Proposal Title: Lick Creek Demonstration-Research Forest: 25-year fire and cutting effects on vegetation and fuels

Principal Investigator Name and Affiliation: Christopher R. Keyes, Department of Forest Management, University of Montana, Missoula, MT 59812

1. Overview

Knowledge of forest vegetation and fuel dynamics following restoration treatments, and how these differ among restoration treatment alternatives, is essential for managers to understand and prescribe treatments with efficacy and longevity. Research in many areas has demonstrated short-term treatment success in meeting ecosystem restoration and hazardous fuels reduction objectives. However, in many forest types the long-term effects of the alternative restoration treatments (e.g. with or without fire) remain unclear. For example, no publications exist on long-term treatment effects on vegetation and fuel dynamics in ponderosa pine forests of the Northern Rockies. As a result, managers lack proper guidelines on the longevity and long-term restoration success of alternative restoration and fuel treatments in these forests (Jain et al. 2012).

The Lick Creek Demonstration/Research Forest (hereafter: Lick Creek) on the Darby Ranger District of the Bitterroot National Forest, MT offers a truly unique opportunity to assess 25-year-effects of burning and cutting restoration treatments (see below). Lick Creek is the site from which the iconic images documenting forest change from fire exclusion were developed from a photographic series dating from 1909 to 1997 (Smith and Arno 1999, see attached poster appendices in GTR). In 1991, a cooperative venture among the Bitterroot National Forest, University of Montana, and Forest Service Intermountain Research Station (now Rocky Mountain Research Station) initiated a new research experiment with seven prescribed burning and cutting treatment variants to test restoration alternatives in restoring the site's ponderosa pine vegetation community and reduce fuel loads down to historically-appropriate levels. In doing so, they embraced virtually the full suite of possible treatment combinations that managers of ponderosa pine forests in this region employ. Silvicultural treatments were implemented in 1992, followed by prescribed burning in 1993 and 1994, under a fully replicated experimental design involving randomization of treated units and a permanent, systematic plot sampling network. In a formal recognition of its long-term research value, the site was officially designated as a Demonstration/Research Forest by the Bitterroot National Forest to encourage its integrity as a long-term research site. No other study of this kind exists in the Northern Rockies.

Lick Creek offers an unparalleled opportunity to gain understanding of 25-year responses of vegetation and fuels to ponderosa pine restoration treatments (1991-2016). No other study of this length exists in the Northern Rockies and the inferential value of treatments employed is very high: the forest type is ubiquitous in the northern Rocky Mountains, and the treatments performed more than 20 years ago remain staples of ponderosa pine forest management in this region. Additionally, treatments implementation was meticulously documented, the plot network is fully intact, the stands remain unmolested, and historic data records are complete. Here, we request funding to capitalize on this unique opportunity by re-measuring Lick Creek.

1. Project Justification & Expected Benefits

The fire regime and successional dynamics of low- to mid-elevation ponderosa pine forests in the Northern Rockies is different from other regions. Historically, fires in low- to mid-elevation Northern Rockies ponderosa pine forests were frequent and of low severity, which contrasts with the greater role of mixed-severity fires in the Colorado Front Range. Also, in the absence of fire, Northern Rockies ponderosa pine forests exhibit a dramatic increase of shade tolerant species, which is not the case in other areas, such as the Southwest and Black Hills. Given the different historical fire regimes, species composition, and successional dynamics after disturbance across the range of ponderosa pine, we predict that responses to restoration treatments over time are region- and treatment-specific (e.g. thinning alone, thinning combined with prescribed burning, and severity and season of burning). This suggests that recommended management (specific prescriptions and subsequent maintenance) are also region-specific. However, lack of data on long-term (20+ years) effects of restoration treatments based on well-replicated studies across biogeographic areas of ponderosa pine prevents us from making inferences about region-specific management approaches. Such information is therefore crucial for managers to select optimal management alternatives in terms of efficacy, longevity, cost and risk, and to anticipate the need for subsequent treatment maintenance.

The Lick Creek study objectives and initial results are reported in several articles and books (Carlson et al. 1994 (see attached), Arno et al. 1995, Arno and Allison-Bunnell 2002, Arno and Fiedler 2005). A summary of 5-year post-treatment effects was reported in Smith and Arno (1999); a 9-year post-treatment tree growth, physiology and reproduction in Sala et al. (2005; see attached) and Peters and Sala (2008), and shrub response to treatments in Ayers et al. (1999). However, an overall assessment of treatments effects is not available. While the potential and importance of the site is very high, lack of proper funding has prevented capitalizing on its true value. Much of the initial maintenance and re-measurement of Lick Creek was done through funding from the Bitterroot Ecosystem Management Research Project (BEMRP), which no longer exists due to waning federal funding. Therefore, there are no longer funds to continue measurements at the site (see attached letter of support from Kristine Lee). This fact, coupled with retirements of the original 1991 PI team (Steve Arno, Carl Fiedler, and Michael Harrington) and personnel turnover at Bitterroot National Forest, leave Lick Creek in a precarious place. The data and metadata is not formally archived and vital institutional knowledge could be lost with further personnel turnover. Essentially, we have a true gold mine for management-related research in terms of diversity of treatments, replication, experimental design, permanent monitoring plots, and available (but largely unpublished and non-archived) data that is at risk of being lost due to lack of funding and the retirement of the personnel initially involved. We strongly believe that reinvigorating research at Lick Creek is not only an extraordinary opportunity, but a responsibility to capitalize on past investments and efforts at the site and produce timely and extremely valuable information to managers and the public at large.

Other elements add to the urgency of this project. The study site is located in the center of the proposed Como Forest Health Project, a landscape-scale treatment project designed by the Bitterroot National Forest to improve forest health in what has become a recreational watershed with very high visitor use (see letter of support from Cheri Hartless). Some treatment units in the study are slated for re-entry harvesting as part of that project. Re-measuring this site prior to any management action is imperative to maintain the integrity of the site as a research area, and will contribute significantly to reinforcing the research value and investment of the site.

Re-measurement of Lick Creek would result in many benefits, including:

- Complete 25-year (1991-2016) effects of seven silvicultural cutting and burning treatments on fuels and vegetation.
- Archived data with complete documentation of study protocols to encourage future data analysis.
- Demonstration site that is easily accessible to a large population center to communicate forest restoration and management treatment results to both the public and managers.
- Photo-history of the effects of fire exclusion and restoration treatments from 1909-2016.

In addition, re-measurement would give added value to past data collection through modern data analysis techniques to examine treatment effects on aspects of forest resilience, including:

- Resistance to bark beetle outbreaks: Mountain pine beetle populations are currently high on the Bitterroot National Forest (Egan et al. 2013), providing a unique opportunity to directly test treatment effects on resistance to bark beetles, a natural disturbance enhanced by warming and drought associated with climate change. This is possible because we have past censuses of tree mortality causes through 2005. We will combine these results with similar studies of mid-term treatment effects in the region (Hood et al. In Prep) to help inform how management actions impact forest resistance to bark beetles.
- Resilience from drought: We will apply newly developed methods (Lloret et al. 2011) to quantify tree resilience from drought in the different treatments. This novel method has already been advocated as a very promising resilience metric for use in the Sierra Nevada (North and Stine 2012).
- Resilience from wildfire: Potential fire behavior using canopy fuel loading and different weather scenarios has never been simulated for Lick Creek. Methods to quantify canopy fuels were not available at the time the study was established, but all required data to calculate canopy fuels were collected. Re-measurement will allow us to assess differences in fire hazard among treatments over time using modern fire behavior systems (e.g., BehavePlus, FFE-FVS, Nexus) with real surface, canopy, and vegetation data as inputs to models.
- Treatment longevity and successional trajectories: Ten-year physiological responses to treatments reported in Sala et al. (2005) indicated that trees in the cutting and burning treatments had less water stress and faster growth compared to trees in the control treatment. Re-measurement will allow us to assess the degree to which treatment-specific differences in vegetation characteristics have changed over time. More sophisticated multivariate analyses techniques are now available that allow incorporation of both vegetation and fuel variables to examine the successional trajectories of treatments over 25 years.

2. Project Objectives & Hypotheses

Our objectives are to address questions that are essential to effective forest management using data from Lick Creek from seven restoration treatments: control, shelterwood, shelterwood+wet prescribed burn, shelterwood+dry prescribed burn, commercial thin, thin+Fall prescribed burn, and thin+Spring prescribed burn. We have three overarching study objectives:

1) How have restoration burning and cutting treatments affected vegetation dynamics?
2) How have restoration burning and cutting treatments affected fuel dynamics?
3) How have restoration burning and cutting treatments affected ponderosa pine forest resilience to:
    - Drought
    - Fire hazard
    - Mountain pine beetle

By examining each of these components, we will then be able to pool results of each analysis to examine treatment succession trajectories over the past 25 years and also predict how vegetation and fuel in the treatments will continue to change in the future.

We hypothesize that tree density has increased in all treatments, and that this increase is largely due to Douglas-fir ingrowth. Treatments with cutting and burning will also have increased ponderosa pine seedling and sapling establishment and faster annual growth compared to the control treatments. We expect, however, that treatment benefit on residual tree growth will have decreased relative to 2001 (Sala et al. 2005) due to increased density and canopy cover since then. We also predict cut+burn treatments will have higher tree growth and treatment longevity than the cut-only treatments because the burns killed many seedlings and saplings. Surface and ground fuels have likely increased in all treatments over time, but we predict loading to be highest in the control, followed by the cutting treatments, with the treatments including burning to have the lowest loading, perhaps more so for the dry-prescription burn treatment. We predict that treatment differences in vegetation and fuel dynamics will translate to differences in forest resilience from drought, wildfire, and bark beetles.

3. Relation to Task Statement Research Questions

We seek funding to conduct a 24 year post-treatment re-measurement of vegetation and fuels in a representative ponderosa pine forest in the Northern Rockies to address the following questions required in Task Statement 7:

- What are the successional patterns of vegetation and fuels following fire?
- How have fires affected achievement of ecosystem restoration objectives?

The ecosystem restoration objectives we propose to evaluate are tied to the original study goal of "returning to stand structures that are sustainable and consistent with historical fire occurrence in the area" (Smith and Arno 1999). This overarching goal was predicted to increase forest resilience to insects and wildfire, but the success of these objectives has not been tested to date. This project would increase understanding of long-term changes in vegetation and fuels in response to a variety of prescribed burning and cutting and treatments, and importantly, test treatment effects on forest resilience to drought, wildfire, and insects. It would also provide numerous added values as outlined above which would greatly increase the likelihood of Lick Creek remaining a long-term research site for years to come.

A thorough reconnaissance of all treatment units was conducted during summer 2014 (Keyes) to verify that treatments remain undisturbed and to relocate all original sampling plots within each unit (see below). We have the original sampling protocols and have confirmed trees tags are still intact. This effort not only confirms with certainty the feasibility of conducting the proposed research, but facilitates the proposed data collection and reduces overall project costs.

II. Methods

1. Study Design

Our proposal seeks funding to re-measure vegetation and fuels in silvicultural cutting and prescribed burning treatments to evaluate the effects of treatments on six major forest components (Figure 1).

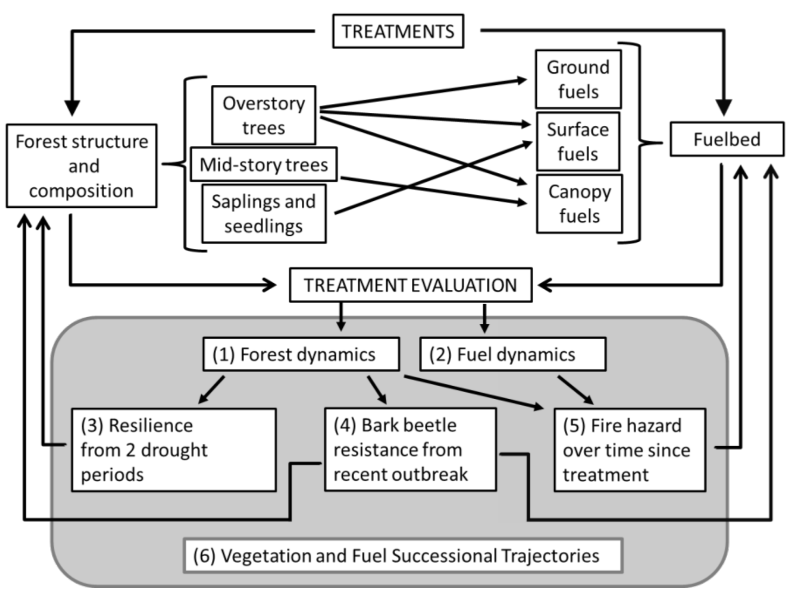

Figure 1. Study components and connections.

Cutting treatments were completed in 1992 and prescribed burns were conducted in Spring 1993, Fall 1993 and Spring 1994. We propose to describe (1) forest and (2) fuel dynamics over the 25 years from pre-treatment measurement (1991) through the re-measurement (2016). We will then test treatment differences to resilience from (3) drought, (4) a mountain pine beetle outbreak, and (5) fire hazard. Lastly, we incorporate empirical data and model outputs from 1-5 to examine (6) vegetation and fuel successional trajectories.

2. Study Site(s)

Lick Creek is located in western Montana on the Darby Ranger District of the Bitterroot National Forest. Site conditions are comprehensively described by Arno et al. (1995) and by Sala et al. (2005). The site is dominated by approximately 100-year old ponderosa pine with scattered Douglas-fir. The historical fire regime was low-intensity surface fire, occurring at a fire-return frequency of approximately 7 years (Smith and Arno 1999). Two studies, the shelterwood study and the commercial thinning study (see sampling design for treatment descriptions), were designed in 1991. The studies were designed as separate experiments, but have the same treatment implementation years and sampling protocol, allowing us to pool analyses.

Photopoints throughout the larger, Lick Creek Demonstration Forest were established in 1909 (Smith and Arno 1999). These points are permanently monumented and have been photographed in 1909, 1925, 1938, 1948, 1958, 1968, 1979, 1989, 1997, and 2009. We will re-take the photopoints in 2016. The last compilation of these points included 1909-1997; therefore, we will add photographs through 2016 to show a 107 year sequence of forest change.

3. Sampling Design

Both studies are randomized complete block designs with three blocks (replicates) and four treatments.

- The shelterwood study includes 12, 3-ha experimental units of four treatments: control, shelterwood, shelterwood + low fuel consumption burn, and shelterwood + high fuel consumption burn. The shelterwood was designed to leave a target stocking of 9 m^2 ha^{-1} of the healthiest, largest ponderosa pine trees. Harvest was completed in Fall 1992. The prescribed burns were conducted in May 1993 under two different moisture conditions. Complete treatment descriptions, including fuel moisture contents, are described in Ayers et al. (1999).

- The commercial thinning study consists of 12, 3-4 ha experimental units, with four treatments: control, thin-only, thin + Fall burn, and thin + Spring burn. Units were thinned from below in 1991 to reduce Douglas-fir and basal area to a target of 11 $m^{-2}ha^{-1}$. Low-to-moderate intensity prescribed burns were conducted in the Fall of 1993 and Spring of 1994. Complete treatment descriptions are reported in Sala et al. (2005) and Smith and Arno (1999).

4. Field Measurements

In each experiment unit for each study, prior to treatment implementation, 12, 0.04-ha circular plots (subplots) were established and permanently marked (total = 288 plots). Pre-harvest measurements were completed in 1991; post-harvest measurements were completed in 1992; post-burn vegetation and fuel measurements were conducted in 1993, 1994, 1998, 2001, and 2005 (1, 5, 8, and 12 growing seasons post-fire). All plots were relocated in 2013.

Restoration Burning and Cutting Treatment Effects on Vegetation Dynamics
Sampling protocols for trees and saplings will follow past measurement protocols. Each vegetation plot consists of nested circular fixed-area plots of 2 sizes: 0.4 ha for trees > 15cm dbh and saplings and 0.02 ha for seedlings. Species, diameter, height, and live crown base height will be recorded for each tree. For snags, diameter, height, and cause of death will be recorded. Trees > 15 cm dbh are tagged.

Restoration Burning and Cutting Treatment Effects on Fuels Dynamics
Fuels will also be sampled following past protocols that used the planar intercept method (Brown 1974) to estimate ground and surface fuel loading. At each vegetation plot (n=12/experimental unit), two, 9-m transects extend from plot center. On each transect, 1000-hr time-lag (≥ 3 in) fuels will be individually measured for diameter and decay class along the full 9 m length, 100-hr (1-3 in) fuels will be tallied along the first 3.6 m from plot center, and 1-hr (< 1/4 in) and 10-hr (1/4 – 1 in) fuels will be tallied for the first 1.8 m. Litter/duff depths will be recorded at each transect midpoint and endpoint. Surface shrub and herbaceous vegetation height and cover will be estimated on 2 m diameter plots at points/transect. Tree measurements collected above will be used to calculate canopy fuel loads, according to protocols described in Data Analysis, below.

Restoration Burning and Cutting Treatment Effects on Ponderosa Pine Resilience
In 2001, trees from each unit were selected for coring based on the same criteria used for the 1994 post-treatment measurements: DBH between 25–31 cm; a live crown ratio between 60 and 70%; and crown scorch (the percentage of crown length with foliage killed by fire) between 10 and 20% in burned units. These criteria represented the dominant size class, mean crown ratio and mean fire damage in burned units. From among these trees, six were selected at random for coring in each unit, with no two trees selected in the same 0.04-ha plot. Cores were extracted with an increment borer at 1.4 m above ground on the west side. These cores were sanded and mounted and are currently available. In 2016, we will extract two cores from each of the same sample trees to examine growth trajectories since 2001 (6 cores/unit = 144 trees; 288 cores). Climate data will be obtained from the nearest meteorological station (GHCND:USC00242221). Yearly Palmer Drought Severity Index (PDSI) for the region will be obtained from the National Climate Center. Severe drought periods during the last 40 years will be identified based on PDSI values < -2, and consistent patterns of local precipitation and temperature. Preliminary analyses suggest that the droughts in the early 2000 and the 2007 are the best candidates for an analysis of resilience.

5. Data Analysis

Please see attached Statistical Review from University of Montana statistician, Brian Steele.

Restoration Burning and Cutting Treatment Effects on Vegetation Dynamics
Stand and canopy fuel attributes will be calculated using the Fire and Fuels Extension of the Forest Vegetation Simulator (FFE-FVS; Reinhardt and Crookston 2003). Calculated structure metrics will include average seedling, sapling, and tree density, basal area, and quadratic mean diameter (QMD). Proportional species composition (live trees) will be calculated in terms of trees hectare^{-1} and basal area.

We will analyze treatment differences using general linear mixed models in SAS (Proc Glimmix) using a model for randomized complete block design with subsampling. We will identify year as the subject to account for repeated measures. Using a randomized complete block design with subsampling, we intend to construct a mixed effects model specified as:

$$y_{ijk} = \mu + \alpha_i + B_j + (\alpha b)_{ij} + \gamma_k + \epsilon_{ijk} \quad (1)$$

Where y_{ijk}= vegetation/fuel response variable, μ = grand mean of response variable, α_i = fixed effect of treatment i (whole-plot effect), B_j = j^{th} block random effect, $(\alpha b)_{ij}$ = random effect of interaction between i^{th} treatment and the j^{th} block, γ_k = k^{th} measurement year effect, and ϵ_{ijk} is the within-subject experimental error. Please see attached Data Management Plan for all response variables.

<u>Restoration Burning and Cutting Treatment Effects on Fuels Dynamics</u>
Surface fuel transect data will be processed using the software program FIREMON (Lutes et al. 2006) to estimate fuel loading for each fuel load element: duff, litter, 1-hr fuels, 10-hr fuels, 100-hr fuels, 1000-hr fuels, live herbaceous fuels, and live shrub fuels. The fuel profile will be completed by using tree and regeneration data to calculate canopy fuels using FFE-FVS, which uses loading adjustment factors calculate canopy bulk density (CBD) and canopy base height (CBH) (Brown 1978).Current fuel loads will be compared to previous fuel loads to determine trajectories of fuel aggradation/degradation per fuel particle class. The resulting changes in fuel load serve as the responses variables of interest; these changes will be analyzed on an absolute basis (loss or gain of fuel, kg m^{-2}) and relative (percent loss or gain) basis using the same model design as for vegetation.

<u>Restoration Burning and Cutting Treatment Effects on Ponderosa Pine Resilience</u>
Drought: Tree cores will be dated and crossdated using standard methods (Grissino-Mayer 2001). We will scan cores at 2400 dpi and measure tree total ring widths and seasonwood (earlywood and latewood) using CooRecorder. Detrending and basal area increment (BAI) calculations will be done using the R dplR package. Several components of drought resilience will be calculated as in our previous work in ponderosa pine (Lloret et al. 2011). Briefly, BAI is measured before (pre), during (D) and after (post) the drought event. Resistance is the ratio between the growth during the drought and the growth during the respective pre-drought period (the impact of drought). Recovery is the ratio between the post-drought growth and the growth during the respective drought period (ability to bounce back from the drought). This index is positive, with values < 1 indicating a decline in growth after the episode. Resilience is the ratio between post-drought growth and pre-drought growth. Relative Resilience is the resilience weighted by the magnitude of the drought effect, and it is estimated as follows: Relative Resilience = ((Post-D) / (Pre-D)) (1-(D/Pre)) = (Post-D) / Pre. The advantage of the relative resilience index is that it accounts for the fact that the ability to reach pre-drought performance depends on the impact (in our case reduction of growth) during the disturbance (Lloret et al. 2011).

Fire Hazard: Using the vegetation and fuel data, we will use FFE-FVS to estimate fire hazard parameters under 95 and 98.5 percentile weather conditions. We will test treatment differences in predicted torching index, crowning index, rate of spread, and flame length. We will also test the differences in predicted tree mortality under these weather conditions.

Bark Beetles: To determine if treatments have affected resistance from the current mountain pine beetle outbreak we will examine differences in mortality from bark beetles based on the 2016 data. Beetle attacks are typically highly spatially-dependent, so we plan to use zero-inflation models to test treatment differences.

<u>Restoration Burning and Cutting Treatment Effects on Successional Trajectories</u>
Non-metric Multidimensional Scaling (NMS) will be used to investigate treatment-related successional trajectories, including both vegetation and fuel components in the matrix. NMS is one of the ordination methods most widely used in plant ecology, as data may be correlated and non-linear. NMS reduces dimensionality of the original data to display how variables are related to each other and to which treatments over time. We will use both empirical data variables(i.e., density, basal area, loading, percent ponderosa, etc.) and modeled variables (i.e., torching index, crowning index, rate of spread, etc.) from pretreatment (1990) and several post-treatment timesteps (at least 1994, 2001, and 2016) to understand how treatments have changed over time in relation to each other. Ordination goodness-of-fit will be evaluated by the stress measure. All ordination will be conducted in R, using the vegan package.

III. Project Duration and Timeline

Project Milestone	Description	Delivery Dates
October 2015	Project begins – development of database and compilation of past data. Complete metadata and archive historical data on USDA Forest Service Research Data Archive	April 2016
Oct 2015 – Feb 2016	Website development and Science Brief through Northern Rockies Fire Science Consortium site	Feb. 2016
Jun – Aug 2016	Data collection	Oct. 2016
Jun 2016	Field trip	Jun 2016
Sep – Dec 2016	Data entry and quality control	Oct. 2016 – May 2017
Jan 2017 – Mar 2018	Data analysis and manuscript preparation; Data archiving of 2016 re-measurement data	Jun 2017 - Mar 2018
Jun 2017	Field trip	Jun 2017
Oct. 2018	Final Report and project completion	March 31, 2018

IV. Project Compliance - NEPA and Other Clearances

All treatments have been implemented and NEPA is not required at either site. Proposed data collection has been approved by the Bitterroot National Forest.

V. Research Linkage

This study builds on a substantial level of previous work. At Lick Creek, the 1-5 year treatment effects on fuels and tree structure (Smith and Arno 1999) and 9-year post-fire treatment differences in physiology (Sala *et al.* 2005) and reproductive output (Peters and Sala 2008) have been published. A comprehensive description of the history of Lick Creek and 1992-1993 treatments are found in (Menakis 1994, Smith and Arno 1999). These projects are completed, and there are no current or pending related research grants to fund additional site re-measurement or analysis of vegetation and fuel responses. There is linkage to one externally-supported project currently underway. An ongoing study sponsored by the US-DOE is investigating the forest productivity responses to restoration treatments at Lick Creek (soil nutrient contents; foliar nutrient contents; foliar area and growth efficiency). Co-PI's on that project are Keyes and D. Page-Dumroese (Research Soil Scientist, USDA Forest Service Rocky Mountain Research Station, Moscow, ID). That work has provided for site reconnaissance and plot re-monumentation at Lick Creek, and identification of related Lick Creek documents, that have facilitated and informed this proposed study.

Table 2. Current and pending related research grants

Grant Program	Project or Proposal Description/Identification	Funding Amount	Project Completion Date
AFRI-Biomass Research and Development Program	Consequences of Biomass Harvesting on Northern Rocky Mountain Forest Condition and Productivity	Approx. $75,000 to Lick Creek analysis	Est. Dec 2016

VI. Deliverables and Science Delivery

We will develop a suite of non-technical and technical deliverables to target multiple audiences. The majority of the non-technical deliverables will be in cooperation with the Northern Rockies Fire Science Network (NRFSN; see attached letter of support from Vita Wright). We will develop material for a Lick

Creek website hosted on the NRFSN website, as well as two science brief describing the history of Lick Creek and current project. We will also partner with the NRFSN to host field trips both for managers and the general public. Working with the NRFSN will leverage our project funding because NRFSN has funding for field trips, website support and maintenance, and has already developed an email database to disseminate information to the fire science community. Written deliverables include one University of Montana MS thesis, several refereed publications (3 anticipated), and two or more summary articles for general audiences of natural resource managers. Science delivery will also include presentation of project results at a diverse set of regional, national, and international meetings consisting of scientists and managers. Lastly, all existing and newly collected data from previous and current project at Lick Creek will be compiled and formally archived.

Table 3. deliverable, description and delivery dates

Deliverable Type (see proposal instructions)	**Description**	**Delivery Dates**
Science Brief	Northern Rockies Fire Science Network Science Brief: Overview of Lick Creek project history and future plans	Dec 2015
Website	Description of Lick Creek history and current project hosted by NRFSN (http://nrfirescience.org/)	Feb 2016; updated as necessary
Field tour	Field trip to Lick Creek for managers to discuss treatments, re-measurement methods, and preliminary results co-hosted with NRFSN	Jun 2016
Science Brief	Northern Rockies Fire Science Network Science Brief: Managing to maintain resilient ponderosa pine forests in the Northern Rockies.	Mar 2017
Field tour	Field trip to Lick Creek for the general public to discuss treatments and study results co-hosted with NRFSN	Jun 2017
Research paper	Applied paper on restoration treatment effectiveness, focused on vegetation community changes over time	Nov 2017
Research paper	Applied paper on fuel treatment longevity and fuel dynamics, focused on fuel load changes over time	Nov 2017
Master's thesis	University of Montana MS thesis on 23-year vegetation and fuel responses to forest restoration treatments at Lick Creek	Dec 2017
Research paper	Article reporting how treatments differ in forest resilience to drought, wildfire, and bark beetle attacks	Jan 2018
Summary article	Fire Management Today article summarizing the long-term impacts of restoration treatments in Northern Rockies ponderosa pine forests; targeted toward forest practitioners	Feb 2018
Conferences	3-4 regional, national & international conferences to present study results; to include the SAF and AFE Convention	2016-18
Dataset	Archive of historical and 2016 re-measurement data and metadata	March 2017

VII. Roles of Investigators and Associated Personnel

Table 4. Roles and responsibilities of associated personnel

Personnel	**Role**	**Responsibility**
Christopher R. Keyes	Lead-PI	Project coordinator, lead for non-technical deliverables (science briefs, field trips), analysis and writing, M.S. student advisor
Sharon M. Hood	Co-PI and post-doc	Database development, re-measurement coordination, lead on analysis and peer-reviewed journal deliverables

Anna Sala	Co-PI	Provide expertise of past data collection protocols and activities. Help coordinate field sampling. Participate in data analyses, writing and field tours
Duncan C. Lutes	Co-PI	Forest Service liaison, database development; data archiving
M.S. student	Graduate student	Data collection, analysis and reporting of regeneration dynamics and treatment longevity
Michael G. Harrington	Collaborator	Provide expertise in historical data collection protocols and past activities, provide historical photographs for deliverables

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