STARFire

Strategic Budgeting and Planning for Fire Management

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BLM Idaho Northern Great Basin Pilot Project Report

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Contents

Purpose

On January 5, 2015, DOI Secretary Jewell signed Secretarial Order 3336 (SO3336) – Rangeland Fire Prevention, Management and Restoration. The order directed the creation of a Rangeland Fire Task Force to develop a comprehensive science based strategy to reduce the threat of large-scale rangeland fires to greater Sage Grouse habitat and the Sage-Steppe ecosystem. The order directed the Task Force to develop a strategic plan for addressing rangeland fire prevention, management and restoration. The *Final Report, An Integrated Rangeland Fire Management Strategy* (Interior, 2015) outlines actions to better prevent and suppress rangeland fire and to improve efforts to restore fire-impacted landscapes in the near future.

This report is in response to SO3336 Final Report Section 7.b.iii Fuels – Action Item 4*: Coordinate the development of effective landscape-level fuels treatments plans.*

a. *Initiate a pilot project to test existing tools and/or prototype versions of new tools and/or prototype versions of new tools.*
b. *Use results from pilot projects to make improvements in models and identify appropriate tools for developing strategies for future landscape-level fuels treatments in sagebrush-steppe ecosystems. Coordinate with other agencies and organizations that may develop and lead additional pilot projects.*

Introduction

This report is in response to SO3336 Final Report Section 7.b.iii Fuel – Action Item 4*: Initiate a pilot project to test existing tools and/or prototype versions of new tools.* When considering a tool to accomplish this task additional federal directives were also taken into consideration. The U.S. General Accounting Office (GAO) continues to recommend that land management agencies improve the cost effectiveness of fire programs with better accountability for spending (2002, 2005, 2009). Similarly, item (4) of this action item identifies improvements that are needed in the development of "economic models to describe the cost-effective return of investments." While many decision support systems exist to guide wildfire management decisions, few can address these economic considerations. The complexity of providing these types of metrics is highlighted in a United States Department of Interior (USDOI) Office of Policy Analysis (2012). It identifies the challenge of quantifying nonmarket goods and services and characterizing them in terms of a common metric. STARFire is a spatial fire planning and budget system developed in collaboration with the USDOI's National Park Service (NPS), Fish & Wildlife Service (FWS), and the Bureau of Land Management (BLM) at the WESTFIRE Research Center at Colorado State University. STARFire was developed to address these types of needs. This report focusses on the results of a pilot project using STARFire on a large landscape-level analysis (~15,732,000 acres) within the Northern Great Basin (NGB) Fire and Invasive Assessment Tool (FIAT) assessment area.

Report Goals

1. Evaluate the capacity of STARFire to support the goals of SO3336
2. Highlight issues identified during the project
3. Articulate data and modeling limitations encountered, that highlight future STARFire research and development priorities

Project Objectives

1. Generate a wildfire risk analysis that identifies where wildfire is expected to produce the greatest loss to Sage Grouse and other fire-affected resources and where fire can generate ecosystem benefit.
2. Inform the strategic location of fuels treatments to aid planners in prioritizing and optimizing fuel treatments that reduce risk to Sage-grouse while considering the NGB's full spectrum of fire-affected resources and maximizing return on investment. STARFire includes the ability to analyze user-defined treatments and STARFire selected treatments. These two scenarios are applied to illustrate the flexibility of the STARFire system. The scenarios facilitate a comparison of alternatives and demonstrate the strategic advantage of treatment alternatives.
   i) User-Defined Treatments: the FIAT assessment team designed and suggested a suite of treatments prior to this analysis. STARFire was applied to prioritize these treatment locations.
   ii) STARFire Selected Treatments: STARFire was applied across the entire NGB landscape to prioritize and optimize treatments across the entire NGB landscape without being restricted to the previously suggested FIAT treatment area.

BLM Northern Great Basin Pilot Project

Pilot Project Analysis Overview

The STARFire spatial planning system was applied to the NGB FIAT pilot study site (Figure 1). The pilot project demonstrates how STARFire applies the latest science and technology to support the fundamental principles of SO3336 by using a Risk-Based approach to address the fuels action item. Key inputs for applying STARFire are identified and described including those pertaining to fire-affected values, burn potential and management costs. The pilot project analysis generated a wildfire risk assessment and applied two fuel treatment scenarios. First, STARFire prioritized the proposed (pre-designed) NGB treatments as designed by the FIAT. Secondly, the STARFire pilot project prioritized and optimized fuel treatments across the entire NGB landscape (without being constrained by the pre-designed treatment locations). These two scenarios demonstrate how STARFire can prioritize user-input treatments and/or STARFire system generated treatments. These two scenarios establish a basis for comparison while highlighting some of the benefits of STARFire in addressing SO3336 Section 7.b.iii Fuel - Action Item 4.

Pilot Project Site

The pilot project area is located in the Snake River Plain Sage-grouse Management Zone IV; NGB FIAT assessment area. The entire NGB FIAT area encompasses 15,732, 000 acres covering four states: Idaho, Oregon, Nevada and Utah and is within 7 BLM District Office boundaries. Sage-grouse habitat loss and fragmentation due to wildfire and invasive plants are two of the most significant challenges to conservation of Sage-grouse, particularly in the western sage-grouse FIAT management zones (Chambers et, 2014), (Brooks et, 2015). The NGB FIAT area was chosen for this pilot project because of its high risk for loss of Sage-Steppe due to wildfire (Figure 1) and invasive plants (cheat grass). The area has a high density of Sage-Grouse and Sage-Grouse leks. It has fuels treatments in place and planned for Sage-Grouse habitat restoration and protection.

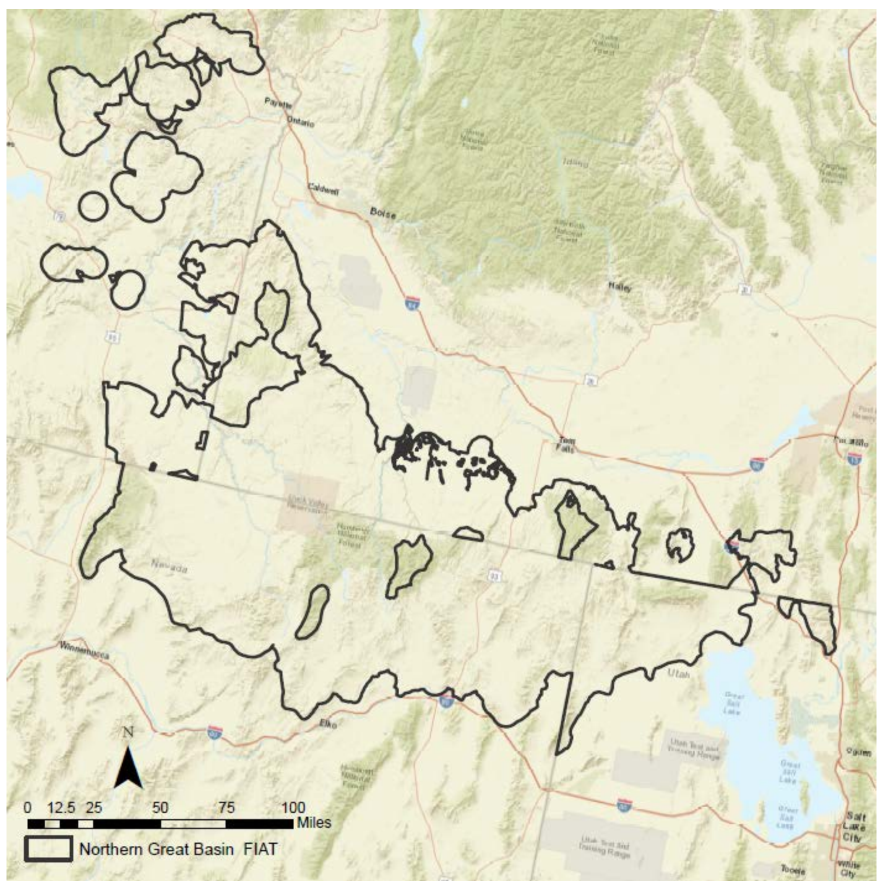


Figure 1: Northern Great Basin FIAT location MAP encompassing 15.7 million acres.

Pilot Project Findings

Report Goal 1: Evaluate the capacity of STARFire to support the goals of SO3336

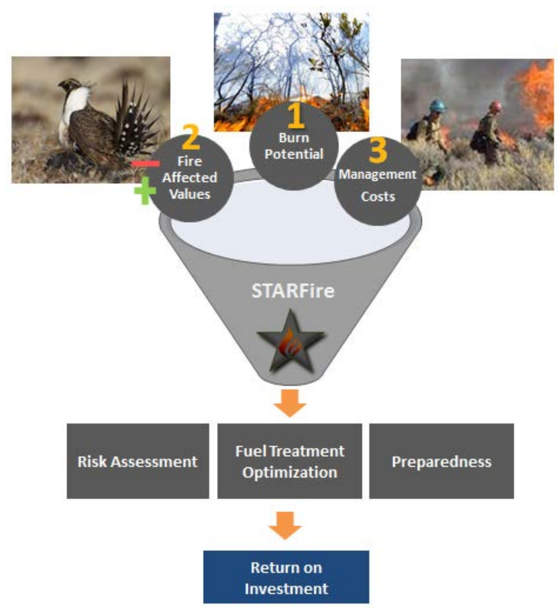
STARFire Overview

STARFire is a spatial fire planning and budgeting system that allows planners and managers to evaluate the risks of wildland fire while restoring and maintaining resilient landscapes in a single integrated system. It can consider the entire spectrum of wildfire-affected values including life, property, protection and nonmarket goods and services in a single metric.

STARFire uses a comprehensive performance metric of return on investment (ROI) to support scalability and comparisons across programs such as fuels and preparedness. The system can be applied at individual planning units (Rideout *et al* 2014) or expanded to address large-scale problems (as demonstrated here) as well as national level analysis (Wei *et al* 2016). The full range of fire-affected resource values, management costs and burn potential can be incorporated in the analysis. The ROI computation, as used in STARFire, can account for, compare and defend management decisions for the following wildland fire programs:

a) Risk and benefit assessment – identifies where wildfire is expected to produce the most loss and where it can generate the greatest ecosystem benefit.
b) Fuel treatment locator – aids fire planners in locating and prioritizing fuel treatments that reduce hazards or improve the ecosystem condition and provide the highest ROI across the pilot application. Treatment locations can be suggested by STARFire or provided by the analyst and evaluated and prioritized by STARFire as demonstrated in the pilot study.
c) Preparedness ROI – STARFire models the ROI for different levels of the preparedness budget[1].

STARFire was developed as a system of integrated analysis modules by program. The program modules use a common set of inputs that are integrated with a common metric called relative marginal value (RMV). This integration yields efficiency in data acquisition, storage and system computations and enables the system to address large-scale applications as demonstrated in the pilot project. The entire 15.7 million acre pilot study was singularly processed under a contract with Colorado State University.



At the national scale, STARFire could provide decision support for the BLM to efficiently allocate the funds received from Congress. With an in-depth analysis of ROI, the BLM could prioritize expenditures across the country or districts. At the program scale, STARFire could be used to quantify ROI for planning alternatives and assess the impact of budget

[1] Not included in this pilot study.

increases/decreases across fire programs. The STARFire system (Rideout *et al* 2016a and 2016b) and the components of STARFire have been scientifically vetted through peer reviewed literature.

STARFire Data Requirements

All modules depend on a set of inputs that are largely shared. These include fire-affected resource values, management costs, and burn potential. The set of inputs and their role in STARFire is summarized in Appendix 1. These inputs are combined in two separate approaches: one is to assess wildfire risk (Project Objective 1) and the other is to assess the potential to add value on the landscape from wildfire management activities (used in Project Objective 2). The specific data used in this pilot study are discussed in the sections that follow.

Project Objective 1 - Wildfire Risk Assessment

STARFire uses fire behavior information to build a custom fire footprint based on conditional probabilities[2] for each ignitable cell on the landscape (Rideout *et al* 2008). Using the fire-affected resource value information, the expected net benefit or loss within the fire footprint is calculated and stored back at the ignition cell. The risk and benefit of wildfire is quantified for every cell on the landscape and displayed (Rideout and Wei 2013). Fire starts that occur outside the landscape boundary and burn into the pilot study area are also considered. The resulting output can help managers assess the appropriate response to wildfire anywhere on the landscape as well as adaptive management after a large fire. A Wildfire Risk Assessment was generated for the NGB FIAT (Figure 2). It provides a preliminary validation of system inputs that was collaboratively verified with BLM team members. Collaborative validation of the risk assessment is an expected step that sets the stage for the analysis that will follow.

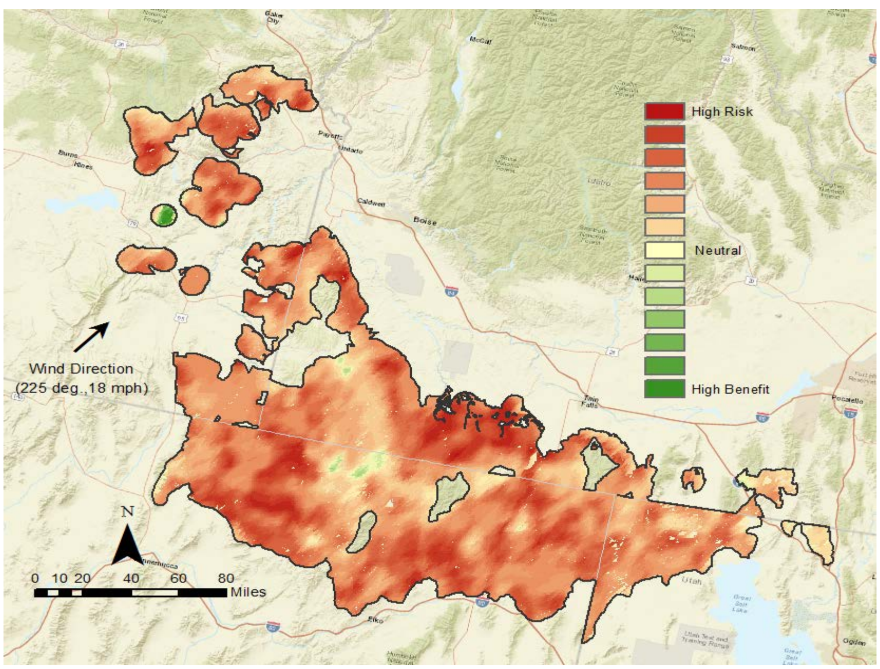


Figure 2: Wildfire Risk Assessment within NGB FIAT. Areas in red represent areas at high risk of loss from wildfire and areas in green may provide ecosystem benefit if burned.

[2] Conditional probabilities refer to burn probabilities that have been calculated given the condition of an ignition.

The risk assessment outputs displayed in Figure 2 show the expected value of outcome for any cell igniting on the NGB FIAT landscape. Green areas indicate cells that would produce a positive expected outcome while red cells indicate a negative, or detrimental expected outcome. Darker colors indicate greater impacts.

Project Objective 2 - Inform the strategic location of fuels treatments

STARFire estimates the expected value added (Rideout and Kernohan, 2012) from wildfire management activities (for resource protection of sage-grouse or ecosystem benefit to habitat) by combining the unconditional burn probabilities with fire-affected resource values across the entire landscape.[3] The unconditional burn probability is calculated for each cell on the landscape using fire behavior information and ignition probability information (generated from the fire history data). The RMV added is used with cost information to locate fuel treatments. The RMV is used across all modules in STARFire to closely integrate the components, to validate comparisons of alternatives and to support the ROI performance metric. These calculations are used in the Fuel Treatment Optimization and Prioritization module discussed in detail on page 13 to address the Project Objectives 2.i) and 2.ii).

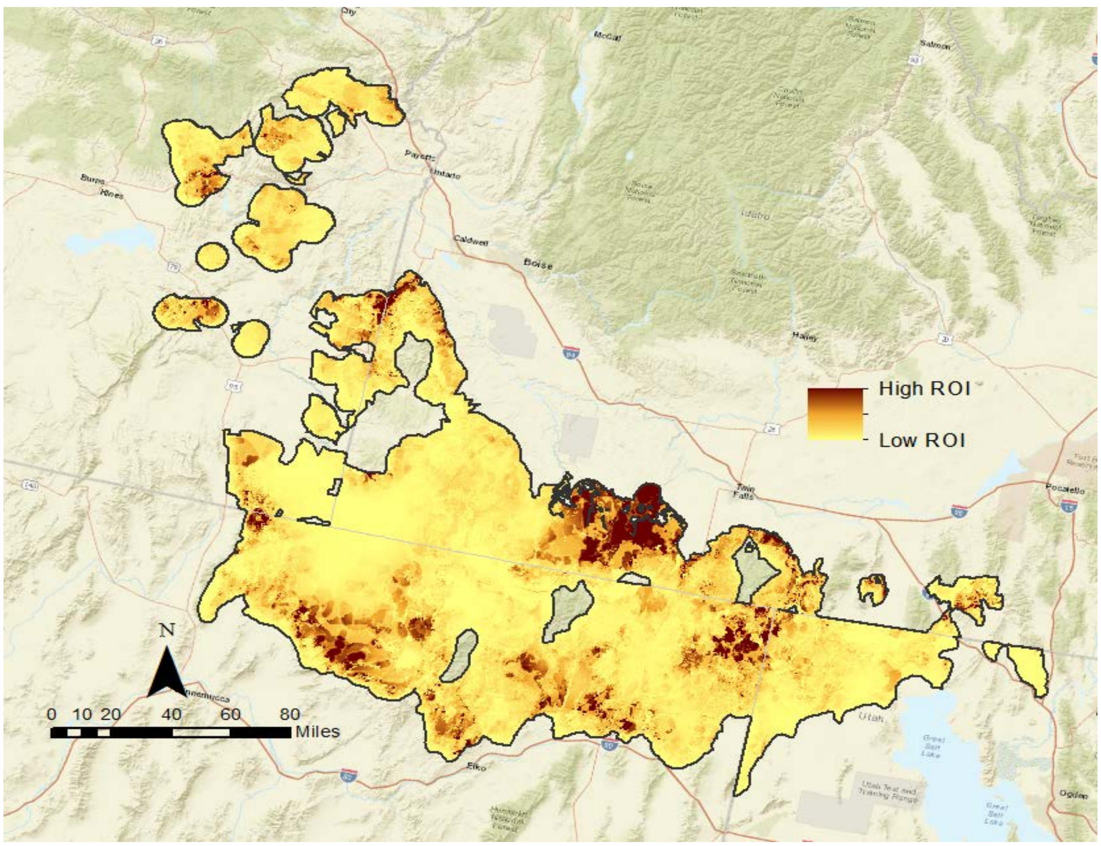


Figure 3: Return on investment at the NGB FIAT. Areas that are darker in color represent areas on the landscape that would generate a higher return on investment from a management action such as a fuels treatment.

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[3] The Wildfire Risk Analysis uses conditional burn probabilities because it shows the impact given an ignition. In contrast; the fuels treatment analysis requires actual (unconditional) burn probabilities.

NGB FIAT Assessment STARFire Inputs

Data were collected for the NGB FIAT for each required STARFire input. All geospatial inputs were modified into raster format. Due to the scale of the NGB FIAT landscape a cell size of 480m was chosen for this analysis. The large cell size, equivalent to approximately 57 acres was necessary to holistically process the analysis. Smaller landscapes can be run at finer scales compatible with the data source (LANDFIRE data is typically available at as fine as a 30 m resolution).

Burn Potential

Burn potential refers to ignition probability, spread probability and burn probability and is estimated from fire behavior information and fire history. Fire Behavior information was generated for this analysis using FlamMap (v5.0) for a given weather scenario. The most recent version (v1.3.0) of LANDFIRE data (fuel model, aspect, canopy bulk density, canopy base height, canopy cover, canopy height, elevation, slope) was used with FlamMap. A 90th percentile weather scenario was modeled using the following:

- Dead Fuel Moistures: 1-hr: 3%, 10-hr: 4%, 100-hr: 5%
- Live fuel moistures: Live herbaceous : 30%, Live woody: 70%
- Wind: Constant 18mph, Southwest wind (225 degrees)

The resulting flame length, heat/unit area, rate of spread and spread direction outputs are used in the STARFire analysis. Flame length and heat/unit area are used as a proxy for fire intensity. The BLM defined high intensity as flame lengths greater than four feet for this analysis. Rate of spread and spread direction are used in the burn probability calculations. The inputs used in the pilot study are summarized in Figure 4.

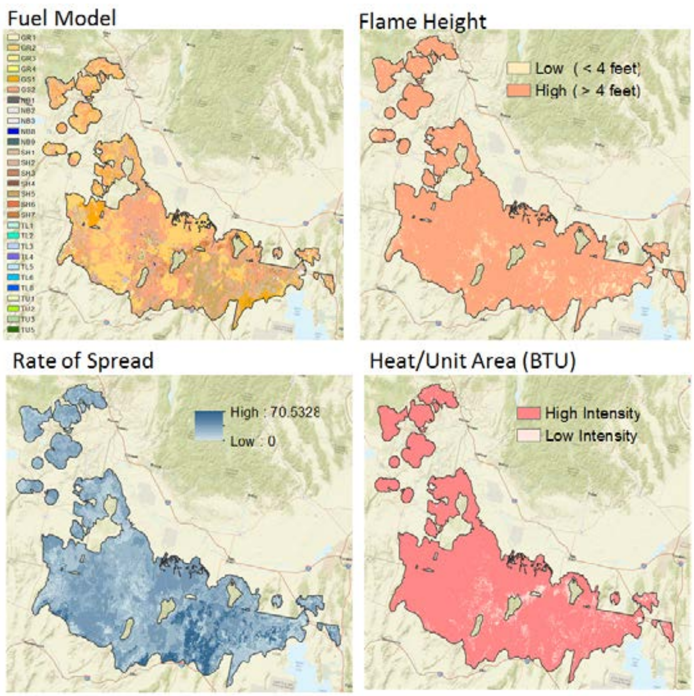

Figure 4. STARFire fire behavior inputs generated from FlamMap. Panel a) represents the Scott and Burgan fuel model, panel b) represents the flame lengths based on BLM's delineation of high and low intensity flame lengths, panel c) represents the rate of spread and panel d) depicts the heat/unit area measured in BTU for high and low intensity.

Fire history information includes ignition locations and large fire perimeters that were provided by the BLM. The ignition locations were used to generate an annual ignition probability surface. The fire perimeters and the corresponding ignition location are used to calculate an annualized spread risk used in the burn probability calculations. Fire perimeters were also used to estimate the time since an area previously burned (Figure 5). This information is used in the fire-affected value section (next).

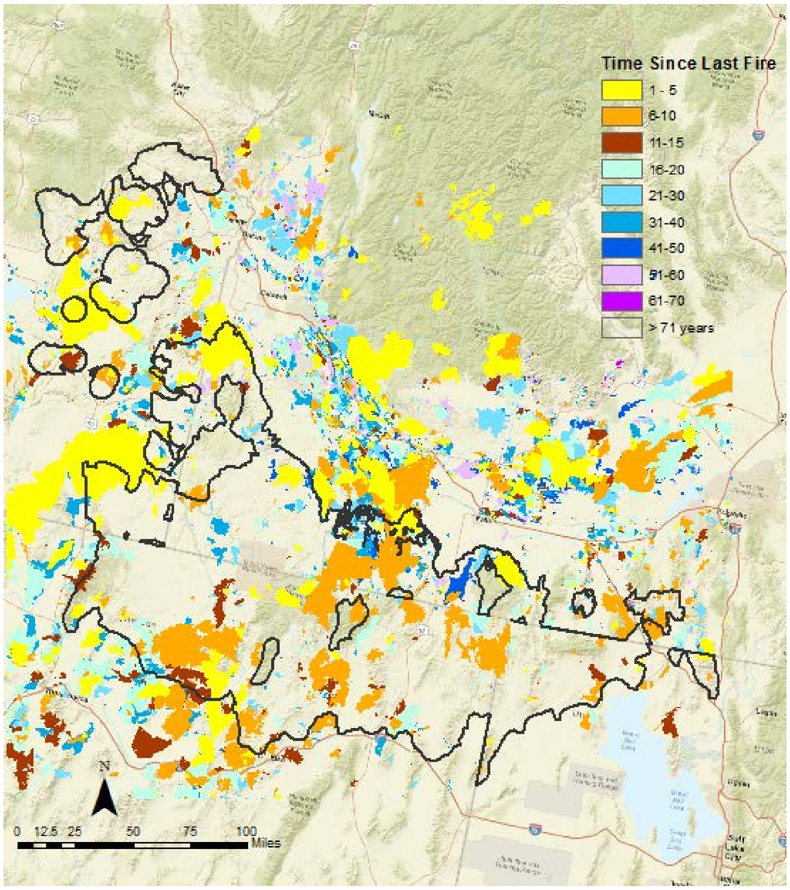

Figure 5. The amount of time elapsed since the last large fire.

Fire Affected Resource Values

STARFire requires spatial data layers for resources that would be positively or negatively affected by fire within the analysis area. Many of the spatial data layers for fire-affected resources in this analysis were incorporated directly from the Greater Sage-Grouse Wildfire, Invasive Annual Grasses, and Conifer Expansion Assessment for the Northern Great Basin (BLM, 2015). Resources included developed areas (infrastructure, developed areas, and communities at risk), sage-grouse density (high breeding bird density (100%), moderate breeding bird density (75 to 100%)), low breeding bird density (< 75%)), conifer encroachment (phase 1 (< 15% canopy cover), phase 2 (15-30% canopy cover) and phase 3(< 30% canopy cover)), and the ability of the sagebrush ecosystem to resist and be resilient to the impacts of invasive annual grasses and altered fire regimes based on the methodologies developed by Chambers et al. (2014). The spatial locations of these fire-affected values are summarized in Figure 6.

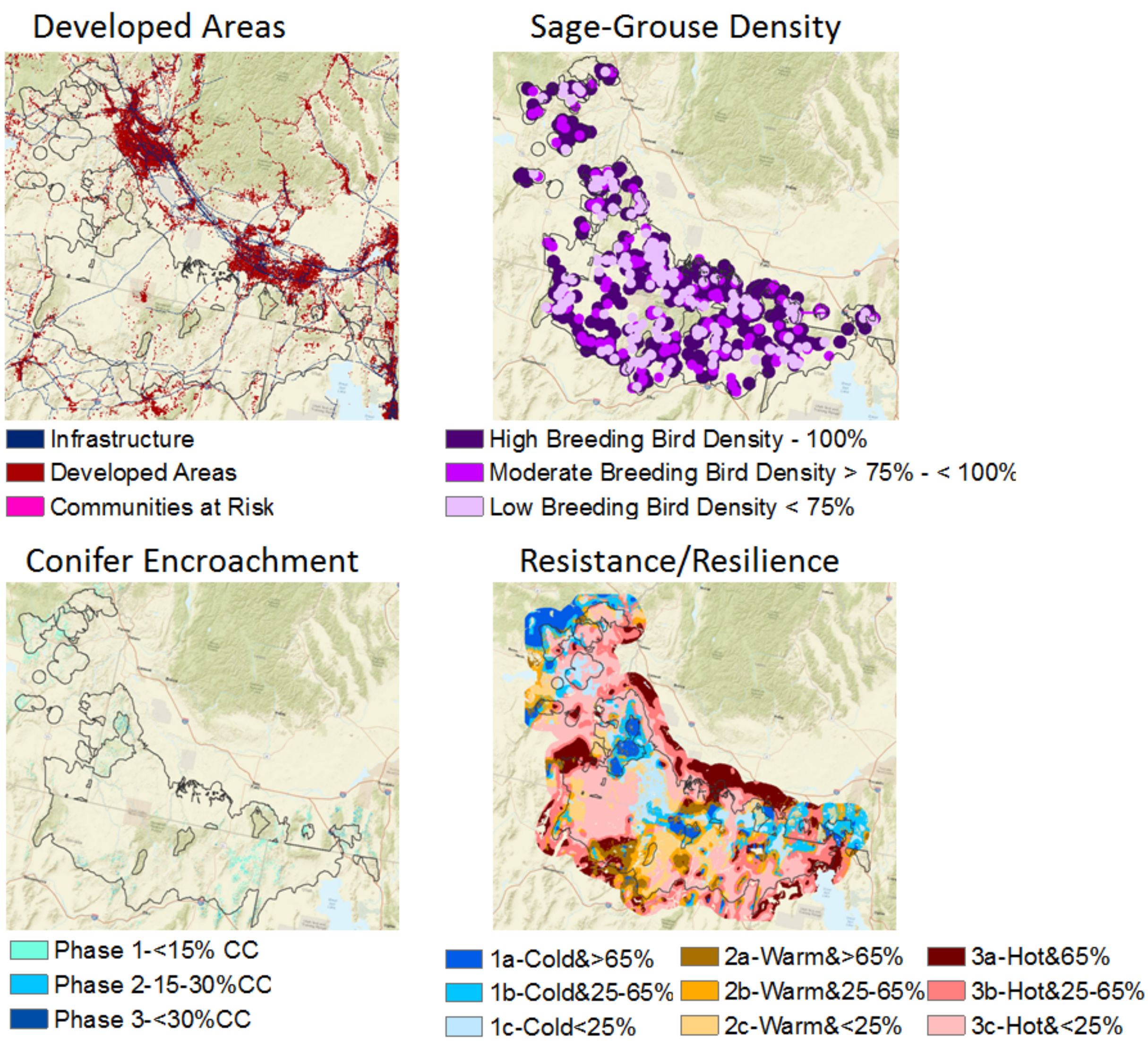

Figure 6. The spatial representation of the NGB FIAT fire affected values. Panel a) shows developed areas including infrastructure, developed areas, and communities at risk. Panel b) shows Sage-Grouse Density representing high breeding density (dark purple), moderate breeding density (light purple) and low breeding density (lightest purple). Panel c) shows conifer encroachment based on canopy cover. Light blue represents phase1, medium blue represents phase 2 and dark blue represents base3. Panel d) shows the sage grouse resistance/resilience model.

The fire-affected values for the resources defined above were estimated using a unique non-market and non-monetized economic valuation system known as MARS (Marginal Attributes of Substitution) (Rideout *et al* 2008). The MARS method requires a team of subject matter experts (SMEs) to participate in a highly structured elicitation process to define rates of substitution. Rates of substitution define relative marginal value (RMV) and need not be monetized. For an applied guide to MARS valuation see STARFire Gear Head, 2013.

For this pilot study, a group of NGB FIAT fire and resource SMEs assembled at the WESTFIRE Research Center for an introduction to MARS concepts and their application to fire management valuation (STARFire Gear Head, 2013). This was followed by a formal elicitation of the RMVs for each fire-affected resource by fire intensity and resource condition. The intensity with which fire engages resources can have an important effect on resource value. Hence, flame height was used as a proxy for establishing RMVs by fire intensity and was divided into categories of 'high flame height' and 'low flame height'. The effect of fire on resources also depends upon the resource condition. The amount of time since the resource last experienced fire was used as a proxy for the resource condition. For resources "recently" experiencing fire, their condition was referred to as "has experienced fire" and for resources that had not recently burned, their condition was termed 'has not experienced fire'. The amount of time required for a recently burned resource to transition to "has not experienced fire" is given by the "years since last fire breakpoint" shown in the valuation table (below). This amount of time is guided by the natural fire return interval.

In addition, the RMVs, by resource condition, are adjusted using linear interpolation. For example, in areas where the importance of introducing a restoration treatment increases with time since last fire (i.e. where the ecosystem degraded with time), the RMV is adjusted upward through internal interpolation depending upon the number of years. With these interpolations, an infinite set of values is used in the STARFire application; greatly increasing the accuracy of the value information. Table 1 summarizes the RMV for each resource by fire intensity and resource condition generated from the NGB FIAT MARS elicitation process.

		Great Basin						
	Fire Intensity:	High Flame Height		Low Flame Height				
	Resource Contition:	Has Experienced Fire	Has Not Experienced Fire	Has Experienced Fire	Has Not Experienced Fire	High Flame Length Threshold	Years since last fire breakpoint	
Category	***Resource:***							**Fuel Tmt? (y/n)**
Sage-Grouse Density	High-BBD 100%	-100.00	-100.00	-100.00	-100.00	4'		Y
	Moderate-BBD >75%	-75.00	-75.00	-75.00	-75.00	4'		Y
	Low-BBD<75%	-50.00	-50.00	-50.00	-50.00	4'		Y
Resistence/Resilience	1a-Cold&>65%	-20.00	-20.00	-20.00	-20.00	4'	15	Y
	1b-Cold&25-65%	0.00	0.00	0.00	0.00	4'	15	Y
	1c-Cold<25%	25.00	25.00	25.00	25.00	4'	15	Y
	2a-Warm&>65%	-100.00	-100.00	-100.00	-100.00	4'	30	Y
	2b-Warm&25-65%	-75.00	-75.00	-75.00	-75.00	4'	30	Y
	2c-Warm&<25%	-50.00	-50.00	-50.00	-50.00	4'	30	Y
	3a-Hot&65%	-100.00	-100.00	-100.00	-100.00	4'	70	Y
	3b-Hot&25-65%	-100.00	-100.00	-100.00	-100.00	4'	70	Y
	3c-Hot&<25%	-100.00	-100.00	-100.00	-100.00	4'	70	Y
Conifer Encroachment	Phase 1-<15% CC	75.00	-25.00	75.00	25.00	4'	15	Y
	Phase 2-15-30%CC	-50.00	-25.00	-50.00	-25.00	6'	30	Y
	Phase 3-<30%CC	0.00	0.00	0.00	0.00	8'	70	Y
Developed Areas	Communities at Risk	-100	-100	-100	-100	4'		N
	Developed Areas	-100	-100	-100	-100	4'		N
	Critical Infrastructure	-100	-100	-100	-100	4'		N

Table 1. Rates of substitution (RMV) for the NGB FIAT.

Management Costs and the ROI Calculation

Locating fuels treatments to make the best use of the budget requires including treatment costs. Otherwise, costly treatments will be excessively preferred wasting the budget and damaging the total value of treatments. A simple example illustrates the importance of this key principle and how it is used in STARFire in footnote four.[4] The footnote example shows how STARFire uses ROI to select the set of projects that will produce the highest net benefit (benefit minus cost) under a limited budget. The example introduces costs to each of four projects that have the same net benefit. Using ROI, as is programmed in STARFire, the two correct projects are selected that maximize the total net benefit. The alternative of ignoring costs and using value added would waste half of the net benefit. Selecting based on project level net benefit results in the inability to distinguish among the projects.

A series of inputs are required by STARFire to include the cost information that supports the ROI analysis. These are:

- identifying the drivers of cost (cost categories)
- estimating cost coefficients
- generating the associated spatial layers defined by the drivers.

With these inputs STARFire can select the appropriate cost coefficient for each cell.

The WESTFIRE Research Center worked in collaboration with BLM officials to identify the key drivers of cost for the NGB FIAT pilot study. The cost drivers were identified as distance from road, vegetation type (grass-like, shrub-like, tree-like) and time since last fire. If the resource had experienced fire within the 'years since last fire breakpoint' column from Table 1, it is included in the 'has experienced fire' cost category in Table 2, otherwise it is included in the 'has not experienced fire' category (Table 2). The distance from road cost driver was divided into '< 2 miles from road' and '> 2 miles from road' categories. This was based on BLM data indicating that costs for treatments are higher on average if a treatment is located or extends greater than two miles from a road or access point.

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[4] Locating fuels treatments, without consideration of cost, promotes inefficient treatments that would not meet the bureau's desired outcome, goals, and allocation requirements. Let's choose among four treatments, A-D, all the same size, but with value added and costs as shown in the table. Suppose also that we are allocated a budget of only \$60. Ignoring cost and spending on the highest value added until funds are exhausted, we would choose A <u>or</u> B (not both). This would produce a net benefit (benefit minus cost) of \$40 (100-60). By including cost and using ROI and spending until funds are exhausted we would choose projects C <u>and</u> D. This would produce a net benefit of \$80, doubling the net value! Ignoring cost leads to wasteful decisions, poor project selection and an inability to demonstrate cost-effectiveness, to defend decisions and to support appropriations. This example demonstrates how STARFire solves the capital budgeting problem by making the best use of a scarce budget.

Project	A	B	C	D
Value added	100	100	70	70
Cost	60	60	30	30
Net benefit	40	40	40	40
ROI or B/C	1.67	1.67	2.33	2.33

Using these drivers, the cost coefficients were estimated by the BLM. The BLM estimated averages of historical contracting and program fuels treatment costs to arrive at the relative cost per acre for the vegetation types in these categories. The treatment costs are summarized in Table 2. The cost coefficients are relative (proportional) meaning that a coefficient value of three denotes three times the cost as a coefficient value of one. Because these are entered into a ROI (Benefit/Cost) calculation, they can remain non-monetized without affecting the choice of fuel treatments.

	Has experienced fire & < 2 miles from road	Has not experienced fire & < 2 miles from road	Has experienced fire & > 2 miles from road	Has not experienced fire & > 2 miles from road
Grass-like	1	5	2.3	11.67
Shrub-like	3	7	7	16.33
Tree-like	9	18	21	42

Table 2: Fuel treatment coefficients. Note: for comparing across vegetation types, comparisons of coefficients are made vertically.

The spatial allocation of the cover types was generated from the LANDFIRE fuel model layer (Figure 7, panel a). The BLM provided a roads layer that contained paved and dirt roads within the FIAT boundary and it was used to calculate the distance of the center point of any cell from a road (Figure 7, panel b).

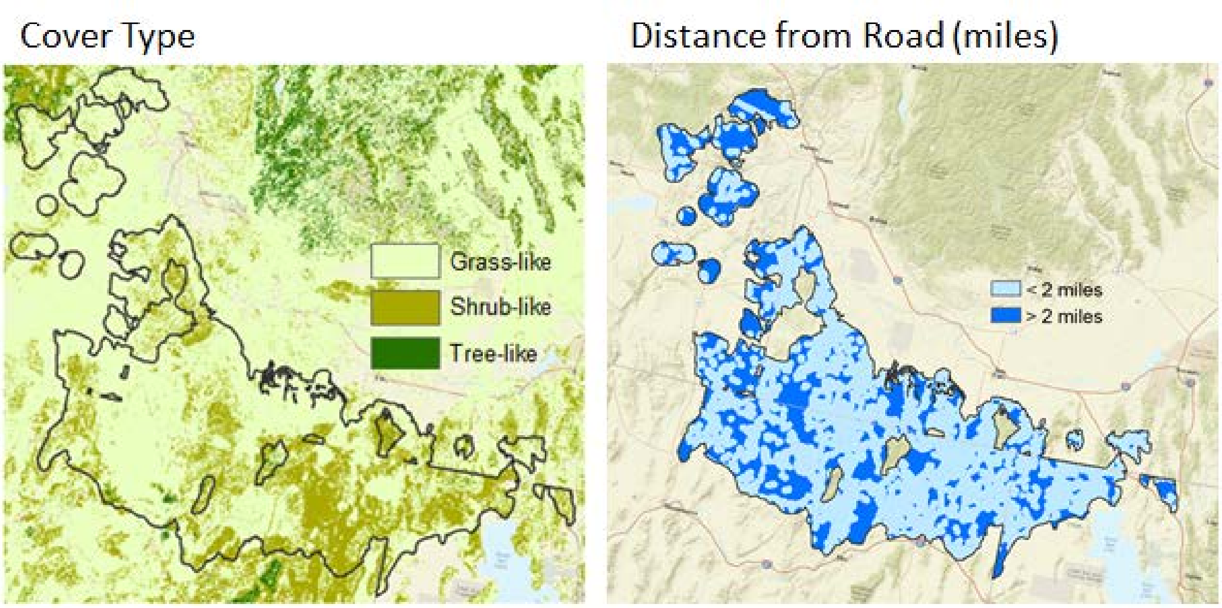

Figure 7. Spatial distribution of key elements that comprise the cost coefficients.

Given this collection of inputs, STARFire can select the appropriate cost coefficient for each cell on the landscape. STARFire determines if there is a fire-affected resource (or collection of resources) on that particular cell. It then determines if the cell has experienced fire (based on the resource's 'years since last fire breakpoint' from Table 1.), how far the cell is from a road and the associated vegetation type. Given this information the appropriate cost coefficient can be assigned to the cell. This information is included in the fuel treatment analysis. The selected cost coefficient is then included with the cell's RMV to estimate ROI.

The NGB FIAT Fuel Treatment Analysis (Project Objective 2.i and 2.ii)

The inputs identified above were used in STARFire's Fuel Treatment analysis to assess the NGB FIAT and accomplish Project Objectives 2.i and 2.ii.

Project Objective 2.i – Optimizing treatments within the proposed FIAT treatment areas

In March 2015, the BLM completed a "Fire and Invasives" assessment to identify potential project areas and management strategies in highly valued sage-grouse habitats within the NGB (BLM, 2015). Potential fuel treatments were identified to reduce the threat from wildfire to the sage-grouse. The treatments were ranked as high, moderate and low priority (Figure 8). While these ranking provide some degree of prioritization, they did not account for the treatment cost and they cannot prioritize treatments within a priority level. For example, if a manager does not have the funds to treat the entire high priority area there is no guidance regarding which acres within the high priority treatment areas would provide the highest return for their limited funds. STARFire was applied to address these types of questions.

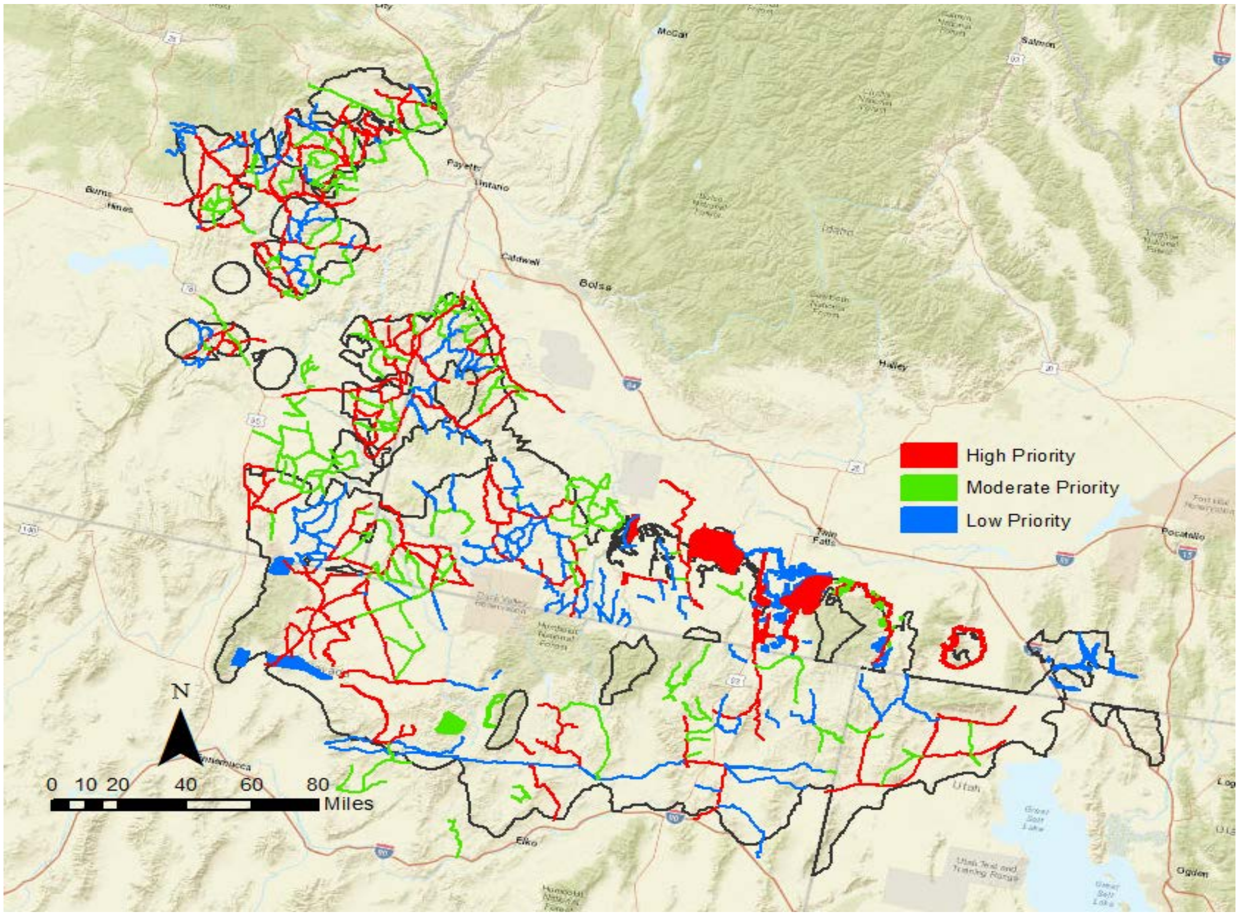

Figure 8: Proposed NGB FIAT fuel treatments ranked by priority

Applying the STARFire Fuel Treatment Analysis

To compare the results of STARFire with the proposed NGB FIAT fuel treatments, we converted the proposed NGB FIAT treatments to the same 480m-raster resolution as the input data. The number of acres that comprised the proposed fuel treatment area was re-calculated at this new resolution. For a valid comparison, the fuel treatment analysis was **restricted to select locations only within the proposed NGB FIAT treatment area**. The output was divided into corresponding priorities based on the number of acres in each proposed fuel treatment ranking. The locations selected for each priority level are compared to the proposed NGB FIAT fuel treatments in Figure 9. Further, the treatment locations were optimized within a priority level (based on fire-affected values, burn potential and management cost) addressing the limitation described above.

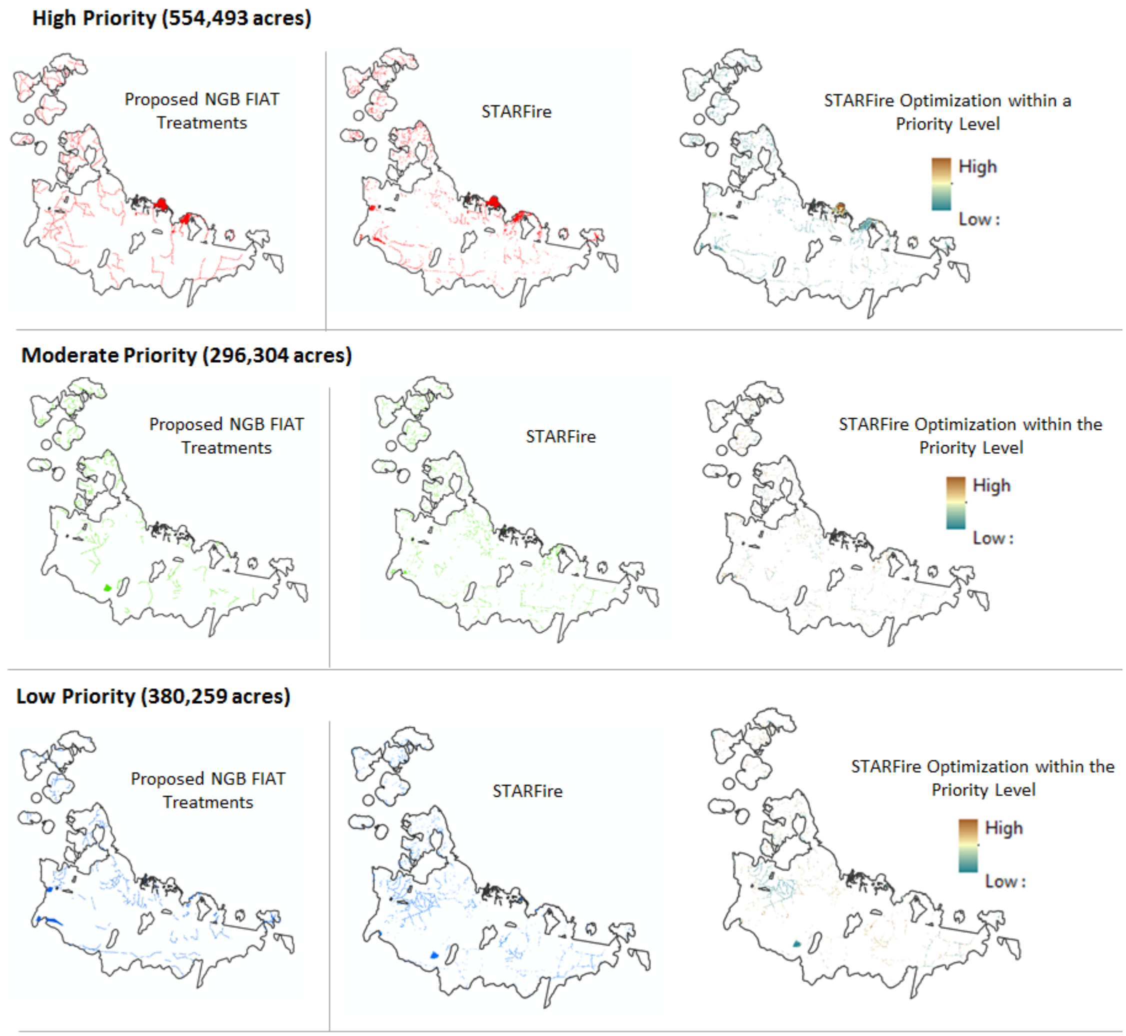

Figure 9. Comparison of the fuel treatment selections of the proposed NGB FIAT locations and STARFire selections based on ROI and the number of acres in each priority level.

Some of the treatment priorities selected by STARFire are similar to those selected by the NGB FIAT assessment. Figure 10, Box B identifies such an area. Other treatment priorities selected by STARFire differ from those in the NGB FIAT assessment as represented by Figure 10, Box A. In this area, the proposed NGB FIAT priority is moderate and the STARFire treatment priority is low.

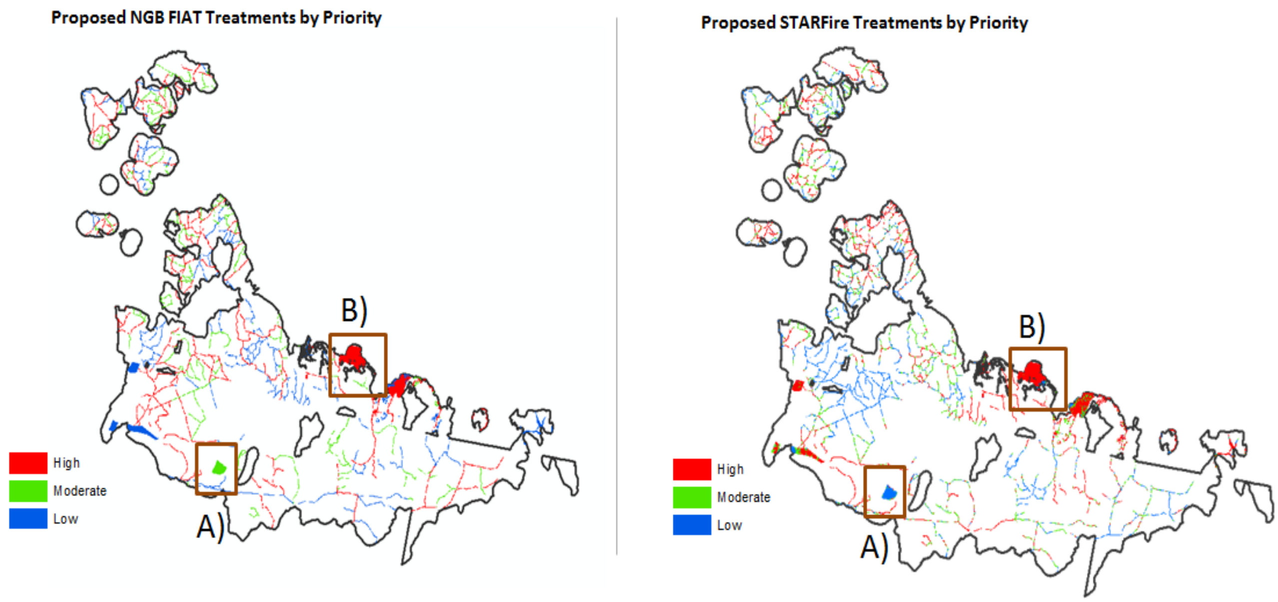

Figure 10. Comparison of proposed NGB FIAT treatment locations by priority to STARFire treatment priorities. Box A) represents areas where the priorities differ and box B) represents an area where the priorities are similar.

The underlying STARFire inputs (fire-affected resources, management costs and burn potential) are examined to demonstrate why these areas differ. The area identified in Box A) is used to explain the STARFire result. First, we review the fire-affected resources and their associated values (Figure 11, Panel a). The only fire-affected resource that is significantly represented in this area is warm soils (class 2a and 2b) (Figure 11, Panel a, image iv). A very small amount of moderate sage-grouse Breeding Bird Density (Figure 11, Panel a, image i) is represented and there is minimal conifer encroachment (Figure 11, Panel a, image iii). The area is void of developed areas (Figure 11, Panel a, image iv). While the associated fire loss value for the warm soils is high (-100 and -50 respectively (Table 1)), the resulting collective value of fire-affected resources in this area is much lower than other areas on the landscape that contain multiple resources on the same cells. Next, consider the management cost inputs (Figure 11, panel b). This area is greater than two miles from a road and the majority of the area is covered by a tree-like cost coefficient. This tree-like vegetation is independent of the conifer encroachment resource layer and likely represents an area of natural conifer. Both factors contribute to a high cost coefficient (Table 2). The final input, burn potential, reveals that this area has a very low probability of burning (Figure 11, panel c)). When these factors are considered together within STARFire and compared to other areas on the landscape, this area has a lower priority for treatment in comparison to other areas on the landscape.

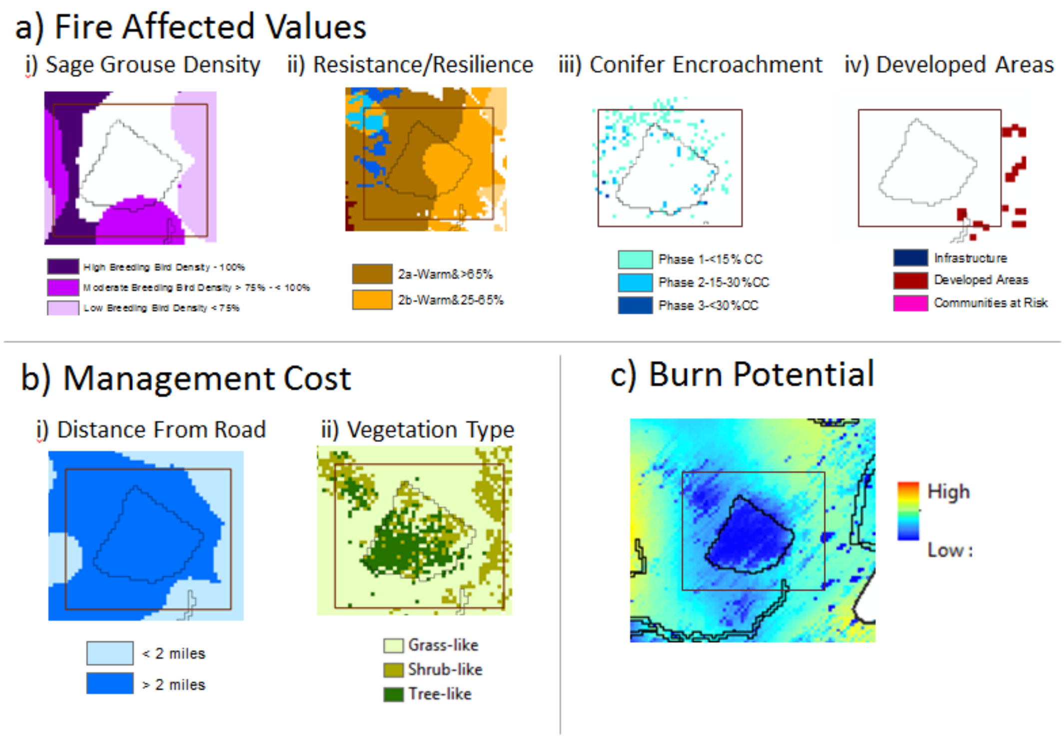

Figure11. STARFire inputs for region a) in Figure 11. Panel a) depicts the fire-affected values, panel b) depicts the inputs associated with treatment cost and panel c) depicts the burn probability for the area.

Further, the STARFire priorities can be compared to the proposed NGB FIAT treatment priorities by FIAT Planning Area and by State. This information is included as GIS attribute information and in tabular form. Figure 12 provides a screen shot of the proposed treatments sorted by STARFire's highest ROI.

FID	Treatment Name	FIAT Planning Area	State	Treatment Purpose	Treatment	NGB FIAT Priority	STARFire Priority	ROI
10860	Rogerson Fuel Breaks 2nd	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	Moderate	High	0.091492
17689	Oneil Fuel Breaks 3rd	Oneil	Nevada	Sagebrush_Protection_Enhance	Fuelbreak	Low	High	0.091293
11986	Oakley Fuel Breaks 1st Priority	Oakley	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.090531
10859	Rogerson Fuel Breaks 2nd	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	Moderate	High	0.089848
10858	Rogerson Fuel Breaks 2nd	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	Moderate	High	0.087833
13862	Oakley Fuel Breaks 2nd Priority	Oakley	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	Moderate	High	0.081211
8657	Rogerson Fuels 1st Priority	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.080332
10784	Rogerson Fuel Breaks 1st	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.079841
8672	Rogerson Fuels 1st Priority	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.079571
8690	Rogerson Fuels 1st Priority	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.079469
17732	Oneil Fuel Breaks 3rd	Oneil	Nevada	Sagebrush_Protection_Enhance	Fuelbreak	Low	High	0.079427
8671	Rogerson Fuels 1st Priority	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.079336
8655	Rogerson Fuels 1st Priority	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.079266
15017	Oakley Fuel Breaks 1st Priority	Oakley	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.079013
8670	Rogerson Fuels 1st Priority	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.078957
8656	Rogerson Fuels 1st Priority	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.078577
8688	Rogerson Fuels 1st Priority	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.078071
8689	Rogerson Fuels 1st Priority	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.077839
8667	Rogerson Fuels 1st Priority	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.07748
8713	Rogerson Fuels 1st Priority	Rogerson	Idaho	Sagebrush_Protection_Enhance	Fuelbreak	High	High	0.077294

Figure 12. Subset of GIS attribute information associated with STARFire's prioritization sorted by the highest return on investment.

Project Objective 2.ii – Optimizing treatments across the entire NGB Landscape

The BLM was interested in seeing the fuel treatments STARFire would prioritize **without being restricted to the identified NGB FIAT treatment priorities**. In this scenario, the fuels treatment analysis was performed for two different acre budgets. The first budget (131,100 acres) represents BLM's current acre expenditure for the NGB (Figure 13, panel a). The second budget (1,231,056 acres) reflects the same treatment area that was used in Project Objective 2.i (Figure 13, panel b). Recent fires (areas that have burned in five years or less) were excluded from analysis to account for recent fires that may not have been updated in the LANDFIRE dataset.

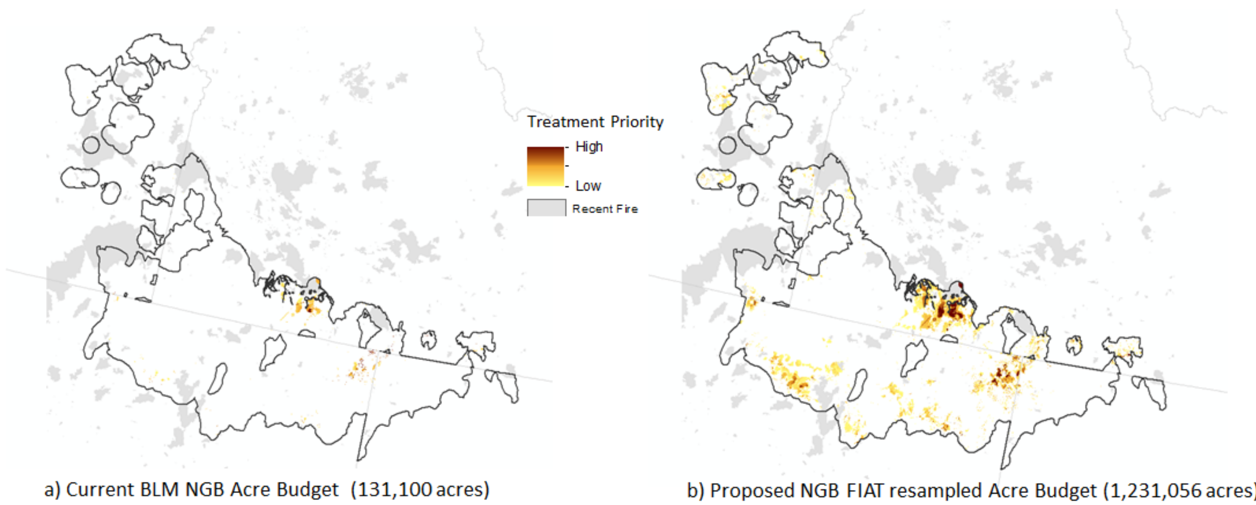

Figure 13. STARFire fuel treatments located on the entire NGB landscape excluding areas that have burned in the last 5 years. Panel a) identifies treatments based on the BLM's current acre budget and panel b) identifies fuel treatments based on the same budget used in resample proposed NGB FIAT treatments (Project Objective 2.i).

In Figure 14, panel a) the treatment locations identified by the proposed NGB FIAT assessment are overlaid on the STARFire fuel treatments to provide a comparison. Areas contained by box A) and box B) represent areas that show a similar priority for treatment. The NGB FIAT assessment proposes numerous fuel breaks in the area contained in box C). Due to comparatively lower burn probabilities in this area, the STARFire analysis focuses the treatment selections to areas with higher burn potential.

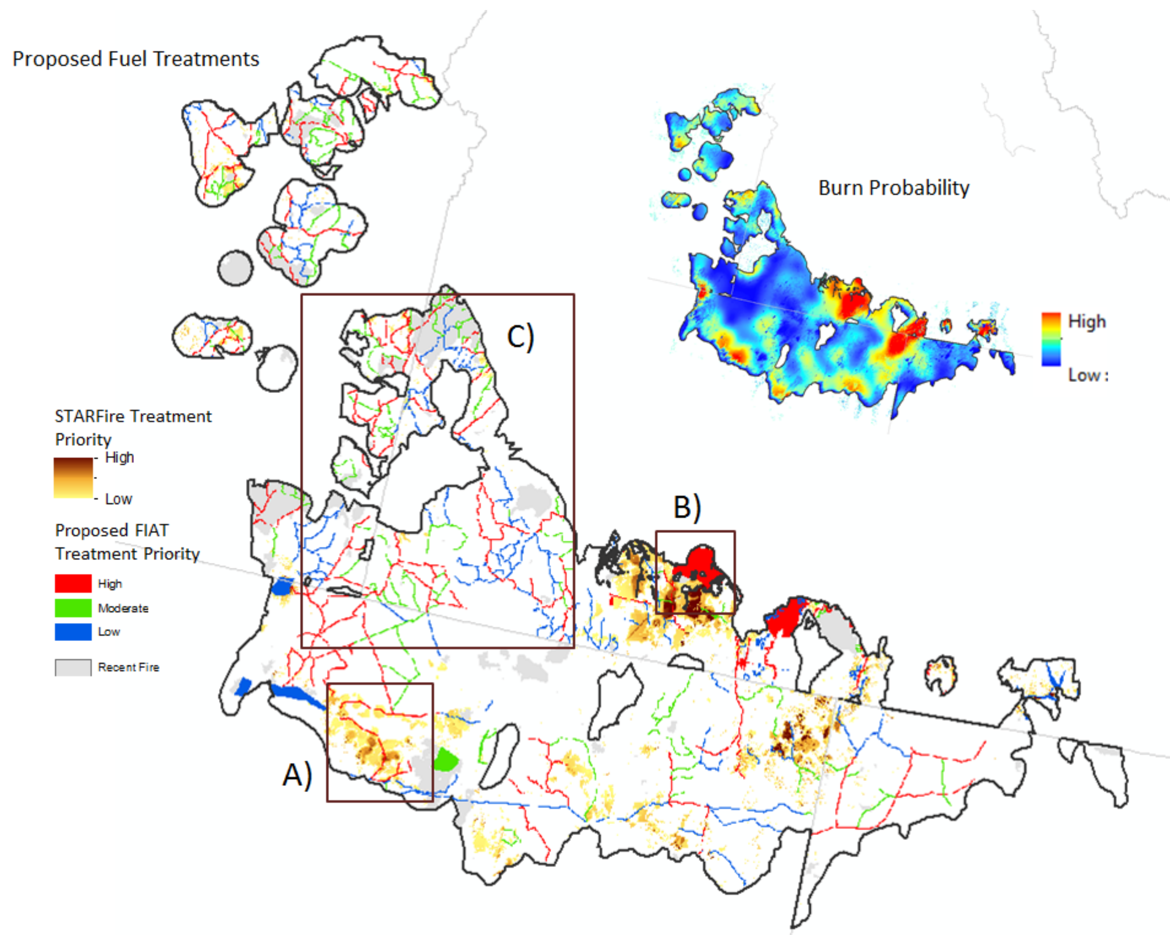

Figure 14. Comparison of proposed NGB FIAT fuel treatments to STARFire fuel treatments for a 1,231,056 acre budget. Box a) and box b) identify similar treatment priorities. Box c) identifies and area where the NGB FIAT recommends treatments and STARFire does not. When assessing the STARFire inputs the biggest factor contributing this difference is the burn probabilities for this region.

The BLM was also interested in knowing which states contained the high ROI treatment values across the acre treatment budget (1,231,056 acres). For illustration, we defined the high ROI treatment acres (612,314 acres) as those producing the top 50% of ROI. These were summed across the FIAT and then sorted and displayed by state (Figure 1, panel a). This shows that Idaho contains the highest number of high ROI treatment acres, followed by Nevada, Oregon and Utah. The second chart (Figure 15, panel b) displays the number of high ROI acres divided by the number of treatable acres in a particular state. The charts convey different messages. Panel a) shows where the highest ROI acres are by state and this is influenced by how many acres each state has in the FIAT. In contrast, panel b) displays the proportion of high ROI acres per treatable acres by state. In panel a) Idaho and Nevada have a similar number of high ROI acres (Idaho slightly more). However, panel b) shows that Idaho has a much higher proportion of high ROI acres per treatable acres in the study (than does Nevada).

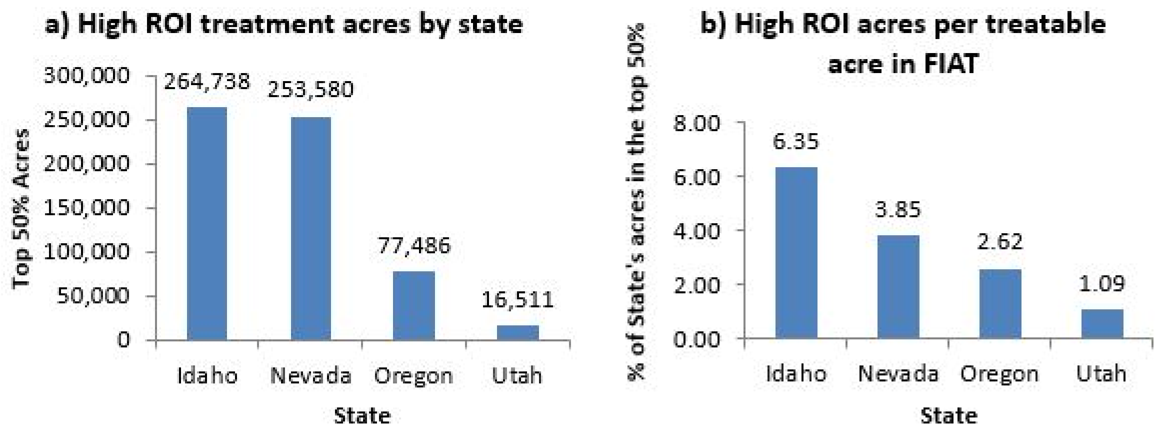

Figure 15. Panel a) summarizes the high ROI acres by state and panel b) shows the proportion of each state's acres that are high ROI.

Summary

STARFire offers many capabilities for fuels treatment prioritization planning and budgeting including flexibility of analysis and scalable application. STARFire's Wildfire Risk Analysis and Fuel Treatment analysis were applied to the NGB FIAT to address SO3336 Final Report *Section 7(b)iii- Fuels*. The analysis was applied using coarse-scale 480 M pixels across the 15 million acre landscape at the NGB FIAT. The STARFire platform provides a risk-based landscape scale assessment that was demonstrated across the pilot study area. The assessment identified fuel management priorities within the proposed NGB FIAT treatment areas and across the entire landscape. The analysis considered the full range of fire-affected values, management costs, and burn potential all related to a common interagency performance metric (ROI). ROI could be used to coordinate effective landscape-level fuel treatments and to compare the NGB FIAT with other FIATs in the WAFWA SG Management Zones.

SO3336 Final Report Section 7(b)iii- Fuels Action Item	STARFire Component that Address Action Item
1) Identify fuels management priorities	Fuel Treatment Locator
2) `Develop common interagency metrics to validate fuels management activities in sagebrush-steppe	Core STARFire metric provides comparability between units within an agency, between agencies (with disparate values and missions) and across national programs
4) Coordinate the development of effective landscape-level fuel treatment plans	Fuel Treatment Locator
8) Use risk-based, landscape-scale approaches to identify and facilitate investments in fuels treatments in the Great Basin	Entire STARFire analysis: The Wildfire Risk Analysis uses conditional burn probabilities to assess risk. The Fuel Treatment Locator and the Preparedness component use burn probabilities and ROI to inform budgetary decisions.

Table 3: Summarized action items STARFire address in SO3336 Final Report Section 7(b)iii- Fuels.

Report Goal 2: Highlight issues identified during the STARFire application pilot project.

The NGB FIAT covers a diverse and large landscape. There are some known issues with the LANDFIRE data misrepresenting range land fuel types within the NGB. To expedite the STARFire pilot project, the LANDFIRE data was used in the analysis without any modification. Future refinements of the analysis should include updated LANDFIRE data that has been reviewed and corrected by a team of rangeland fire behavior specialists.

Modeling a representative weather scenario is also necessary to generating useful results. In this analysis a 90^{th} percentile weather scenario was used. More analysis and discussion is required to ensure an appropriate weather scenario is being applied.

The values identified by the BLM specialists provided the inputs to meet the Secretarial Order 3336 pilot project goals and objectives. However, they may not represent the entire suite of values that need to be considered across the entire FIAT management zones. Consistent values will be required to be identified by BLM managers for any future FIAT-wide analysis.

Standard business rules should be developed and applied to identify and determine consistent cost coefficients for future analysis across the entire sagebrush system.

Report Goal 3: Articulate data and modeling limitations encountered

The pilot project applied a subset of STARFire's functionality. Future research and development opportunities include applying the remaining components to the NGB FIAT. A remaining component of the Fuel Treatment analysis has yet to be applied. This component analyzes a post-treatment surface and compares it to the pre-treatment surface to determine the value obtained from the treatments. In other words, a post treatment assessment can be compared with the pre-treatment landscape to quantify the overall valued added from the proposed treatment plan (Rideout *et al* 2015). Further, a series of increasing treatment budgets can be analyzed to show how increases or decreases to the budget affect the program. Such an analysis would demonstrate how increasing budgets augment the value of the landscape at a decreasing rate.

STARFire provides the ability to integrate the fuel treatment analysis with preparedness programs to guide management and budgeting decisions for an entire integrated fire program. The outcome of fuel treatment programs ultimately affects spread rates. Reduction in spread rates reduce the amount of preparedness required. STARFire provides the ability to quantify this relationship using the common metric of ROI. A future research and development opportunity would involve using STARFire's programmatic analysis capabilities to guide decisions on how to allocate funding between FIATs and between fuel treatment and preparedness programs to maximize the value added to the Sage Grouse BLM landscape.

Conclusion

The intent of this report was to address SO3336 Final Report Section 7.b.iii Fuels – Action Item 4 In response to Action Item 4a) the STARFire spatial planning system was selected and applied to the NGB FIAT. A pilot study was initiated to assess STARFire's ability to provide effective landscape-level fuels treatments plans within this sagebrush-steppe ecosystem. The pilot study indicates that the STARFire model addresses the fundamental principles of the SO3336 by applying the latest science and technology using a risk-based approach. The application successfully generated a wildfire risk analysis and fuel treatment recommendations to maximize return on investment (ROI). The model incorporated the fire-affected values from the NGB FIAT with burn potential calculations to assess the marginal value of treatments. Management cost information was also included to support a common and consistent performance metric "return on investment". These calculations allowed STARFire to prioritize fuel treatments within the pre-designed treatment areas proposed by the NGB FIAT. In response to Action Item 4b), STARFire was used to prioritize future landscape-level fuel treatments by applying the fuel treatment analysis to the entire NGB landscape. STARFire was able to directly address the concerns identified by the GAO and DOI by providing an analysis that improves the cost effectiveness of fuel programs and provides for accountability in spending. The results from the pilot project demonstrate STARFire's effectiveness in landscape-level fuels treatment analysis, programmatic analysis, and the support of a common performance metric.

Additional Applications

The results of this pilot project demonstrate that STARFire addressed the key elements of the fuels component of SO3336. However, STARFire has the potential to address other Secretarial Order 3336 Action Items.

Integrated Response Plan 7.b.i; Action Item 1 of: *"Update Fire Management Plans to enhance protection of the sagebrush-steppe from wildfire.* Updated plans will include consideration of areas and suppression objectives identified in the FIAT process, as well as reflect land management objectives" Initially developed as a spatial fire planning and budgeting system, STARFire potentially addresses the concept of this Action Item well; especially with the integration of the preparedness module.

Integrated Response Plan 7.b.i; Action Item 2. *"Develop a national technology plan to increase the availability of technology and technology transfer to wildland fire managers."* With future development for different platforms and data storage systems, STARFire outputs could be accessed for direct consumption through computer service protocols.

SO3336 (7bvi) also addressees Post Fire Restoration. While a post fire restoration module is not included in the STARFire system of modules, it could be with additional development and a key advantage is the direct integration of Post Fire Restoration with the fuels and preparedness modules. This is also related to section 7(bvii) "Commitment to Multi-year Investment in Restoration" in the event that the STARFire temporal analysis were to be combined with a new restoration module.

The STARFire application includes a Preparedness component. In preparedness planning and budgeting land management agencies must consider the dual importance of reducing wildfire risk to highly valued resources (initial attack) and the management of beneficial wild fire (BWF) for resource or ecological improvement. These dual purposes require the employment of a similar set of resources including crews, equipment and planning. STARFire provides the unique ability to allocate a single ‘preparedness’ budget to these dual purposes and assess how much ROI each component contributes (Rideout *et al* 2016a). This assessment could also be applied the NGB FIAT. STARFire can also be applied to assess and plan for temporal changes. This is accomplished by applying STARFire sequentially at designated time intervals and by aging the landscape and by incorporating disturbances such as fuel treatments. Aging fuels and weather conditions are also one way of addressing potential impacts of climate change using a temporal perspective.

The direct partnership between Colorado State University and the USDOI’s agencies (BLM, NPS, FWS) enables the WESTFIRE Research Center to fuse the latest developments in wildfire science and economics with the agencies’ expertise and knowledge of fire planning, budgeting and management into the STARFire modules. The agility of the STARFire development team fosters continual advances in the scope, efficiency, scale and run times of the STARFire analysis.

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Appendix 1: STARFire Data Summary

Table 4: STARfire data summary

STARFire Input Category	Data Source	Intermediate Process	STARFire Calculation	STARFire Component
Burn Potential • Fire Behavior	LANDFIRE: (elevation, slope, aspect, fuel model, canopy cover, stand height, canopy cover, canopy base height, canopy bulk density)	FlamMap • Flame Length (m) • Heat/Unit Area (BTU)	Directs the selection of the appropriate fire affected value	• Wildfire Risk Assessment • Fuel Treatment
	Weather Scenario: (90th percentile) Wind speed (constant): 18mph Wind direction: 225° Fuel Moistures: (1-hr: 3%, 10-hr: 4%, 100-hr, 5%, LH: 30%, LW: 70%)	• Rate of spread (m/min) • Max Spread Direction (degrees)	Used in conditional and annual burn probability calculations	• Wildfire Risk Assessment • Fuel Treatment
• Fire History	BLM Ignition Points	Annual ignition density	Used in annual burn probability calculations	• Fuel Treatment
	Large Fire Perimeter polygons	Time Since Last Fire	Used in annual burn probabilities and fire affected values	• Wildfire Risk Assessment • Fuel Treatment
Fire Affected Values	BLM	MARS Valuation	Relative value of fire affect	• Wildfire Risk Assessment • Fuel Treatment
Management Costs	BLM Roads Fuel model (grass, tree, shrubs)	Distance from road	Relative Management Costs	• Fuel Treatment