Estimating surface and canopy fuel conditions after stand-replacement disturbance events in northern Rocky Mountain ecosystems

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ABSTRACT

It is generally assumed that insect and disease epidemics, such as those caused by the mountain pine beetle, predispose damaged forests to high fire danger by creating highly flammable fuel conditions. While this may certainly be true in some forests, these dangerous fuel conditions many only occur for a short time when evaluated at a landscape level. Others feel these epidemics may cause high surface fuel loadings when the dead material from dead trees falls to the ground. These high fuel loadings may result in abnormally severe fires. This study will evaluate, through intensive field collections and simulation modeling, the effect that exogenous disturbance events, namely fire and beetles, have on future fire hazard and risk. We will measure surface fuel deposition and decomposition rates for a number of forest types after wildfire events and after beetle epidemics to quantitatively describe fuel dynamics to ultimately estimate resultant fire behavior in heavy mortality stands for up to 10 years after the disturbance. Fuel deposition will be measured using semi-annual collections of fallen biomass sorted into six fuel components (fallen foliage, twigs, branches, large branches, logs, and all other material). This litterfall will be collected using a network of seven, one meter square litter traps installed on plots established on fifteen sites across the northern Rocky Mountains USA. We will also measure decomposition using litter bags installed in one set of five bags for three surface woody fuel components and monitor biomass loss from the bags each year for 5-10 years. We will also measure stand and fuel characteristics of the plot using FIREMON techniques at the beginning, and every year till the end of the study. We will last quantify fire behavior for each plot using collected or measured tree and fuels data, local weather summaries coupled to the BehavePlus fire model and the NEXUS crown fire model. We will summarize and report fuel deposition and decomposition rates in these disturbed stands over the 10 year period and the describe fire hazard in these stands for each of the 10 years.

INTRODUCTION

Conventional wisdom in fire management holds that stands having trees that are killed by insects, disease, or fire will remain at high fire hazard for decades after the disturbance because the foliage and fine woody material killed by the disturbance agents will be highly flammable and therefore create landscapes that have high risk for abnormally severe fire (Gara et al. 1984). This assumption, however, is currently being disputed for many ecosystems across the western United States. There is only a small period of time, probably only weeks, when the disturbance-killed tree foliage will be markedly more flammable than the remaining live foliage, especially during moisture conditions when surface fuels can burn. This dead foliage will eventually fall to the ground within a year or two. Others feel that the fine woody material from dead trees will fall to the ground and create surface fuel conditions that could foster wildfires of high intensity and severity. But, recent litterfall studies have shown that only small amounts of fine fuel are deposited each year and much of this material is lost to duff in a decade or two (Keane 2008[in press]). What is needed is an in-depth analysis and corresponding field study that quantitatively describes fire behavior for both crown and surface fires in stands that have been recently killed by various disturbance agents.

This study will describe fire hazard in recently disturbed stands of major stand types in the northern Rocky Mountains by measuring fuel deposition and decomposition rates, implementing them in models of ecosystem dynamics, simulating fuel dynamics within these stands over time, and calculating the corresponding fire behavior in these simulated stands.

PROJECT OBJECTIVES AND SUMMARY

The project has one primary objective and a number of specific objectives:

- *Determine if recently disturbed stands in the northern Rocky Mountains have high fire hazard over 10 years*

This objective can be achieved using the following steps described as sub-objectives;

- *Measure the litterfall and decomposition rates of major fuel components across major forest types in the northern Rocky Mountains after a major disturbance event for 10 years*
- *Measure stand conditions at the beginning, and every year to year 10 of this study*
- *Implement findings in ecosystem models containing explicit simulations of fuels dynamics*
- *Model fire behavior and fuel conditions in these stands for the decade after the disturbance events using the collected stand data*
- *Model fire behavior and fuel conditions after the 10 years of this study using ecosystem models parameterized using the data from this study*

The audience for this effort is managers and researchers interested in describing and sampling fuels after stand-replacement disturbances for future fire behavior and effects prediction. This research may lead to new methods of prioritizing fuel treatments after major insect, disease, or fire events. Moreover, it should provide important parameters and values for fuel sampling efforts.

BACKGROUND

Six surface fuel components are recognized in this study. Freshly fallen leaves and needles from trees, shrubs, and herbaceous plants are considered *foliage* while all other non-woody material, such as fallen cones, bark scales, lichen, and bud scales, are lumped into a category called *other canopy fuels*. The woody material is sorted into four diameter classes using definitions required by the fire behavior and effects models (Anderson 1982, Burgan 1987, Fosberg 1970, Rothermel 1972, Reinhardt and Keane 1998). The smallest size class, called *twigs*, defines 1 hour timelag fuels with diameters less than 3 mm. *Branches* with diameters between 3-25 mm are 10 hour timelag fuels and *large branches* with diameters ranging from 25-75 mm are 100 hr timelag fuels. The *logs*, downed woody fuels greater than 75 mm in diameter, are referred to as coarse woody debris (CWD) and define the 1,000 hr timelag fuel component but this CWD does not include snags or stumps (Hagan and Grove 1999). We use the term litterfall to describe the process of fuel deposition so all fuels that hit the ground are called litter for simplicity and the devices used to measure fuel dynamics (litterfall and decomposition in this study) are referred to as litter traps and litter bags.

Litterfall rates have been measured for many ecosystems of the world (Bray and Gorham 1964, Facelli and Pickett 1991, Harmon and others 1986a, Van Cleve and Powers 1995) and especially those of the Unites States Pacific Northwest (Figure 1), but none have quantified fuel dynamics after disturbance. Most studies only measured the rate of foliage or CWD deposition (Harmon and others 1986b, Vogt and others 1986). Small woody debris additions to the forest floor, such as twigs and branches, are rarely reported even though they are may be the most important to fuels management and fire behavior prediction because they contribute to fire spread (Albini 1976, Rothermel 1972). There are some exceptions, such as Ferrari (1999) who measured twigfall in hardwood-hemlock forests and Meier and others (2006) who measured fine woody material, along with other canopy litterfall, in an alluvial floodplain hardwood forest. Deposition rates for CWD are usually measured from historical tree mortality and snag fall rates over time, but this assumes tree fall is the only input to CWD buildup. Large branches and tree tops, however, also contribute to CWD inputs to the forest floor in some ecosystems (Harmon and others 1986b).

Decomposition rates have also been documented for many ecosystems (Aber and Melillo 1980, Horner and others 1988, Millar 1974, Olsen 1963), but again, these rates are usually for the foliage and large log material, especially in the western United States (Figure 1). The exceptions here are Edmonds (1987) and Taylor and others (1991) who measured decay of twigs, branches, and cones, and Carlton and Pickford (1982) and Christiansen and Pickford (1991) who estimated small wood losses by sampling different aged timber slash.

The parameter k is often used to describe rates of decay because it is the parameter in the following exponential curve that describes decay over time (Olsen 1963, Robertson and Paul 2000).

$$\frac{A_0}{A_t} = e^{-kt}$$

where A is the amount of material at time zero (A_0) and time t (A_t), and t is time. Decomposition is often expressed as an exponential function because organic material takes longer to decay as time progresses. Easily decomposed cellulose is quickly decayed while the less digestible lignin remains and it decomposes slower (Kaarik 1974, Moorhead and Sinsabaugh 2006).

It is difficult and costly to measure surface fuel dynamics in the field because it requires extensive networks of litterfall traps that must be frequently monitored over long time periods (5-10 years or longer). The density and spacing of the collection devices are highly dependent on the type of fuel collected with large fuels requiring larger traps installed across larger areas and monitored for longer time periods but small fuels require smaller and fewer traps but these traps are more frequently visited to minimize decomposition losses. Forest fuel accumulation is highly variable in space due to the clustered forest canopy and small scale canopy disturbances (Brown and Bevins 1985).

MATERIALS AND METHODS

In this study, we will quantify the rates of deposition and decomposition for several surface fuel components in a number of forest types across the northern Rocky Mountains. We have specifically designed the study to quantify fuel dynamics parameters for use in complex landscape models of fire and vegetation dynamics (Keane and others 1996a, Keane and others 1996b, White and others 1998). We will also investigate the spatial and temporal properties of litterfall and decomposition and discuss their implications on fuel modeling and mapping. Since it is impossible to measure fuel dynamics for all stand types in all northern Rocky Mountain ecosystems, we have only established plots in some major forest types that have been disturbed by common disturbance agents.

This study originated from two previous studies that explored the use of ecosystem modeling and gradient analysis to create digital maps of current and future landscape characteristics. In 1993, we installed a set of litter traps on two sites in western Montana to parameterize and validate two ecosystem models: Biome-BGC (White and others 2000a) and Fire-BGC (Keane and others 1996b) (Sites CO and SB in Table 1; Figure 2). Then, in 1995, we started an intensive project, called Gradient Modeling and Remote Sensing (GMRS), where we used measured and simulated environmental variables to map ecosystem characteristics, such as fuels, across landscapes (Keane and others 1997, Keane and others 2002a, Rollins and others 2004). To validate the various models used in both studies, we expanded the number of sites from two to six by establishing four new sites along elevational and aspect gradients within the larger Northern Rockies study area (Figure 2). We only established plots in mature stands that had no evidence or record of disturbance for at least 20 years. In 1997, we decided to represent the ubiquitous lodgepole pine (*Pinus contorta*) ecosystem that occurs east of the Continental Divide in our study. Results from this study are reported in Keane (2008, 2009).

Site Selection – We have established one plot on a number of sites that represent major forest types across Montana and Idaho (Table 1). Three plots in the Red River lodgepole pine stands were established immediately after a mountain pine beetle epidemic in 2002 near Elk City ID and were originally part of the Keane (2008[in press]) study. A number of other sites were established in the summer of 2007, 2008, 2009, and 2010. These sites were selected using the following criteria:

- Within close proximity to a major secondary or primary road (100 meters)
- Slopes less than 10 percent to avoid littertrap movement downhill
- Representative of a major stand type of the Northern Rocky Mountains
- Litter traps hidden from view from the major road to prevent vandalism
- Inside area of at least 3 acres that represent the disturbed stand
- Mature forest in the latter stages of succession
- Greater than 90% mortality in the pine species.
- Needles still on trees are preferable but not required

Each plot was permanently located using a 1 meter iron rebar that is about 1 cm thick. Numerous photos of the plot and surrounding area were taken to document the setting. The plot was georeferenced using a GPS (Global Positioning system). We then recorded the plot location and directions for finding the plot in field notebooks complete with maps, drawings, and photos. The plot is circular and one tenth acre in size (37.2 foot radius).

Table 1. List of sites that are included in this study

Site Name	**Disturbance**	**Forest Type**	**Overstory Mortality (%)**	**Year Established**
		Wildfire		
Jocko Lake (JL2) there is no JL1	Wildfire	Mixed larch, Douglas-fir, lodgepole pine	100	2008
Marais Pass (MP1)	Wildfire	lodgepole pine	100	2007
Merriwether 1 (MW1)	Wildfire	ponderosa pine (thinning unit)	25	2007
Merriwether 2 (MW2)	Wildfire	ponderosa pine	98	2008
		Beetle Epidemic		
Lost Trail (LT1)	Douglas-fir Beetle	Douglas-fir	90	2007
Bull Run (BR1)	Mountain pine beetle	ponderosa pine	98	2010
Flesher Pass (FP1)	Douglas-fir beetle	Douglas-fir	90	2009
Galena Summit (GS1)	Mountain Pine Beetle	whitebark pine	100	2007
Morgan Creek (MC1)	Douglas-fir Beetle	Douglas-fir	50	2009
Red River 5 (RR5)	Mountain Pine Beetle	lodgepole pine/subalpine fir	100	2001
Red River 6	Mountain Pine	lodgepole	100	2001

(RR6)	Beetle	pine/subalpine fir		
Red River 7 (RR7)	Mountain Pine Beetle	Mixed lodgepole pine, spruce	100	2001
Homestake Pass (HP1)	Mountain Pine Beetle	lodgepole pine	70	2007
Twin Peaks 1 (TP1)	Mountain Pine Beetle	whitebark pine	80	2009
Twin Peaks 2 (TP2)	Mountain Pine Beetle	whitebark pine	70	2009

Plot measurements -- At each plot, we will measure a number of topographic, vegetation, and ecosystem characteristics on 0.1 acre (0.04 ha) circular plots using the FIREMON sampling methodology (Lutes and others 2006) based on the ECODATA methods (Hann and others 1988, Jensen and others 1994, Keane and others 2002a). All plot measurements will be done each autumn for every site and at the time of installation of the litter traps. We will fill out a FIREMON PD, TD, FL, and SC form, along with a separate log inventory form and Fuel Microplot form, each year for each plot. The sites will be visited twice a year (spring and fall) but plot measurements will only be taken in the fall; litterfall collection is done at each visit. See appendix A for all equipment needs, appendix B for all plot forms not in FIREMON, and Appendix C for an abbreviated list of all tasks needed to be performed on the plot.

In summary, the most important measurements are an inventory of all trees within the plot to compute canopy fuels, basal area, leaf area, and stand density, and a network of 3, 60 foot fuel transects (Brown 1970) to estimate surface fuel loadings for the five fuel components used in this study. First, we will fill out the entire FIREMON Plot Description form that describes general plot site conditions. We will GPS the center of the plot and record all biophysical characteristics provided on the PD form. Next, we will record tree population data using the FIREMON Tree Data method. We will tag and measure all trees above 4.5 in DBH. Tags are pointed towards plot center and nailed at near ground-line. For live trees we will record species, tag number, health class, and crown class and measure the DBH (inches), tree height (feet), canopy base height (feet). The height measurements (tree and canopy) are measured using a hypsometer or clinometer for the first 3-5 trees and then estimated for the rest. For dead trees we will record species, tag number, decay class, and mortality code and measure DBH (inches) and tree height (feet). At the first plot measurement (plot installation), a live crown class and canopy base height is approximated from the dead crown so that the pre-disturbance stand structure can be created. We will measure all live trees less than 4.5 in DBH but greater than 4.5 feet (1.37 meters) in height (saplings) on Table 2 of the FIREMON TD plot form within the macroplot. We will not tally these trees but instead record the species, health, diameter class, height, and crown base height for each live sapling. Seedlings (tree less than 4.5 feet in height) will be tallied by species and 1 foot height classes on the FIREMON TD Table 2 form for a 1/100 acre subplot (11.8 ft radius from plot center).

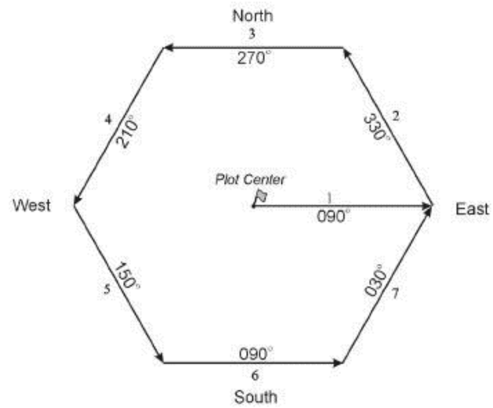


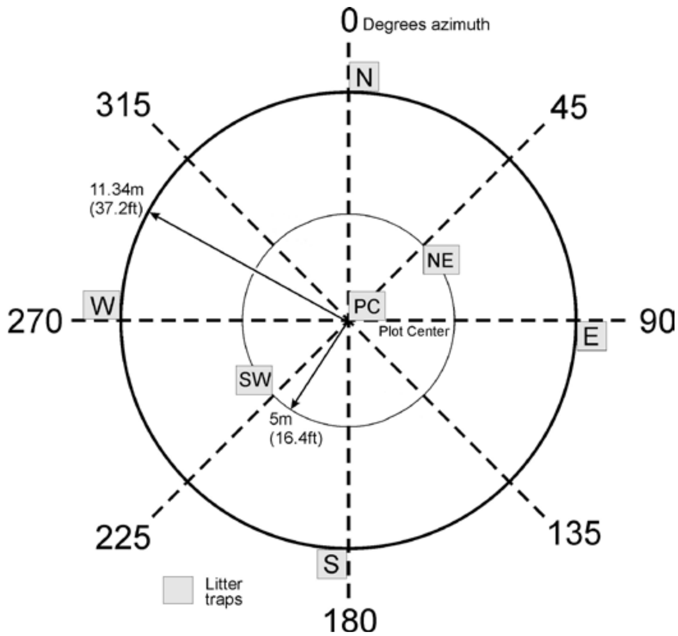
Figure FL-13—The FL plot design allows a representative sample of DWD to be obtained while reducing or eliminating the bias introduced by nonrandomly oriented pieces. Data are collected on and along three to seven sampling planes.

We will also sample downed woody fuels characteristics using the FIREMON Fuel Loading method. Here, we will establish three, 60 foot transects starting at plot center and circling the outside of the plot using the directions suggested in FIREMON (see figure to right). Each transect will be permanently located using 10 inch spikes at the beginning and end of the transect and flagged to identify locations in the future. We will measure fine fuels (1 and 10 hour timelag) starting at 10 feet and going to 16 feet (6 feet). The 100 hour fuels will be measured starting at 10 feet and going to the 20 foot mark. The logs (>8 cm diameter logs) will be measured along the 10 to 60 foot transect length. The direction of the first transect is 90 degrees, the second 330 degrees and the third is 270 degrees.

Next, we will measure the small and large end diameters (cm), length (m), and decay class of all logs within the entire plot as specified in the FIREMON FL method. A log's length always terminates at the boundary of the 37.2 radius circular plot. Only logs whose central longitudinal axis is above the litter-duff surface will be measured.

We will measure fuel loadings of all fine woody, shrub, and herbs using the visual Photoload estimation method (Keane and Dickinson 2007). Here, we will permanently establish five 1 m^2 microplots exactly 5 meters from plot center in each of the cardinal directions AND at plot center. The bottom, left-hand corner of the microplot will be placed at the 5 meter mark and a 10 in spike will be driven into the ground at that corner and the corner that is in line with plot center to mark this placement permanently. Each spike will be flagged and painted to aid in relocation. We will then estimate fuel loadings within each microplot for the shrub, herb, and 1, 10, and 100 hr woody fuels. We will also measure duff/litter depths in an area within 1 foot of the two nailed corners of each microplot. Then, we will estimate the ground cover inside the microplot. We will take digital pictures of the north microplot from eye level facing north, and we will also establish a photopoint by selecting a tagged tree and standing at the tagged tree and taking a photo back across plot center trying to capture stand and fuel conditions. A hemispherical photo will be taken at plot center to document canopy changes.

As a last step, we will complete an SC form recording cover and height (feet) for all species of plants on the plot. We will key to species if possible, then to genera, then to lifeform if expertise in plant species identification is low. These data will be used to compute shrub/herb fuels and compare against the microplot data.



Measuring litterfall -- At each plot, we have installed 7 litter traps in the pattern shown in the figure to the right to collect fallen biomass. The litter traps were constructed by creating a 1x1 meter frame (inside dimensions) with 2x9 cm (1x6 inch) boards and then tacking a coarse grid hardware cloth on the bottom of the frame to allow water drainage and minimize losses from accumulated material due to decomposition and wind (Figure 5). We also tacked a plastic screen (mesh size 0.7 mm) on top of the hardware cloth to block fine material from falling through the coarse hardware grid and to facilitate litter collection.

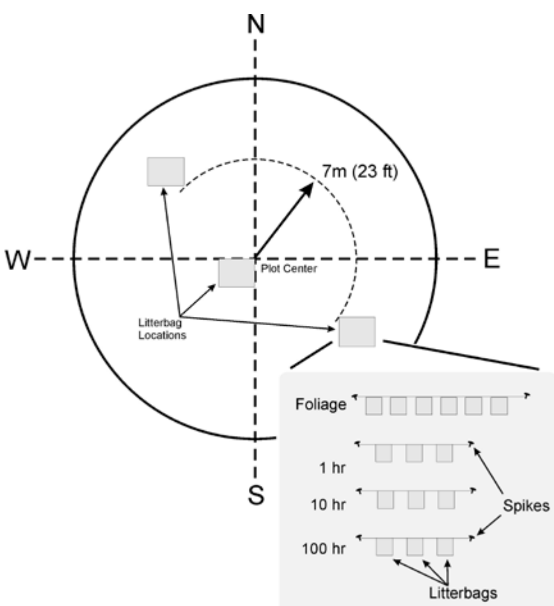
Each plot will be visited twice a year: 1) just after snowmelt and 2) just before first major snowfall. All material in each trap will be placed into heavy paper bags that are labeled to identify site, plot, trap, and date. Woody fuel particles that lay partially out of the trap were sawed directly at the trap border as defined by the inside dimension of the trap boards. If a large woody fuel falls over the plot (>3 in diameter), the large and small diameters where the log leaves the trap along with the length can be measured and written directly on the sample bag.

The collected materials will then be transported to the laboratory and the labeled bags placed in an oven set at 90^{o}C for 2-3 days. The dried litter will be placed in cake tins and sorted by hand into the six fuel components (foliage, twigs, branches, large branches, logs, and other canopy material). The weight of each fuel component will be recorded to the nearest 0.01 g along with the date, site, plot, and trap information written on the bag. A small sample of the dried material will be aside for the decomposition experiment and other unanticipated analyses.

Measuring fuel decomposition -- We will use litter bags to estimate the rate of decay for the four fuel components of freshly fallen foliage, twigs, branches, and large branches (Bocock and Gilbert 1957, Edmonds 1979, Johannsson 1994, Prescott and others 2000, Preston and others 2000, Robertson and Paul 2000). We will make these bags by sewing a fiberglass screen with a pore size of about 2 mm for the top with a rumen bag or pool cover material with a pore size of 0.055 mm for the bottom (Figure 6a). These materials will be sewn together with UV resistant thread and one end of the bag will be left open. Bags for foliage will be roughly 15x20 cm (6x8 inch), while bags for the woody fuels were roughly 20x30cm (12x8 inches). For the litter, we

will first weigh the bag and then we will put approximately 100 g of dried litter material collected from the litter traps (see previous section) into each bag. The bag will then be stapled shut and weighed. A numbered tag will then be firmly attached to the bag using wire or staples to uniquely identify the bag, and the stapled bag with tag with then be weighed. The weight of the bag, the stapled bag without the tag, and the weight of the stapled bag with the tag will be recorded in a spreadsheet. Decomposition rates for logs, duff, and other canopy material will not be measured because of limited time, lack of appropriate equipment, and incompatible methods. For the 1, 10, and 100 hr fuels, we will place approximately 100-200 g of material into the lag bags. This material should be collected from each FUELDIST site from standing trees. These fuels should be collected from the dead branches that are the most likely to fall. These fuels should be dried for at least 3 days before placement into the decomposition bags. We will then follow the same procedure as the litter where first the bag is measured, then the stapled bag with material, then the stapled bag with material and tag. For each of the FUELDIST sampling sites we will prepare 15 bags for each of the four fuel components (litter, 1, 10, 100 hr) to create three sets of five bags.

At each plot, we will install three sets of five bags for the litter and three fine woody fuel components (1, 10, and 100 hour timelag) (Figure 6b; note that there are only three for the downed woody fuels in the figure – we will install five). One set is placed near plot center, with another at about 7 meters (23 feet) northwest of plot center, and the third about 7 meters southeast of plot center (Figure 6). We will lay the bags on top of the litter layer in spring and secure them by a wire stake driven into ground to a depth of 19 cm (7.5 inches) to prevent movement downslope and ungulate damage. Locations of each bag set will be identified by orange flagging and a large orange painted stake. Decomposition is measured over five years by taking one bag from each wire set every 12 months (each spring). The retrieved bags are taken from the wire and any material that had fallen onto the bag or that became attached to the bottom of the bag will be scraped off using a knife. The litter bags will be placed in paper bags and brought back to the laboratory to be dried at 80^{o}C for three days and weighted to the nearest 0.01 g with the weight, tag number and tag date recorded for analysis.



Analyzing collected data -- We will summarize the deposition and decomposition rates by fuel component for each plot to create tables to use as parameters and validation in fuel dynamics models. We will compute the annual litterfall rates (kg m^{-2} yr^{-1}) by dividing the total amount of accumulated material over all traps on a plot for the entire time period by the number of days in that time period, and then multiplied this daily rate by 365 to obtain an annual rate.

We will calculate two estimates of decomposition. We will first estimate the parameter k by parameterizing the exponential decay function described in Equation 1. We will also estimate a mass loss rate (% yr^{-1}) from differences in bag weights over the three year period. Statistical summaries included an analysis of variance to determine the adequate level of sampling intensity and strength of the fuels flux estimates. The analysis to determine the decomposition parameter *k* in the Olson (1963) equation will be performed in SPLUS using a linear mixed effects model whose form is as follows:

$$\ln\left(\frac{x_{ij}}{x_{0ij}}\right) = -kt + b_i + \varepsilon_{ij} \qquad \textbf{(1)}$$

where x_{ij} is the weight of the jth observation at trap i and x_{0ij} is the initial weight of the jth observation at trap i; b_i is the random effect of trap i representing the deviation from the fixed effect for trap i; and ε_{ij} are the random errors assumed to be independently distributed with a normal distribution.

We will perform an analysis of variance for litterfall across all fuel components on each plot to determine if we had sufficient sampling rigor. First we will calculate the variation of litterfall using a bootstrap method where we randomly removed each trap to determine the number of traps required to minimize variance. Then we will calculate the probability of detection for each fuel component over the entire length of the study and for one year to verify the results generated from the bootstrap variance calculations.

We will compute fire hazard by calculating various fire behavior descriptors (flame length, fire intensity, rate of spread, crown fire intensity, crown fire index) for the stands at each year of development using the sampled tree and fuels data. These predictions will be compared and contrasted to other stands where the trees are living.

We will then use the measured and synthesized litterfall and decomposition rates to simulate future stand conditions using the FireBGC model that mechanistically simulates stand development using weather and climate drivers. FireBGC will output tree and fuel conditions each year for 100 years and we will analyze the predicted fire behavior across the 100 year time span.

SAFETY

The field portion of this project may be somewhat dangerous for field crews. We plan to conduct daily safety sessions to remind crews of dangers in sampling surface fuels. The crews will be given extensive training and the state-of-the-art safety equipment to complete their tasks. Windy days when the crowns are swaying will also pose a risk to the crews, so sampling will also be curtailed during these days. This is especially true during thunderstorms when wind AND lightning are problems. Crews will be informed of the proper procedures to report accidents and we will train some crew members in first aid in case of an accident. This project will also require endless hours of driving to field sites so the proper precautions will be taken to ensure no automobile accidents including defensive driving.

PROJECT SCHEDULE

We will complete littertrap installation, plot measurements, and autumn collections in 2007. We will then continue this study for 10 years until 2017. There will be an additional six months of analyses, report writing, manuscript preparation, and review.

PERSONNEL

Dr. Robert Keane has extensive experience in ecological modeling and conducting large ecological field studies. Dr. Keane will support the project through his expertise in LAI instrumentation and procedures, and through his experience in developing canopy fuel data for FARSITE. His is primarily responsible for the field sampling design and analysis of the LAI instrumentation and its relationship to crown fuel characteristics. He will also write the various programs specified in this study plan.

BUDGET

ITEM	EACH YEAR	TOTAL
RMRS budget		
Keane salary	Contributed	0
Technicians *	$12,000	
field equipment		
Travel		
Publications		
RMRS subtotal		
Project Total		

* Technician salary includes a crew of 4: 1 GS-7 crew leader/data manager, 12 months/year, and 3 GS-5 crewmembers, 4 months/year.

DELIVERABLES

This project will result in several products that will be useful to managers in any agency with responsibility for fire management in conifer forests. Excepting the normal publication delays, all deliverables will be available at the conclusion of the study (spring 2002).

- A journal article describing the fire behavior after stand replacement disturbances.
- A USDA Forest Service GTR that describes the litterfall and decomposition data after stand-replacement disturbances.

TECHNOLOGY TRANSFER

Technology transfer will include:

- The USFS General Technical Report describing the fuel dynamics
- Publication in IJWF of the analysis of fire hazard

Appendix A
Equipment list

Equipment List

Plot setup
- Compass
- Clinometer
- Logger’s tape (DBH tape)
- GPS unit
- Flagging
- Pencils, field notebook
- Field sheets
- Rebar 3 foot, ½ inch dia
- 10-12 inch spikes
- 1 m2 microplot FM frame
- Wire flagging with 2 foot lathes
- Cloth tapes at least 75 feet long
- Go-no-go gauges
- FIREMON plot sheets – PD, FL, TD, CM, SC
- Other plot sheets – LS, FM

Photos
- 1 digital camera
- Hemiview camera
- 1 range pole for center

Field Sheets
- Location notebook with plot directions
- Tree data – FIREMON TD sheets
- Herbaceous canopy cover – FIREMON PD sheet adding a species listing option
- Species Composition (SC)
- Cover Microplot (CM)
- Fuel loading (FL)
- Log plotform (see this appendix)
- Fuel Microplot sheet (see this appendix)
- Plot setup sheet to record tape bearings, witness trees, and photo numbers

Appendix B
Plot forms

Log Plot Form

Plot: Page 1

Log Number	*Log Characteristics*				
	Small Diameter (cm)	**Large Diameter (cm)**	**Length (m)**	**Decay Class**	**Notes**

Fuel Microplot (FM) Plot Form

Macroplot: Date: Crew: Page 1

Measurement	***Microplots***				
	Pos:	**Pos:**	**Pos:**	**Pos:**	**Pos:**
PhotoloadMicroplot					
1 hour					
10 hour					
100 hour					
Shrub					
Herb					
Fuel Depths (duff+litter/wood)					
1-NW corner					
2-NE corner					
3-SE corner					
4-SWcorner					
Microplot cover					
Rock					
Soil					
Wood					
Duff/litter					
Moss					
Shrub					
Herb					
Picture Number					
Photoload Macroplot					
1 hour					
10 hour					
100 hour					
1000 hour					
Shrub					
Herb					
Hemi photo number					

Appendix C
Sampling Checklist

This is the list of tasks that must be performed for each site each time it is visited.

1. *Describe site conditions*.
    a. Complete FIREMON PD Plot Description form. Here it is important that all dynamic fields be completed such as tree, shrub, and forb cover.
    b. Take pictures of plot in four cardinal directions
    c. Take hemispherical photograph over plot center.
    d. Record any notes of observations such as the status of littertraps and decomp bags.
    e. Flag plot if difficult to find

2. *Empty littertaps*.
    a. Collect all litter and place in paper bags and record plot, date and trap ID.
    b. Record any problems with littertrap.
    c. Put all bags in a sack and label sack as to plot and date.

3. *Measure fuel loadings*.
    a. Complete the FIREMON FL Fuel Loading methods for the three permanently installed transects.
    b. Measure the length and diameters of all 1000 fuels and use the Log Plot form to record data.
    c. Complete the FIREMON PC Plant Composition form for all five microplots
    d. Compete photoload estimates for all but 1000 hr fuels in five microplots
    e. Compete photoload estimates for all fuels at the microplot level.
    f. Take pictures of each microplot.

4. *Estimate plant species cover*
    a. Complete the FIREMON SC Species Composition form to the best of your ability.

5. *Measure tree populations*.
    a. Complete FIREMON TD Tree Data form
        i. Measure species, health, dbh, height, and height to crown base for all live and dead trees>4.5 inches. Measure heights using clinometer for first 3-5 trees and estimate the rest.
        ii. Measure species, dbh, height, and height to crown base for all live trees<4.5 in
        iii. Measure species, height on 0.01 ac plot (11.2 feet) for all live trees < 4.5 feet tall.

6. *Check decomp bags*.
    a. Check all decomp bags to ensure nothing is wrong.
    b. Brush off any accumulated litter from the bags.
    c. Record any unusual observations.

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