndviwest_buffers_ex_10	Wavelet derived tree center points, southwestern section		1 m	vector
ndviwest_points_ex_10	Wavelet derived canopy area, southwestern section		1 m	vector