1999

Modeling the occurrence of stand replacement fire in regeneration stands following the 1994 wildfires on the Kootenai National Forest, northwest Montana

Wendy L. Hall
The University of Montana

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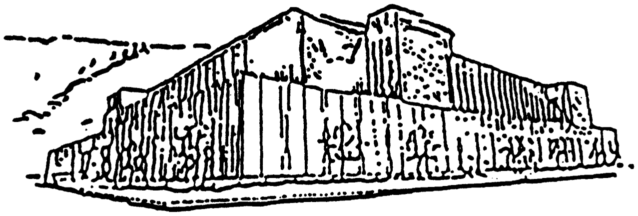

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MODELING THE OCCURRENCE OF STAND REPLACEMENT FIRE IN REGENERATION STANDS FOLLOWING THE 1994 WILDFIRES ON THE KOOTENAI NATIONAL FOREST, NORTHWEST MONTANA.

By

Wendy L. Hall

B.S., UNIVERSITY OF MONTANA—MISSOULA. 1992

Presented in partial fulfillment of the requirements

for the degree of

Master of Science

University of Montana

1999

Approved by

Chairman, Board of Examiners

Dean, Graduate School

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ABSTRACT

Hall, Wendy L., M.S., November 1999 Forestry

Modeling the occurrence of stand replacement fire in regeneration stands following the 1994 wildfires on the Kootenai National Forest, Northwest Montana.

Director: R.H. Wakimoto

In 1994 fire mangers on the Kootenai National Forest observed that wildfires produced regeneration loss in some stands and not in others. The question was what site characteristics and management activities were responsible for this loss. To address this question a logistic regression model was applied to a set of regeneration stands (n=135) located on the Libby, Rexford, and Three Rivers ranger districts. The occurrence of a stand replacement fire was modeled as a logistic function of aspect, habitat type, fuel treatment, and logarithm of trees per acre with $R^2=0.523$. Trees per acre (TPA) were negatively correlated with stand replacement fire in regeneration stands. Except for southeast, northeast, and the Subalpine fir/Menzieza category, all other categories of aspect, fuel treatment, and habitat type were positively correlated with the occurrence of stand replacement fire in regeneration stands. Southwest and south had the largest coefficients (3.0 and 2.2) and highest odds ratio (22 and 9). No fuel treatment had the largest coefficient (2.4) and highest odds ratio (11). Two habitat types had the most noted comparison. Western hemlock/queencup beadlily (*Tsuga heterophylla/Clintonia uniflora*) had a coefficient of 3.4 and an odds ratio of 30. Western red cedar/queencup beadlily (*Thuja plicata/Clintonia uniflora*) had a coefficient of 2.8 and an odds ratio of 17. Stand replacement fire stands had a mean log (TPA) significantly different ($p<0.001$) from that of non-stand replacement fire stands. A significant difference ($p<0.05$) in mean log (TPA) by aspect and fuel treatment but not habitat type category was detected by ANOVA procedures. A downward trend in mean log (TPA) was observed from northerly to southerly aspects. Piled and burned stands had a greater and significantly different ($p<0.05$) mean log (TPA) than stands that had been broadcast, understory, or jackpot burned. Regeneration stands with a southerly aspect, belonging to the cedar-hemlock habitat type, having no fuel treatment, or low mean log (TPA) are most at risk to have stand replacement fire and subsequent regeneration loss. Competition from understory vegetation may explain these findings. Bracken fern (*Pteridium aquilinum*), commonly found in cedar-hemlock stands and on southerly aspects, may out-compete tree seedlings and provide a fine fuel hazard.

Keywords: fuel treatment, stand replacement fire, risk, regeneration, logistic regression

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ACKNOWLEDGEMENTS

Funding and support for this study was provided by the USDA Forest Service, Rocky Mountain Research Station, Missoula, and the Blackfoot Forest Protective Association.

I thank my committee chairman Dr. R. Wakimoto for his support and vision during this study. Critical review of this manuscript is provided by Dr. H. Zuuring and Dr. D. Patterson. Dr. H. Zuuring's data management and GIS expertise is greatly appreciated.

Many individuals contributed to the success of this study. C. Hardy, Research Forester, of the USDA Rocky Mountain Research Station provided invaluable expertise and guidance. M. Cameron and D. Anderson of the USFS Region 1 Office provided data gathering assistance. K. Schmidt of the University of Montana and N. Kmonk of the Kootenai National Forest Supervisor's Office provided GIS support. D. Leavell's insight and encouragement during the study was greatly appreciated.

Numerous Kootenai National Forest personnel contributed their assistance and professional expertise through out the study and they are greatly appreciated as well. I also thank the countless dedicated field personnel that collected the data in the TSMRS. This study would not be possible with out the stand information.

My family, both Hall and Wilson provided the much needed support and reassurance through out my graduate study. Immense gratefulness goes towards my husband Nate for his love and understanding during the most challenging times. I thank all involved for your help.

INTRODUCTION

Long term drought conditions leading into the 1994 fire season set the stage for what has been described as a 20 to 50 year fire event (personal communications, KNF staff 1997). Weather data taken from July 1st through September 30th 1994 at the Libby Ranger Station indicated that the Energy Release Component (ERC) indexes were above the 89th percentile for 66 out of 92 days (72%) for the National Fire Danger Rating System fuel model G (heavy timber). In comparison, only 30 out of 92 days (33%) for 1988 and 29 out of 92 days (32%) for 1998 had ERC indexes above the 89th percentile (Bradshaw pers. comm. 1999).

During mid-August of 1994, the Kootenai National Forest (KNF) experienced the start of over 160 lightning-caused fires that burned approximately 53,000 acres (USDA Forest Service 1994). Resources became limited and suppression forces were not able to prevent regeneration loss in intensively managed stands.

Reconnaissance surveys conducted by USFS personnel during the summer of 1995 documented regeneration mortality in intensively managed forest stands. Some stands experienced a stand replacement fire with regeneration mortality. Other stands, however, seemed fire resistant experiencing only an underburn.

Those stands that experienced the effect of a stand-replacement fire were coded as 4250 in the Activities file of the Oracle database that houses information about stands at the forest level. This coding was assigned to stands that experienced partial or complete regeneration mortality. Stands that experienced sufficient regeneration mortality to reduce stocking to less than 300 trees per acre were replanted. Those stands that experienced fire that reduced the existing fuels, but did not create a change in the character of the stand were coded as 4981. These stands did not have any regeneration mortality or need replanting. The TSMRS and Oracle database are designed to keep track of silvicultural systems that are applied to stands. Stand exam and timber management information is kept in the TSMRS. For legal purposes, all activities done to a stand are documented in Oracle.

The fire behavior models constructed by Albini (1976) identify the independent variables that predict the rates of spread, growth, flame front, and duff burned off by a fire. Some of these independent variables are wind speed, slope, aspect, fuel characteristics, and temperature. Fire behavior, and the subsequent effects of a particular fire on vegetation, are dependent on site characteristics such as slope and aspect as well as weather conditions during the fire (Rothermel 1983).

A few researchers have investigated the relationship between fuel loads of managed and unmanaged stands. Omi and Kalabokidis (1991) examined the relationship between fuel loads, fire severity, and fire damage in extensively managed (not harvested) mature forests and intensively managed (clear-cut) stands that burned during the 1988 Greater Yellowstone fires. They found that mature extensively managed stands supported higher fuel loads and experienced greater burn severity compared to intensively managed clearcuts.

Vihnanek and Ottmar (1994) investigated the effects of the 1988 Shady Beach wildfire, that occurred on the Willamette National Forest, on untreated and treated logging slash areas. Results showed that less fuel was consumed on units that had been treated compared to those that were untreated.

A study conducted by Weatherspoon and Skinner (1995) on the Klamath National Forest in ponderosa pine and Douglas-fir habitat types found several independent variables to be significant predictors of fire damage in plantations. Six variables; Grasses, Forbs, Elevation, Site Prep None, Site Prep Machine Piled, and Damage in Adjacent Stand, were the most significant (Weatherspoon and Skinner 1995). The amount of Grasses, Site Prep None, and Damage in Adjacent Stand were positively correlated with fire damage class while the other variables were negatively correlated. The strongest relationship was between the damage in the adjacent stand and damage in the regeneration stand. Comparison of fuel treatments indicated that broadcast burning resulted in the least stand damage and no site preparation resulted in the greatest damage. Mechanical piling and burning resulted in neither an increase nor decrease in regeneration damage. Furthermore, those stands that were broadcast burned suffered significantly less damage, while stands receiving machine pile and burn treatments had suffered intermediate damage. Those harvested stands that had no site preparation burned completely and severely, resulting in total loss (Skinner and Weatherspoon 1996).

The US Forest Service is mandated to have regeneration stands "stocked" within five years after harvest. Large amounts of time, money, and effort are expended in the nursery growth of seedlings, as well as in the planting of these harvested stands. Thus, this study explores the plausibility of predicting regeneration mortality by identifying which stands are most at risk to stand replacement fire due to wildfire under varying fuel treatment and site characteristic conditions. This study will provide the necessary information that would allow resource managers to apply the appropriate treatments to help prevent this loss.

OBJECTIVES

1. Construct a model predicting the occurrence of a stand replacement wildfire in regeneration stands (dependent variable) as a function of site characteristics and management activities (independent variables).

Ho: Occurrence of a stand replacement fire is not a function of site characteristics and management activities.

H_1: not Ho

2. Validate the prediction model constructed under objective number one.

Ho: Predicted occurrence of stand replacement fire is equal to the actual occurrence of stand replacement fire.

H_1: not Ho

3a. Compare the means of selected continuous and categorical independent variables across classes of the dichotomous dependent variable.

Ho: No difference between means or dependency between frequency distribution of selected independent variables for stands receiving and not receiving stand replacement fire.

H_1: not Ho

3b. Compare the means of selected independent continuous variables across classes of selected independent variables.

Ho: No difference between means or dependency between frequency distribution of selected independent variables for each of the independent variable category.

H_1: not Ho

3c. Compare selected categorical independent variables to other selected categorical independent variables.

Ho: No dependency between frequency distribution of selected categorical independent variables.

H_1: not Ho

LITERATURE REVIEW

The objectives of site preparation include reducing harvest residues and exposing sufficient mineral soil to provide suitable conditions for regeneration. Slash that remains after harvesting posses a substantial hazard that can lead to catastrophic fires (Smith et al. 1997). Hazard, as defined by Deeming (1990) is:

> “a rating assigned to a fuel complex (defined by kind, arrangement, volume, condition, and location) that reflects the behavior and severity (of a fire) it would support, and/or the suppression difficulty it represents.”

The probability of a large fire occurring on an area is dependent on weather, topography, and the fuel hazard rating. Of these three variables, the only one that can be altered by management is fuels (Wood 1982).

Substantial quantities of time and funding are spent mitigating the hazards of activity fuels that occur as a product of timber harvest. Whether done by those who possess the contract or agency personnel, slash reduction is essential in order to reduce the occurrence of large fires. Deeming (1990) outlined the historical role that slash played in the spread and severity of large wildfires in the early 1900s. Recognizing this danger, state and federal agencies implemented hazard reduction laws and regulations that must be followed by landowners.

Harvest methods are prescribed to a stand to ecologically simulate a disturbance pattern (Smith et al. 1997). For instance, clearcutting is a regeneration method conducted to mimic severe disturbance and provide an environment for species that require a great amount of sunlight to regenerate. Other harvesting methods such as coppice, seed tree, and shelterwood are conducted to release regeneration that is present in the stand prior to harvest.

Likewise, site preparation methods are selected on an ecological basis (Smith et al. 1997). Treatments that are extensive through out the stand, such as broadcast burning, are conducted to allow species that are adapted to severe disturbance to regenerate. Intensive treatments that focus on only small spots in the stand, such as pile and burn, favor those species that regenerate under less severe conditions.

Bunnell and Christophersen (1982) discuss the use of different timber harvest methods in meeting fire management and silivicultural objectives. They point out that a given method does not necessarily meet the priorities of both interests and may conflict. For example, fire management personnel view clearcutting as the most preferred timber harvesting method due to the ease and lower cost of burning the logging residuals. Seed tree harvesting would be the next preferable choice with shelterwood harvesting being the least preferable. Seed tree and shelterwood cuts are more difficult to burn without damaging the remaining trees and are more expensive. On the other hand, the silviculturist may prefer the seed tree cut because of the reduced regeneration costs.

Different timber harvest methods produce various quantities of activity fuels that must be treated with site preparation. Heald (1996) documents the amount of downed fuel produced by different management types. He found that clearcuts had the least down woody material (6-8 tons/acre) while stands that received group selection and individual tree selection methods had similar amounts of fuel compared to old growth stands (14-18 tons/acre).

Brown (1980) investigated the rates of spread and fire behavior of Douglas-fir *(Pseudotsuga menziesii*), western larch *(Larix occidentalis)* and lodgepole pine *(Pinus contorta)* slash in three silvicultural systems; clearcut, group selection, and shelterwood. Conventional (lopping of tops and branches) and near-complete (everything is taken) utilization was implemented on each of the three systems. Calculations were made on 1 and 5-year-old downed woody fuels left after logging. Results showed a 3 to 4.5 times greater rate of spread (feet/minute) on those sites that had undergone the conventional harvest treatment compared to the near complete utilization. This increase in rate of spread was observed for both 1 and 5-year-old fuels. Fire line intensity (btu/ft/s) was approximately six times greater for units with the conventional method and 1-year-old fuels as opposed to the near complete utilization. Conventional methods with 1-year-old slash had intensities greater than 500 btu/ft/s at wind speeds of 10+ mph. These intensities represent an unacceptable hazard with high probabilities of spotting and crowning, and thus direct suppression tactics would not be possible. For fuels, which were 5-years-old, the increase in intensity was negated on both the conventional and near-complete utilization sites. Thus, within 5 years, the hazard of intensity would not be present.

Skinner and Weatherspoon (1996) explored the relationship between site preparation and regeneration damage following wildfire. They looked at differences in regeneration damage between broadcast burning, machine pile and burn, as well as no site preparation. Results indicated that broadcast burning resulted in little stand damage and no site preparation resulted in much greater damage. Mechanical piling and burning resulted in neither an increase nor decrease in regeneration damage. Furthermore, those stands that were broadcast burned suffered significantly less damage, while stands receiving machine pile and burn treatments had suffered intermediate damage. Those harvested stands that had no site preparation burned completely and severely, resulting in total loss.

Deeming (1990) emphasized the importance of removing the fine and intermediate fuel size class (fuels < 1 inch in diameter) to reduce fire hazard. The successful ignition of a fire typically occurs in the fine fuels (< 1/4 inch in diameter). Furthermore, as Deeming (1990) states:

> "the rate at which a fire spreads is determined by the amount, continuity, and moisture contents of fine and intermediate-sized fuels".

However, the successful removal of the fine and intermediate fuel classes is best accomplished by controlled application of prescribed fire. The other fuel reduction methods such as mechanical and chemical, are not capable of removing these fuels. Prescribed burning is the only method that can remove fine and intermediate fuels Deeming (1990).

Several factors must be considered when writing site preparation plans that prescribe burning. These are: the age and species of the slash to be burned, duff and fuel conditions, the season in which the burn is planned, the aspect of the stand, and desired intensity of the burn. All of these factors play an essential role in determining the success of the burn and obtaining the desired results.

As fuels age they are effected by three processes: fuel compaction, foliage retention, and particle decomposition (Salazar and Bevins 1984). As the fuels compact, the finer fuels shift to the lower levels of the fuel bed resulting in an increase in bulk density, and a decrease in the depth of the total fuel bed. The result of this shift is a lower potential in fire behavior (Salazar and Bevins 1984). Foliage retention effects the flammability of the cured slash. During the first few years after cutting, the red needles and finer fuels are highly flammable. Particle decomposition is effected by the rate at which the slash ages (Salazar and Bevins 1984).

Salazar and Bevins (1984) researched the differences in the effects of slash aging on fire behavior for nine conifer species. Three fuel-loading levels (low, medium, and high) were compared for the nine species. Results showed that Engelmann spruce*(Picea engelmannii)* and grand fir *(Abies grandis)* compacted at the fastest rate. Western larch, lodgepole pine, and western white pine *(Pinus monticola)* had moderate, while Douglas-fir and western redcedar *(Thuja plicata)* had the slowest compaction rate. The amount of needle retention correlated proportionally with compaction rates. Spruce and western hemlock *(Tsuga heterophylla)* had the lowest retention amount while the pines had the greatest (Salazar and Bevins 1984). Fire behavior decreased over the ten-year period for both light and medium fuel-loadings. However, severe fire behavior was still evident for heavy fuel loads over the ten-year period.

While the age of the slash greatly influences the potential fire behavior, the duff moisture content and season of burn directly correlate with the amount of fuel consumed by the burn.

The success or failure of a prescribed burn to produce the desired effects is directly related to the duff moisture content at the time of the burn. Brown et al. (1985) points out that there are three ways duff consumption is expressed. One is by depth reduction of the duff, the second is the percentage of depth reduction, and the third is percentage of mineral soil exposed.

Brown et al. (1985) analyzed data from burn studies conducted in western Montana and northern Idaho. They found that the amount of duff depth reduction due to the fire (in inches) increased linearly as the amount of moisture in the duff and total depth of duff decreased. For example, the greatest reduction was observed for the lowest moisture content and the deepest pre-burn duff depth.

However, Brown et al. (1985) noted that percentage duff depth reduction is easier to understand and use. The same relationship as that found for duff reduction was observed with percentage duff reduction. They also found that the amount of mineral soil exposure could be predicted with light (under 10 tons/acre) and heavy (greater than 10 tons/acre) fuel loads. The percent of soil exposure decreased linearly for both light and heavy fuel loads as percent moisture of the lower duff increased up to approximately 125%. However, the rate of increase in percent moisture content drops substantially after 125%.

Brown et al. (1991) also investigated the relationship between pre-burn fuel sizes and woody fuel consumed by fire. As with percent duff depth reduction, diameter reduction is also related in a similar linear fashion. Pre-burn diameter, kind, and amount of surface fuels also appear to be related to diameter reduction, particularly in the larger fuels. Furthermore, diameter reduction in rotten pieces was greater than that of sound pieces.

There is much debate in the literature about the appropriate season to conduct a prescribed burn. While there are significant ecological implications of the resulting effects on the vegetation, there is also considerable evidence that the season of burn impacts the success of reducing the fuel hazard in harvested stands. In general, for the Northern Rockies, fall burns tend to have the greatest success in reducing fuel loads (Artley et al. 1978). The duff moisture content and moisture levels of the slash materials are driest during this season. However, this generalization is not always observed. Artley et al. (1978) found that burning in the fall would not result in successful duff reduction if the duff moisture content is greater than 100 percent in western larch and Douglas-fir. Furthermore, Ryan (1982) found that the desired reduction in fuel hazard depended on the average or drier-than-average summer and drier-than-average fall in the Douglas-fir/larch type. Little (1990) states that for Pacific Northwest forests, fuel loads can be reduced by burning during the spring when the conditions are moist and by removing large fuels prior to burning.

While fall burns tend to have a greater consumption of fuels, Williams and Rothermel (1992) point out that there is a greater risk of fires escaping the containment boundaries. They described the increase in fire danger related to the drying process that occurs from late spring to early fall and the effects of elevation. The pine/grass fuel types are the first to dry particularly on south aspects and low elevations. Thus the window of opportunity to prescribe burning in the pine/grass type (while staying within allowable fire intensities, without loosing control of the burn) occurs in the spring time. In comparison, the windows of opportunity for burning Douglas-fir and alpine fir extend much further into the summer. However, the rate of increase in intensity from a controllable burn to one in which offensive strategies need to be used changes quickly during late summer. With an increase in elevation and shift from southerly to more northern aspects, there is a time lag associated with the increased fire intensity (Williams and Rothermel 1992). Shearer (1975) also brings up the potential for late summer rains, which would extend the allowable burning period for the fir forest types.

Hall (1991) investigated how ignition patterns and intensity of the burn effected fuel consumption in broadcast burned clearcuts. The measured variables included woody fuel moisture content, diameter reduction of fuels, large and small woody consumption, and duff reduction. Results indicated that mass-ignited, high intensity fires actually had a lower amount of total fuel consumption than the moderate intensity fires. Hall (1991) explained that this difference was due to the extended length of time that the actual flaming front remained on the fuels. The length of time of active flaming was too short in a high intensity fire to accomplish the desired fuel reductions. Thus, ensuring adequate fuel moisture conditions is essential in obtaining the desired intensity. However, an advantage to high intensity fires is that the manager is able to limit the amount of particulate produced and comply with air quality guidelines (Hall 1991).

STUDY AREA

Three ranger districts, Libby, Rexford, and Three Rivers, of the Kootenai National Forest (KNF) were included in this study. The KNF occupies 2.2 million acres in the northwest corner of Montana and a small portion of the Idaho panhandle (Figure 1) (Impact Assessment Inc. 1995).

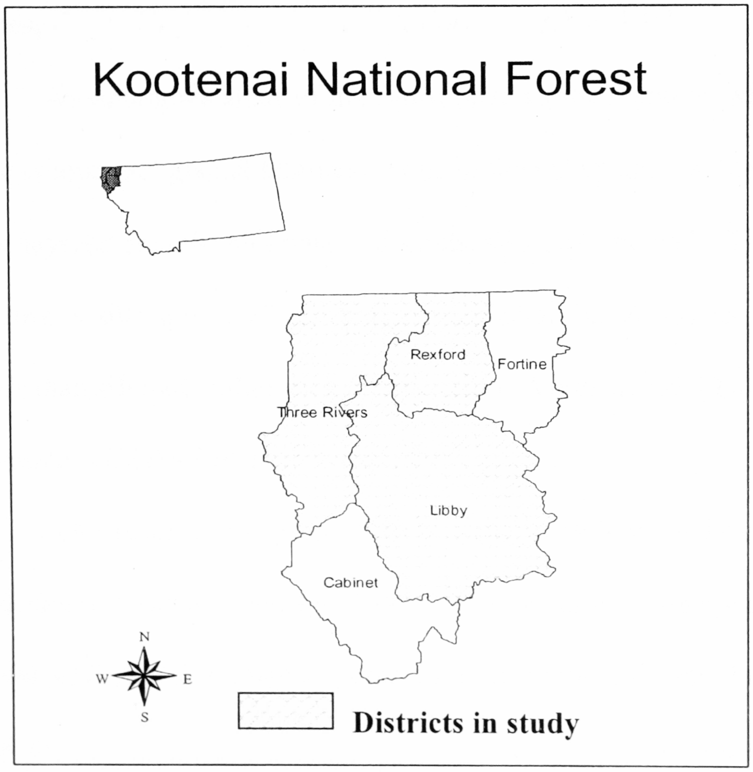

Figure 1. Map of three ranger districts of the Kootenai National Forest comprising the study area in Northwest Montana.

The first timber sale occurred in 1904, four years before the KNF was established from forest reserves in 1908 (Northwest Archaeological Associates, Inc. 1994). The federal government owns approximately 77 percent of the land within the KNF of which 56 percent are suitable for timber management (Impact Assessment Inc. 1995). The average annual timber harvest for the period 1960 to 1990 was 192 million board feet per year with a range of 131.5 to 248.3 million board feet per year (Impact Assessment, Inc. 1995).

The geological history of the KNF includes metamorphosed sedimentary rock of the Belt Supergroup deposited from an inland sea that occurred 800MM to 1,400 MM years ago. Sands, silts, clays, and carbonate materials were compressed into quartzites, siltites, clays, and limestone (USDA Forest Service, 1996).

Mountainous areas of the forest have alpine features, while the valley bottoms have continental glacial features. Soils in the valley are "a mixture of sorted sands and silts, layered gravels, and unsorted sands, silts and gravels". The upland soils are "a mixture of silts and rock" resulting from glacial till. At higher elevations, there are more sands than silt and higher rock composition. Volcanic ash blankets the soils of higher elevations (USDA Forest Service, 1996).

Elevation ranges from 1,820 ft in the Yaak River valley to 8,712 ft at Snowshoe Peak (Impact Assessment, Inc. 1995). The Maritime Climatic regime persists during the winter while the Continental climatic regime persists during the summer. Winters are cool and wet while summers are warm and dry (USDA Forest Service, 1996). Precipitation in the lower elevations ranges from less than 14 to 20 inches while at higher elevations it ranges from 80 to over 100 inches (USDA Forest Service, 1996). Precipitation comes in the form of rain in the valleys and snow in the mountains.

METHODS

Data Collection/ Organization

Three ranger districts, Three Rivers, combined Libby, and Rexford, of the KNF were the focus of this study. These three ranger districts experienced the most fires and contained the majority of the regeneration stands within the 1994 fire boundaries (n=139). Site characteristic and management activity data from the Oracle database were used to assess the occurrence of a stand replacement fire in regeneration stands.

Each ranger district was visited three times between 1996 and 1997 to gather data from the Timber Stand Management Record System (TSMRS) and from personnel regarding the regeneration stands that were effected by the 1994 fires.

The TSMRS has three components: index maps, stand folders, and the Oracle database. The index maps consist of orthophotos, topographic base maps, and thematic maps. The features of thematic maps include township and range, contour lines, streams, compartment and subcompartment boundaries, and delineated timber stands. The stand folders contain all the attribute data of stands. This includes stand examination data, silvicultural prescriptions, activity maps, and narrative reports. The Oracle database contains all the automated current and past stand data (USDA Forest Service, R1 1996).

During the first visit to each ranger district, the identification of regeneration stands that were within the fire boundaries was accomplished through the Forest Assessment of the 1994 fires (USDA Forest Service 1994), TSMRS, and personal communications. Copies of maps delineating subcompartment and stand boundaries were obtained to identify the effected regeneration stands. Duplicates of the events were recorded from suppression personnel. Color copies of aerial photos taken of the fires were gathered from the supervisor's office.

A second visit to the districts was conducted to discuss the study plan, and relevant independent variables that should be considered in the study. Visits to each of the districts and discussions with KNF staff determined that there were 19 possible independent variables to be considered in this study (Table 1).

Table 1. Listing of candidate independent variables identified by KNF staff, their source, measurement scale, and analysis disposition.

#	INDEPENDENT VARIABLE	INCLUDED IN ANALYSIS	FOUND IN ORACLE DATABASE	MEASUREMENT SCALE
1	Aspect	Yes	Yes	nominal
2	Elevation	Yes	Yes	interval
3	Equipment Type	Yes	Yes	nominal
4	Fire Group	Yes*	No	nominal
5	Forest Type	Yes	Yes	nominal
6	Habitat Type	Yes	Yes	nominal
7	Reforestation Method	Yes	Yes	nominal
8	Slope	Yes	Yes	interval
9	Stand Position on Slope	Yes*	No	nominal
10	Trees/Acre (TPA)	Yes	Yes	interval
11	Type of Treatment	Yes	Yes	nominal
12	Vegetative Response Unit	Yes*	No	nominal
13	Year of Origin	Yes	Yes	interval
14	Burning Index	No	No	interval
15	Energy Release Component	No	No	interval
16	Fuel Load	No	No	interval
17	Stand Size Class	No	Yes	nominal
18	Thinning Prior to 1994	No	Yes	nominal
19	Type of Fuel	No	No	nominal
20	Weather **	No	No	interval

*Derived variables
**Weather is a factor. Includes the variable temperature, relative humidity, and wind speed.

On a third visit, information on suppression tactics (if any) applied to the regeneration stands was gathered from discussions with fire staff. Stand folders were examined for pre- and post-harvest surveys, silvicultural prescriptions, and any burn plans containing information on fuel loads. Weather station records, Energy Release Component (ERC) and Burning Index (BI) data were collected.

Stand Selection

In order to insure that all applicable regeneration stands were identified, several database checks were conducted. The Regional Office conducted a query of the entire KNF Oracle database and provided a list of regeneration stands that had experienced fire. This query was based on the harvest and fire codes. I also sorted the KNF Oracle database provided by the RO for the stands that had harvest activities and fire codes. Both query lists were compared to check for discrepancies, and a list of all regeneration stand numbers for this study was developed. This list was then used to develop the database of all the study variables.

Stands were included in this study based on the following criteria:

1. Harvesting prior to 1994.
2. Stands within Three Rivers (D4, Troy) Rexford (D1, Eureka) and combined Libby (D6).

Stands were excluded in this study based on the following criteria:

1. Stands that had undergone stand initiation before 1974.
2. Stands with intermediate harvest methods.
3. Stands with-in the Little Wolf fire.
4. Districts with five or less stands harvested prior to 1994 (Murphy Lake, D3 and Cabinet, D7).

Based on recommendations from Rocky Mountain Research Station scientists, this study focussed on three ranger districts: Three Rivers (D4, Troy), Rexford (D1, Eureka) and combined Libby (D6). Murphy Lake (D3) and Cabinet (D7) were excluded due to the low number of stands (n=10). According to district personnel, a regeneration stand is no longer defined as a regeneration stand 15-20 years after stand initiation. In order to maintain the study focus on very young stands (<20 years old), stands that had undergone stand initiation prior to 1974 were not included in this study. As recommended by collaborative researchers, stands that had undergone intermediate harvest methods were also excluded. Lastly, as advocated by Libby district personnel, stands that were in the Little Wolf fire were also excluded. They believed that given the observed fire behavior during the Little Wolf fire, none of the fuel treatments would have prevented regeneration loss. Sixteen out of seventeen stands in the Little Wolf fire had stand replacement fire and had to have their entire acreage replanted. These findings support the observations made by Libby district personnel and that the Little Wolf stands should be left out of the analysis.

Independent Variables Excluded from Analysis

Of the 20 possible independent variables identified by district personnel, eight were not found in the Oracle database or stand files and seven were not included in analysis (Table 1). These were BI, ERC, Fuel Load, Stand Size Class, Thinning Prior to 1994, Type of Fuel, and Weather.

Although they are important components that affect fire behavior, analysis of ERC, BI, and Weather was excluded from this study because measurements were not recorded during the fires. Furthermore, only three stands in the study had thinning done prior to 1994 which is too small a sample size to include precommercial thinning in the study. Finally, Fuel load data and type of fuel were completely absent in the Oracle database or incomplete in the stand files and thus were not included.

Stand size class information was updated after the 1994 fires. Many of the stands size classes changed to non-stocked. Unlike the activity files, the basic stand data file does not contain the historic data. Rather, only the most recent information is kept in the file. Thus, stand size class was not included in the analysis.

Independent Variables Included in Analysis

Of the 13 variables included in the analysis, three were not present in the Oracle database or stand files (Table 1). Thus, the variables Fire Group, Stand Position on Slope, and Vegetative Response Unit were derived by other means.

The variable Fire Group was determined by placing the appropriate habitat types into the fire groups derived by Fischer and Bradley (1987).

A Digital Elevation Model provided by the Supervisors Office was used to determine the position of each stand on the slope. Slope position was determined by placing an Arc/Info stand boundary coverage on top of a shaded-relief map in ArcView and visually determining the stand position on the slope in five classes. The five classes were: valley bottom; lower, middle, and upper slope; and ridge top. A hydrographic coverage was also used to assist in visually determining the slope position of the studied stands.

The vegetative response unit (VRU) for each stand was determined by similar methods, as was slope position. The Supervisor's Office used Arc/Info and placed the stand boundary coverage on top of the VRU coverage. Using ArcView, they provided printed maps of the stand boundaries and VRUs. The VRU for a stand was determined visually and in the case where a stand consisted of more than one VRU, the VRU that aerially covered the majority of the stand was chosen.

The stand year of origin, as defined by KNF staff, is the same as reforestation year in the Oracle database. Reforestation year is defined as the year when stand initiation actions were taken. Type of treatment included harvest, fuel, and site preparation. Reforestation method is either natural regeneration or planting.

Independent Variable Categorization

The selection of the thirteen independent variables thought to best depict the stand replacement fire in regeneration stands was based on suggestions from KNF personnel, literature review, and univariate regression analysis (Table 1).

Category definitions associated with each independent variable were based on what made the greatest ecological sense, with the exception of habitat type in which groupings were based on the number of observations per category. Candidate independent variables were categorized in several ways in order to explore any possible significance of the variable to model construction. With the exception of Habitat Type, reference categories associated with each independent variable were identified as those having the least proportional occurrence of a stand replacement fire. The Subalpine Fir/Sitka Alder (ABLA/ALSI) habitat type was chosen as a reference category over the

ABLS/MEFE habitat type because of its larger sample size and comparable low occurrence of a stand replacement fire. See Appendix I for the complete description of the categories generated for each independent variable.

In the database constructed for this study, fuel treatment was split into three classes: fuel treatment 1, 2, and 3. These fuel treatment classes were based on type and the sequence in which fuel treatments occurred. Fuel treatment 1 is defined as all those treatments that dealt with moving the fuel (lopping, mechanical piling, and dozer piling) subsequent to fuel treatment 1. If a fuel treatment 1 occurred, then it was the first treatment to occur in the sequence. Fuel treatment 2 and 3 refer to the type of burning that was applied to the fuels (burn dozer piles, burn mechanical piles, broadcast, jackpot, and understory burn).

If a stand had been dozer or mechanical piled and burned, it was categorized as <u>pile and burn</u>. If a stand had been understory, broadcast, or jackpot burned, it was categorized as <u>burned</u>. Likewise, if no sequence of fuel treatments had been applied to the stand, it was categorized as <u>no treatment</u>. The no treatment category also included stands that had been piled but not burned.

Data Analysis

Objective one, construction of a prediction model, was accomplished by using logistic regression techniques outlined by Hosmer and Lemeshow (1989) and using SPSS Professional Statistics 7.5 software (Norusis, 1997). The dependent variable (Z) is the occurrence or nonoccurrence of a stand replacement fire in which the character of the stand has been altered and there has been regeneration loss. These stands are coded 4250 in the Oracle database. The independent variables (X) are site characteristics and management activities that occurred in the regeneration stand. The relationship between the dependent and independent variables can be expressed by the following logistic model:

$$\text{Probability (stand replacement fire)} = \left[\frac{1}{1+e^{-Z}}\right]$$

Or

$$\text{Probability (no stand replacement fire)} = 1 - \left[\frac{1}{1+e^{-Z}}\right]$$

Where Z is the linear combination

$$Z = B_0 + B_1X_1 + B_2X_2 + \ldots + B_pX_p$$

With logistic regression, the outcome or dependent variable is dichotomous with only two possible outcomes. In this study, the outcome is either the occurrence or nonoccurrence of a stand replacement fire (1 or 0). The distribution of the dependent variable is binomial with the conditional mean bounded between zero and one. The binomial distribution also characterizes the distribution of errors (Hosmer and Lemeshow 1989).

Univariate logistic regression analysis was conducted for all thirteen independent variables in the study. Chi-square tests were conducted on all categorical variables. The chi-square statistic tests the null hypothesis that the observed and expected frequencies within the cells of a crosstabulation are independent (not related). The crosstabulation was constructed based on the frequency of observations within each category of a nominal independent variable and the observed occurrence (1) or nonoccurrence (0) of the stand replacement fire. Results from these analyses were used to identify the most influential independent variables to include in multivariable logistic regression analysis.

Multivariable logistic regression analyses were conducted following the recommendations of Hosmer and Lemeshow (1989). Stepwise selection of variables was based on the likelihood ratio (G statistic). Independent variables were entered into the model at 0.15 and removed at 0.20 significance level. Three independent variables, Aspect, Habitat Type, and VRU were thought to be inter-related. The VRU variable is based on certain habitat types and aspects (USDA Forest Service 1996). Some habitat types are thought to be associated with various aspects (Pfister et al. 1977). Thus, these independent variables were not entered into the model until all other variables were considered.

Several statistics are produced as an outcome of logistic regression. These include model R^2 and Log Likelihood, G-statistic, and significance (p-value) for each entered independent variable. Log Likelihood is the same as the deviance statistic (D) or residual sum of squares (SSE) in linear regression, which represents the amount of unexplained variation in the dependent variable. The likelihood-ratio tests the null hypothesis that the variable coefficient (β) is zero. The G-statistic is calculated from the likelihood ratio test and is the same as the partial F-test in linear regression (Hosmer and Lemeshow 1989). The G-statistic measures the change (reduced vs. full model) in deviance due to including the variable in the model (Norusis 1997). The degrees of freedom in logistic regression are one less than the number of categories for each variable. The p-value indicates the degree to which a test statistic is larger than that expected due to random chance. R^2 measures the proportion of explained variation in Z contributed by the independent variable in the logistic model (Norusis 1997).

For each category associated with an independent variable and continuous independent variables, the statistics reported in logistic regression include the coefficient (β), standard error (SE), and p-value, R, odds ratio (ψ), and 95% confidence interval for the odds ratio (Norusis 1997). The SE indicates the reliability of the regression coefficient. The higher the SE the more unreliable is that coefficient. The Wald statistic tests if the coefficient is significantly different from zero while R looks at the partial correlation between the dependent variable and each of the independent variables. The larger the R value, the greater the contribution the variable (category) contributes to the model (Norusis 1997). The odds ratio identifies the category within a variable that is "most at risk" for a stand replacement fire and subsequent regeneration loss in comparison to a reference category. The reference category for each variable was the category that experienced the least amount of stand replacement fire.

Once model construction is completed, the data will be examined to identify and assess the removal of potential outliers.

Objective two, model validation, was addressed by randomly subsampling 90% of the database used to build the prediction model. Once the prediction model was constructed, the observations in the remaining 10% of the database were compared for differences between observed and predicted values of the dependent variable. The database was subsampled in this fashion ten times such that all of the observed frequencies of stand replacement fire (N=135) were compared with predicted ones. A contingency table with the results of the observed and predicted Z-values was constructed and a chi-square test was performed to check for model validity.

Following the cutoff values used by Hosmer and Lemeshow (1989), a stand replacement fire was considered to have occurred when the predicted probability value (Z) was greater than or equal to 0.5. When the predicted probability value was less then 0.5, the stand replacement fire was considered not to have occurred. Other lesser and greater probability values were explored to determine the best prediction probability.

Objective 3a, and b, exploring independent and dependent variable relationships, was accomplished by Levene's test for equality of variances and one-way ANOVA to compare difference in means for continuous variables across the classes of categorical dependent and independent variables. If the ANOVA showed that there was a difference in means across the categories at the 0.05 alpha level, then a multiple comparison test was conducted. For objective 3a cases were separated into those stands receiving stand replacement fire and those that did not and a two-sample t-test was conducted. For objective 3b, where there were more than two multiple comparisons, a Tukey HSD (honestly significant difference) test was conducted to identify the pairs of categories whose means were significantly different. The Tukey HSD test was chosen as the multiple comparison tests because of its sensitivity to detecting mean differences when the number of possible pair combinations is large (SPSS 1997). The Tukey HSD method is capable of adjusting the observed significance level for multiple comparisons. Boxplots and bar graphs (with the mean and 95% confidence interval) of the continuous variable by each class of categorical variable were constructed.

Objective 3c, comparing selected categorical independent variables, was accomplished with chi-square tests. Bar charts, showing the percent composition of a categorical variable by class of another categorical variable, were constructed.

All tests were analyzed at the 0.05 alpha level of significance. All p-values greater than 0.05 were considered not significant while all p-values less than 0.05 were considered significant.

RESULTS

Objective 1. Construct a model predicting the occurrence of a stand replacement fire (dependent variable) as a function of site characteristics and management activities (independent variables).

Univariate Logistic Regression and Chi-square Analysis

I conducted logistic regression and chi-square analysis for each of the independent variables in this study as the first step in model building. The purpose of this step was too narrow down the number of candidate independent variables to be considered for the second step, multivariable logistic regression analysis, and to determine the best way to define categories associated with an independent variable. Examination of the thirteen candidate independent variables determined that four variables, Habitat Type, Fuel Treatment, Elevation, and Harvest Treatment had more than one logical categorical definition. Furthermore, examination of TPA indicated that there were a few outliers present in the dataset. Log TPA was used to normalize the distribution. Thus, twenty-four independent variables were analyzed. Complete descriptions of each independent variable and the categories constructed for each are provided in Appendix I. Logistic regression and chi-square results for each independent variable are presented in Table 2.

The first column in Table 2 has the variable name while the second column has the number of stands (n) observed. The third through seventh columns show the five statistics calculated by logistic regression: Log Likelihood, G-statistic, degrees of freedom (df), p-value (p), and R^2. Columns 8 through eleven in Table 2 show the chi-square (χ^2) results for categorical independent variables. The degrees of freedom are the same as would be found in logistic regression, one less than the number of categories, and the p-value indicates the degree to which a test statistic is larger than that expected to due to random chance. The percent of sparse cells (those with less than 5 observations) indicates possible interpretation problems with chi-square test statistics (Table 2).

Hosmer and Lemeshow (1989) recommend that all independent variables with a univariate regression p-value of less than 0.25 to be considered for model construction. Based on these criteria, univariate analysis did not assist in reducing the number of independent variables to be considered for subsequent multivariable logistic regression analysis. Twenty out of twenty-four of the variables had p-values less than 0.25 (Table 2). However, univariate analyses helped to determine which groupings of observations within a nominal independent variable formed the most significant classes.

Table 2. Univariate logistic regression analysis and chi-square tests results for the twenty-four candidate independent variables (n=139).

Independent Variable	n	Log Likelihood	G Statistic	df	p	R^2	X^2	df	p	Sparse Cells
Aspect	139	-88.930	28.537	7	0.0002	0.257	26.882	7	0.000	19%
Aspect2	139	-88.930	12.782	3	0.0051	0.122	12.962	3	0.005	0%
Elevation	139	-88.930	7.349	1	0.0067	0.071				
[1] Elevation Group	139	-88.930	12.219	3	0.0067	0.117	12.220	3	0.007	0%
Fire Group	139	-88.930	14.630	5	0.0121	0.138	12.216	5	0.032	42%
Forest Type	139	-88.930	8.328	7	0.3046	0.081	5.878	7	0.554	50%
[2] Fuel Treatment	139	-88.930	7.481	2	0.0237	0.073	7.074	2	0.029	0%
[3] Fuel Treatment Group 2	139	-88.930	9.125	3	0.0277	0.088	8.031	3	0.045	38%
Fuel Treatment 2 Month	117	-76.942	8.764	7	0.2701	0.099	7.179	7	0.410	56%
Habitat Type	139	-88.930	65.503	29	0.0001	0.521	54.389	29	0.003	87%
[4] Habitat Type Group 2a	139	-88.930	29.167	7	0.0001	0.262	25.459	7	0.001	38%
[5] Habitat Type Group 2b	139	-88.930	21.099	5	0.0008	0.195	20.837	5	0.001	25%
[6] Habitat Type Group 3	139	-88.930	10.865	4	0.0281	0.104	9.837	4	0.043	30%
[7] Habitat Type Group 4	139	-88.930	17.511	3	0.0006	0.164	15.022	3	0.002	0%
Harvest Equipment Type	98	-57.689	9.285	3	0.0257	0.131	6.160	3	0.104	50%
[8] Harvest Group	139	-88.930	1.049	2	0.5919	0.010	1.007	2	0.604	0%
Harvest Treatment	139	-88.930	10.103	7	0.1828	0.097	8.882	7	0.261	50%
Position on Slope	139	-88.930	19.372	4	0.0007	0.180	17.393	4	0.002	20%
Reforestation Method	139	-88.930	0.512	1	0.4743	0.005	0.507	1	0.476	0%
Reforestation Year	138	-88.516	8.070	1	0.0045	0.079				
Slope	139	-88.930	10.062	1	0.0015	0.097				
Trees Per Acre	135	-86.606	13.766	1	0.0002	0.134				
Log Trees Per Acre	135	-86.606	12.878	1	0.0003	0.126				
Vegetation Response Unit	139	-88.930	12.499	8	0.1303	0.119	12.068	8	0.148	50%

Variable Defined

[1] Grouped by 4 classes based on 25, 50, & 75 percentile of elevation

[2] Grouped by 3 classes: Pile/Burn, Burn, & No Fuel Treatment

[3] Grouped by 4 classes: Pile/Burn, Burn, Pile, & No Fuel Treatment

[4] Habitat Types grouped by n=5/group or else = other (includes habitat phases)

[5] Grouped by 6 classes based on Habitat Type2a without habitat phases

[6] Grouped by 5 classes based Habitat Type Series

[7] Habitat Types grouped by n=9/group or else = other

[8] Grouped by 3 classes: Clearcut, Shelterwood Cut, & Seed Tree Cut methods

Multivariable Logistic Regression Analysis

Preliminary analyses indicated that the independent variable Habitat Type (having thirty categories) did not reduce the unexplained variation in Z when other independent variables were introduced into the process. Although Habitat Type had a large R^2, standard errors and confidence intervals for other independent variables included in the model became large. The large standard errors and confidence intervals are likely due to the high number of categories and high percentage (87%) of sparse cells. Based on these findings, the ungrouped independent variable habitat type was removed from the model construction process.

With the exception of the possible inter-related independent variables Habitat Type, Aspect, and VRU, all independent variables were considered in the regression analyses. Four trees-per-acre (TPA) values were absent from the data set reducing the number of acceptable stands from 139 to 135. Due to the presence of TPA outliers in the dataset, log TPA was used for analysis.

Three independent variables, Fuel Treatment, log Trees Per Acre, and Position on Slope remained in the model when regressed with the other variables. VRU, Habitat Type Group 2a and 2b, Habitat Type Group 4, and Aspect were added separately to the model. Aspect 2 and Habitat Type Group 3 were not used during model construction due to their lower R^2 and higher p-values observed from the univariate analysis. Tables displaying the model statistics for the various model combinations are in Appendix II.

There was no evidence, such as large changes in coefficients, to suggest that the Habitat Type variables and Aspect would be confounded. Thus, a model including Aspect and Habitat Type variable was constructed (Table 3). The variable Habitat Type

Group 2b was used rather than the Habitat Type Group 2a. There were two reasons to justify the use of Habitat Type Group 2b. First, it made ecological sense to group habitat phases with their perspective habitat types and second, an improvement in standard errors and confidence intervals for the individual categories was observed.

Table 3. Aspect and Habitat Type Group 2b model $R^2 = 0.523$.

Independent Variable	**D**	**G-statistic**	**df**	**p-value**
Aspect	-67.945	26.860	7	0.0004
Habitat Type Group 2b	-65.342	21.654	5	0.0006
Fuel Treatment	-58.071	7.112	2	0.0285
log (TPA)	-56.792	4.554	1	0.0328

The model in Table 3 contains four independent variables; log TPA, Fuel Treatment, Aspect, and Habitat Type Group 2b. Position on Slope was removed during the regression creating the most parsimonious model with the greatest R^2 value ($R^2 = 0.523$). Based on these characteristics, the four variable model containing log TPA, Fuel Treatment, Aspect, and Habitat Type Group 2b, was selected for final analysis.

The independent variables log TPA, Aspect, Fuel Treatment, and Habitat Type Group 2b were examined to determine if they were confounded and whether interaction terms might prove to be useful. Comparison of univariate and multivariable coefficients indicated that there was little change. All possible final four-variable combinations of interaction terms were entered into the model. All interactions were not significant

($p>0.15$) and there was a substantial increase in the coefficient size and standard errors. Thus, no interaction terms were added to the final model in Table 3.

When comparing the variables in the final model, the variable Aspect explained the greatest amount of variation in Z ($D = -67.945$), made the largest improvement in explaining variation due to including the variable in the model ($G= 26.860$), and was significant at $p < 0.0004$. Although significant at $p < 0.005$, the variable log TPA had the lowest D and G-statistic ($D= -56.792$, $G= 4.554$) (Table 3). This indicates that Aspect was the most important independent or predictor variable in the model. Furthermore, approximately 81% of the explained variation in the four-variable model was represented by the Aspect and Habitat Type Group 2b variables. Thus, these two variables have the greatest influence on predicting stand replacement fire in regeneration stands in this study.

Regression results displayed in Table 3 provides strong evidence ($p <. 005$) that there is a relationship between the occurrence of the stand replacement fire (dependent variable) and the site characteristics and management activities (independent variables). Thus, regression results cause the null hypothesis that the occurrence of a stand replacement fire is not a function of site characteristics and management activities to be rejected at the 0.005 significance level.

The category results for each variable in the final model as described by the estimated coefficient (β), estimated standard error of regression coefficient (SE), and R are displayed in Table 4. The odds ration and 95% confidence interval are listed for these same variables in Table 5.

Table 4. Coefficient, standard error, and R for each variable category in the final logistic model (n=135).

Independent Variable Category	n	Coefficient (β)	Standard Error (SE)	R
Aspect	135			0.1906*
Reference East	19	1.0000		
Southwest	22	3.0737	1.0740	0.1890*
South	17	2.2241	1.0265	0.1247*
North	5	2.0614	1.2809	0.0584
West	22	1.9504	0.9243	0.1190*
Northwest	13	0.9324	0.9615	0.0000
Northeast	17	-0.3164	0.9376	0.0000
Southeast	20	-0.5163	0.8302	0.0000
Fuel Treatment	135			0.1115*
Reference Pile and Burn	45	1.0000		
No Treatment	18	2.3763	1.0602	0.1321*
Burn	72	0.9680	0.5431	0.0825
Habitat Type Group 2b	135			0.2035*
Reference ABLA/ALSI	14	1.0000		
TSHE/CLUN	30	3.3979	1.0045	0.2335*
THPL/CLUN	7	2.8307	1.3868	0.118*
ABLA/CLUN	23	2.0183	1.0054	0.1082*
All Other	50	1.7416	0.8817	0.1048*
ABLA/MEFE	11	-0.1621	1.1525	0.0000
Log Trees Per Acre	135	-2.1708	1.0835	-0.1078*
Constant		2.9696	3.1589	

* significant at $p < 0.05$

The south, southwest and west Aspect categories were significant ($p < 0.05$) in reference to the east aspect. The southwest aspect had the largest coefficient (3.07) and lowest p-value ($p < 0.005$), and the greatest categorical contribution ($R = 0.189$) for the variable Aspect to the model. The southeast and northeast aspects had small and negative regression coefficients (-0.3164 and -0.5163)(Table 4). An explanation for these observations may lie in the similarities of the southeast and northeast aspects to the reference category east. The southeast and northeast aspects, as did the east, had a very low occurrence of stand replacement fire. Preliminary regression analysis showed similar coefficient size and summary statistics when the southeast and northeast aspects were used as the indicator reference category. Thus, when comparing the southeast and northeast aspects to the east aspect, they are virtually the same making differentiation difficult.

Both categories of Fuel Treatment were significant ($p < 0.08$) in reference to Pile and Burn. The No Fuel Treatment category had the largest coefficient (2.37), lowest p-value (0.025), and greatest contribution (R=0.1321) for the variable Fuel Treatment to the model (Table 4).

Four of the five habitat types were significant ($p < 0.05$) in reference to the Subalpine Fir/ Sitka Alder (ABLA/ALSI) habitat type. The Western Hemlock/ Queencup Beadlily (TSHE/CLUN) habitat type category had the largest coefficient (3.3979), lowest p-value (0.0007), and greatest contribution (R=0.2335) for the variable Habitat Type Group 2b to the model (Table4). The large standard error in the Subalpine Fir/Menziesia (ABLA/MEFE) habitat type category can be explained in a similar fashion as the southeast and northeast aspect's standard error. The Subalpine Fir/Menziesia habitat type had a low occurrence of stand replacement fire and, when used as the reference category during preliminary regression analysis, the regression coefficients and other statistic were very similar to those when the Subalpine Fir/ Sitka Alder habitat type category was used as a reference. Thus, when comparing the Subalpine Fir/Menziesia habitat type to the

Subalpine Fir/ Sitka Alder habitat type, they are virtually the same making differentiation difficult.

Odds ratios for the significant categories (Table5) indicate a southwest stand is approximately 22 times more at risk to have a stand replacement fire compared to the reference category east. South, north, west and northwest stands are approximately 9, 8, 7, and 3 times more at risk to have a stand replacement fire compared to a east aspect stand. The northeast, northwest, north and southeast Aspect category odds ratio confidence intervals contain one, and therefore are not considered significant. For the north and northwest categories however, the confidence intervals are highly skewed to the left.

A stand with the Western Hemlock/ Queencup Beadlily habitat type is approximately 30 times more at risk to have a stand replacement event compared to the Subalpine Fir/Sitka Alder habitat type. Western Redcedar/Queencup Beadlily, Subalpine Fir/Queencup Beadlily, and the Other habitat type group are approximately 17, 8, and 6 times more at risk to have a stand replacement fire. The odds ratio for the Subalpine Fir/ Menziesia habitat type categories contains one. However, the confidence interval is highly skewed to the right. Thus, the odds ratio for this category is not considered significant.

A No Fuel Treatment stand is approximately 11 times more at risk to have a stand replacement fire compared to Pile and Burn, while a Burn category stand is approximately 3 times more at risk compared to piling and burning. The Burn Fuel Treatment confidence interval for the odds ratio does contain one. However, this confidence interval marginally contains one and is skewed to the left.

Table 5. Odds ratio and its associated 95% confidence interval for category variables found significant in the final logistic model (n=135).

Variable	Odds Ratio	95% CI	About ψ
	(ψ)	Lower	Upper
Aspect			
Reference East	1.0000		
Southwest	21.62	2.63	177.46
South	9.25	1.24	69.14
North	7.86	0.64	96.72
West	7.03	1.15	43.04
Northwest	2.54	0.39	16.73
Northeast	0.73	0.12	4.58
Southeast	0.60	0.12	3.04
Fuel Treatment			
Reference Pile and Burn	1.0000		
No Treatment	10.77	1.35	86.00
Burn	2.63	0.91	7.63
Habitat Type Group 2			
Reference ABLA/ALSI	1.0000		
TSHE/CLUN	29.90	4.18	214.13
THPL/CLUN	16.96	1.12	256.92
ABLA/CLUN	7.53	1.05	53.99
All Other	5.71	1.01	32.12
ABLA/MEFE	0.85	0.09	8.14
Log Trees Per Acre	0.11	0.01	0.95

Objective 2. Construct a validation model to test the prediction model constructed under objective number one.

Results from the validation process indicated that the four-variable model correctly predicted outcomes 79% of the time (106 out of 135). The model correctly predicted the occurrence of a stand replacement fire when a stand replacement fire was observed 88% (78 out of 89) of the time. However, the model only correctly predicted the nonoccurrence of a stand replacement fire when the nonoccurrence was observed 61% (28 out of 46) of the time. Sixty-two percent of the model misclassifications (18 out of 29) were due to the over prediction of the occurrence of the stand replacement event when it was not observed (Table 6).

Table 6. Contingency table of observed and predicted frequency of stand replacement fire (1) and no stand replacement fire (0).

		PREDICTED		**TOTAL**	**PERCENT CORRECT**
		No Fire Event	Fire Event		
OBSERVED		0	1		
No Fire Event	0	28	18	46	60.8
Fire Event	1	11	78	89	87.6
TOTAL		39	96	135	78.5

Table 7 displays the Pearson Chi-square and Continuity Correction values for a 2X2 table for the observed and predicted events.

Table 7. Chi-square results of the observed and model predicted fire events using a cutoff value of 0.5.

	Value	**df**	**p-value**
Pearson Chi -Square	34.7	1	0.000
Continuity Correction	32.4	1	0.000

Results from the chi-square test of independence, indicated that there was a dependency between what the model predicted and what was observed, i.e. they belong to the same population ($\chi^2 = 32.4$, df=1, $p<0.001$)(Table 7).

Objective 3a. Compare the means of selected continuous and categorical independent variables across classes of the dichotomous dependent variable.

Further analysis of TPA suggests there is a difference in the mean log (TPA) for stands that experienced a stand replacement fire (1) and those that did not (0) (Figures 2 and 3).

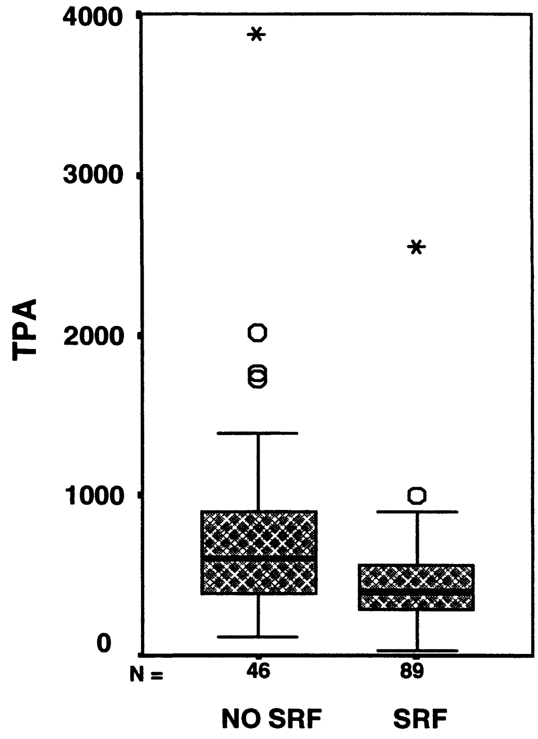

Figure 2. Boxplot of TPA by the dependent variable no stand replacement fire (NO SRF) and stand replacement fire (SRF).

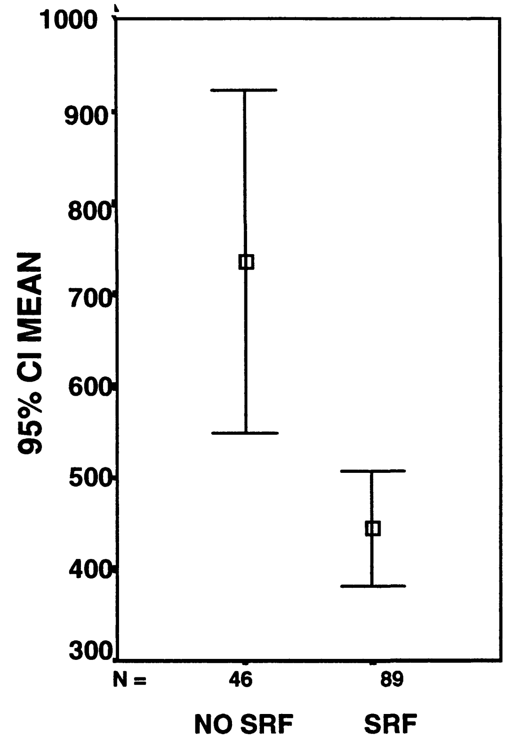

Figure 3. 95% confidence intervals for mean TPA for stands experiencing no stand replacement fire (NO SRF) and those experiencing stand replacement fire (SRF).

Levene's test for equality of variances indicated that unpooled variances could be used for comparing the mean log (TPA) of stands that experienced a stand replacement fire and those that did not (F value=1.203 p=0.275). A 2-sample t-test to test the difference in mean log (TPA) between the stand replacement fire and no stand replacement fire stands was significant (p=0.001) (Table 8). The arithmetic mean TPA for stands not experiencing stand replacement fire was 735 while those experiencing stand replacement fire was 444 for a difference of 291 TPA. These results suggest that regeneration stands with a higher mean log (TPA) are less at risk to a stand replacement fire and regeneration loss than stands having a lower mean log (TPA).

Table 8. 2-sample t-test for equality of means to test the difference in mean log (TPA) between stands that experiencing stand replacement fire and those not experiencing stand replacement fire.

	t	**df**	**Mean Difference**	**Std. Error Difference**	**95%**	**CI**
					Lower	**Upper**
Equal variances assumed	3.385***	82	0.184897	0.05462	0.0762	0.2935

***significant at $p<0.001$

The results from the 2-sample t-test suggests that there is strong evidence ($p < 0.001$) to reject the null hypothesis and conclude that the mean log (TPA) was higher for stands receiving no stand replacement fire than those receiving stand replacement fire.

Objective 3b. Compare the means of selected independent continuous variables across classes of selected independent variables.

Fuel Treatment and TPA

Figure 4 and 5 show the graphical display of mean TPA for Pile and Burn, Burn and None treatments.

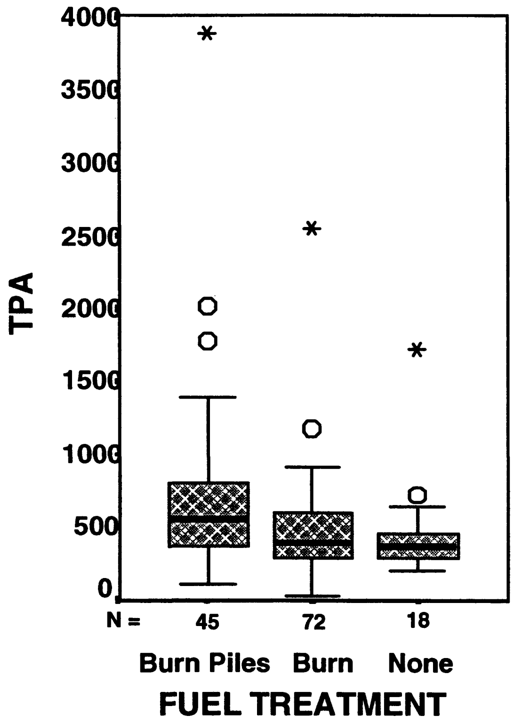

Figure 4. Boxplot of TPA by three fuel treatment categories: Pile and Burn (Burn Piles), Burn (Understory, Broadcast, Jackpot), None (No Fuel Treatment).

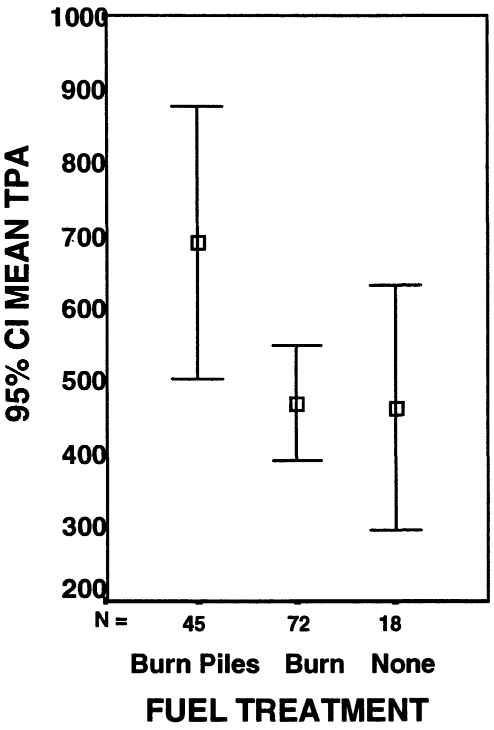

Figure 5. 95% confidence interval for mean TPA over three fuel treatment categories: Pile and Burn (Burn Piles), Burn (Understory, Broadcast, Jackpot), None (No Fuel Treatment).

Levene's test for equality of variances indicated that pooled variance should be used for comparing the mean log (TPA) across the three classes of Fuel Treatment (F value=1.410, p=0.248). Results obtained from ANOVA procedures indicated a significant difference (F value=3.601, p=0.030) in mean log (TPA) across Fuel Treatment class. Thus, there is evidence to reject the null hypothesis that there is no difference in mean log (TPA) across the classes of Fuel Treatment.

Results from the Tukey HSD multiple comparison test indicated that there was a significant difference (p=0.022) between the mean log (TPA) of the Burn Piles and Burn categories (Table 9).

Table 9. Mean log (TPA) differences over three fuel treatment categories: Pile and Burn (Burn Piles), Burn (Understory, Broadcast, Jackpot), None (No Fuel Treatment). Values are from log transformation of TPA.

		Mean Difference	Std. Error Difference	Significance
Burn Piles	**Burn**	0.148738*	0.056	0.022
	None	0.123349	0.082	0.292
Burn	**None**	-0.02539	0.078	0.943

*The mean difference is significant at the 0.05 level.

Aspect and TPA

Figure 6 and 7 show the graphical display of mean TPA for the eight Aspect categories.

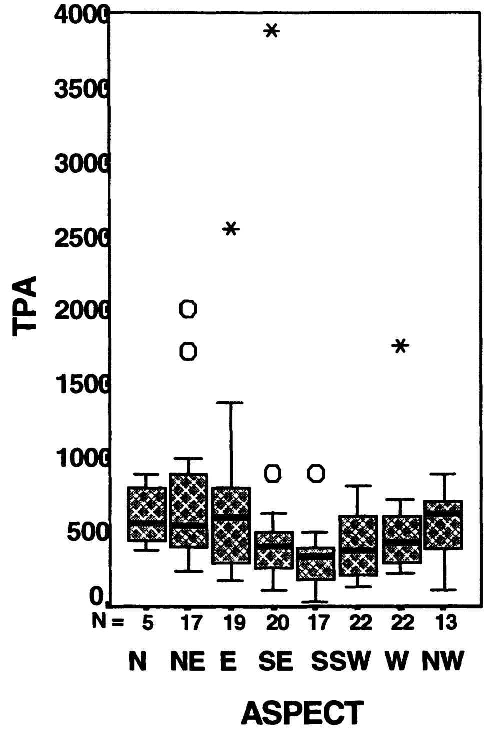

Figure 6. Boxplot of TPA by the eight Aspect categories.

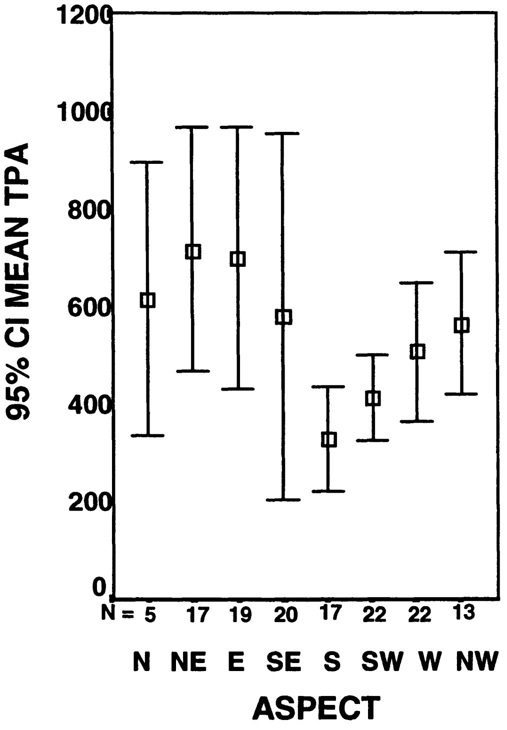

Figure 7. 95% confidence interval for mean TPA over the eight Aspect categories.

Levene's test for equality of variances indicated that a pooled variances should be used for comparing the mean log (TPA) across Aspect classes (F value=1.026, p=0.416). A significant difference (F value=3.288, p=0.003) in mean log (TPA) across Aspect classes was obtained from ANOVA procedures. Thus, there is evidence to reject the null hypothesis that there is no difference in mean log (TPA) across the classes of Aspect.

Although a significant difference in mean log (TPA) across Aspect classes was obtained from ANOVA procedures, Tukey HSD multiple comparison test indicated that there was only two pairings, south to north and south to northeast, in which the mean log (TPA) was significant at the p= 0.05 level (Table 10).

Table 10. Mean TPA differences over the eight Aspect categories. Mean Difference values are from untransformed mean TPA values. Standard Error and significance levels were derived from mean log TPA values.

		Mean Difference	Std. Error Difference	Significance
North	**Northeast**	-0.0710	0.145	1.000
	East	0.0226	0.143	1.000
	Southeast	0.1648	0.142	0.943
	South	0.3718	0.145	0.168
	Southwest	0.2067	0.141	0.826
	West	0.1145	0.141	0.992
	Northwest	0.0743	0.150	1.000
Northeast	**East**	0.0397	0.095	1.000
	Southeast	0.1819	0.094	0.525
	South	**0.3887***	**0.098**	**0.002**
	Southwest	0.2238	0.092	0.224
	West	0.1316	0.092	0.842
	Northwest	0.0914	0.105	0.989
East	**Southeast**	0.1422	0.091	0.774
	South	**0.3491***	**0.095**	**0.006**
	Southwest	0.1841	0.089	0.438
	West	0.0919	0.089	0.970
	Northwest	0.0517	0.102	1.000
Southeast	**South**	0.2070	0.094	0.349
	Southwest	0.0419	0.088	1.000
	West	-0.0503	0.088	0.999
	Northwest	-0.0905	0.094	0.987
South	**Southwest**	-0.1650	0.092	0.622
	West	-0.2572	0.092	0.095
	Northwest	-0.2975	0.105	0.086
Southwest	**West**	-0.9210	0.086	0.962
	Northwest	-0.1324	0.100	0.888
West	**Northwest**	-0.4030	0.100	1.000

***The mean difference is significant at the 0.05 level.**

Habitat Type and TPA

Figures 8 and 9 show the graphical display of mean TPA for each Habitat Type Group 2b classes.

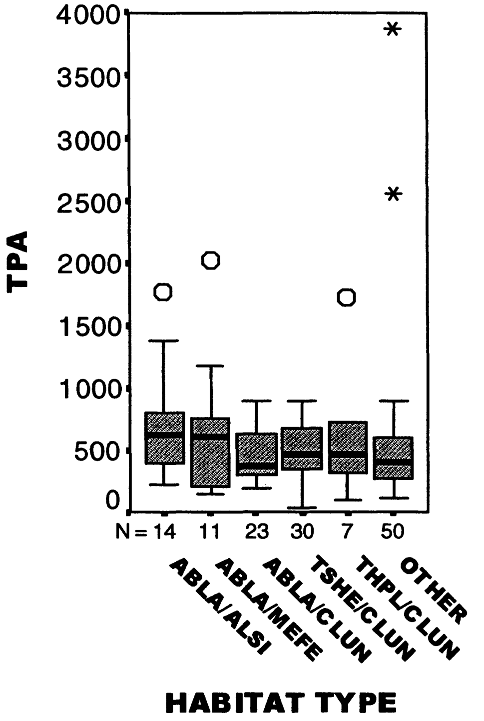

Figure 8. Boxplot of TPA by the six Habitat categories.

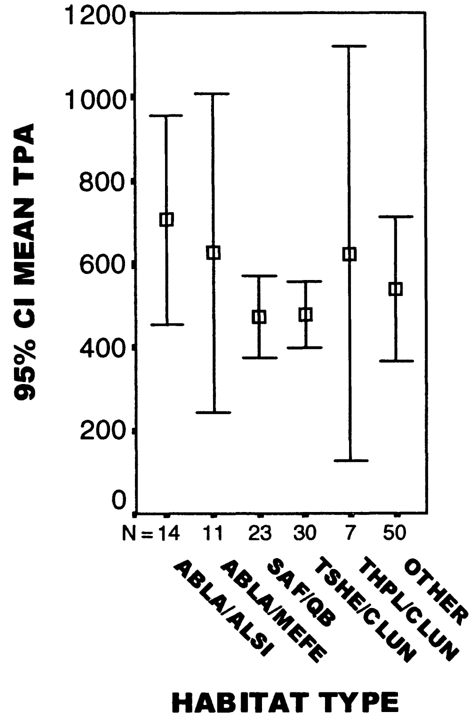

Figure 9. 95% confidence interval for mean TPA over the six Habitat categories

Levene's test for equality of variances indicated that a pooled variance should be used for comparing the mean log (TPA) across the classes of Habitat Type (F value =1.188, p=0.319). No significant difference (F value =0.746, p=0.590) in mean log (TPA) across Habitat Type class was obtained from ANOVA procedures. Thus, there is not enough evidence to reject the null hypothesis that there is no difference in mean log (TPA) across the classes of Habitat Type. Due to the ANOVA findings, the Tukey HSD multiple comparison test was not conducted.

Results indicate that mean log (TPA) for the dichotomous dependent variable and across classes of the independent variables can be summarized as follows: 1) Stands not experiencing stand replacement fire had a mean TPA of 735 compared to stands that experiencing stand replacement fire which had a mean TPA of 444. 2) Stands on southerly aspects had no fuel treatment and one of the cedar-hemlock habitat types had the lowest mean log (TPA).

Objective 3c. Compare selected categorical independent variables to other selected categorical independent variables.

Aspect and Habitat Type

Chi-square results indicate that there is no relationship between Aspect and Habitat Type 2b categories (χ^2=49.18, df=35, p=0.056). Figure 10 shows the aspect by habitat type in percent.

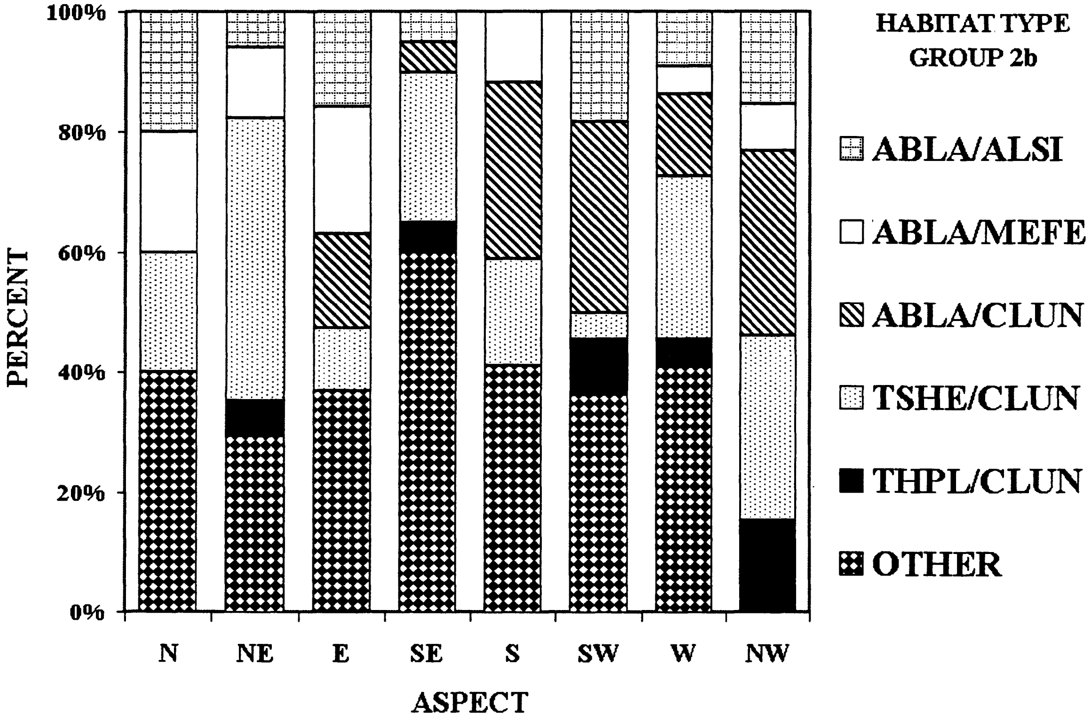

Figure 10. Bar Chart showing the percent composition of Habitat Type Group 2b within each Aspect class.

Aspect and Fuel Treatment

Results obtained from the Chi-square test indicate that there is no relationship between Aspect and Fuel Treatment categories ($\chi^2=12.301$, df=14, p=0.582). Figure 11 shows aspect by fuel treatment in percent.

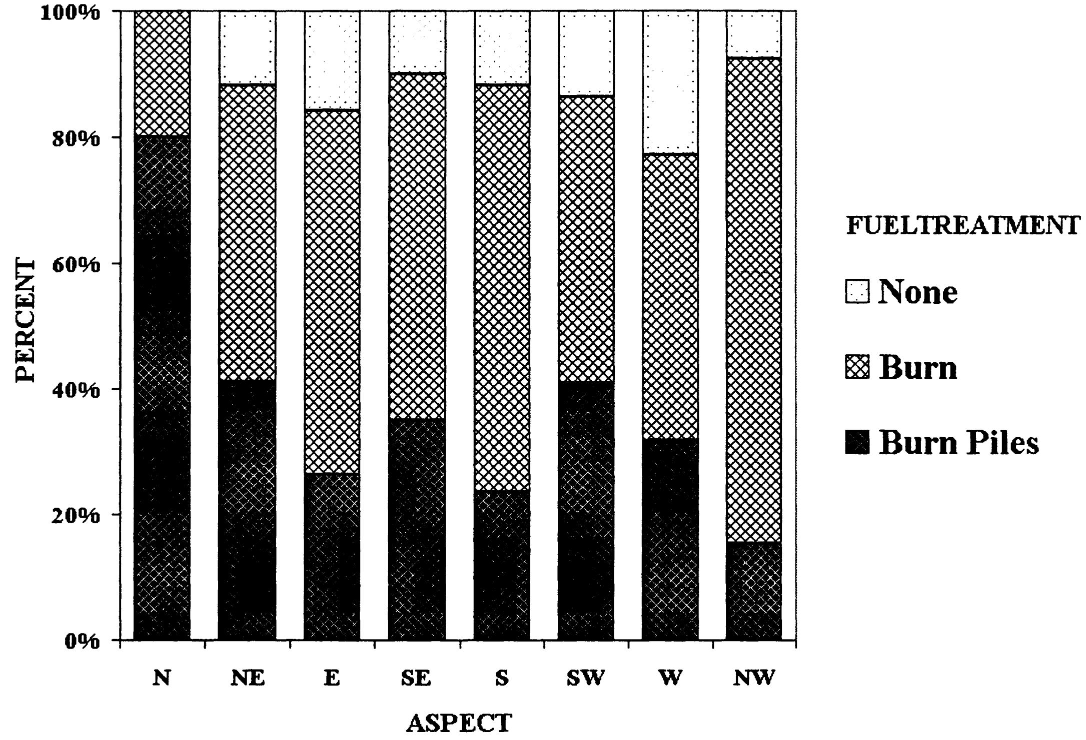

Figure 11. Bar Chart showing the percent composition of Fuel Treatment types within each Aspect class.

Habitat Type and Fuel Treatment

Results obtained from Chi-square test indicate that there is no relationship between Habitat Type and Fuel Treatment categories (χ^2=11.650, df=10, p=0.309). Figure 12 shows fuel treatment by habitat in percent.

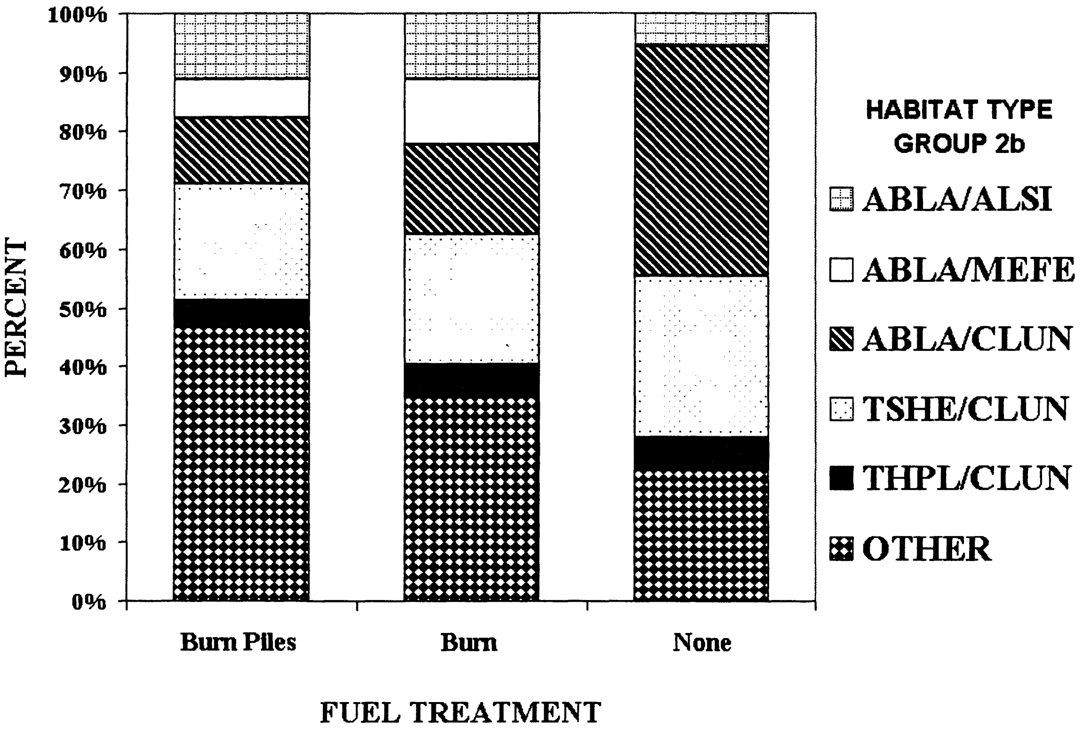

Figure 12. Bar Chart showing the percent composition of Habitat Type Group 2b within each Fuel Treatment class.

DISCUSSION

Logistic regression resulted in the identification of four out of the thirteen candidate independent variables that explained the occurrence of stand replacement fire in regeneration stands ($R^2=0.523$, $p<0.04$)(Table 1). These four independent variables were Aspect, Habitat Type Group 2b, Fuel Treatment, and log (TPA). This four independent variable model correctly predicted outcomes 79% of the time. Aspect ($G=26.861$, $df=7$, $p=0.0004$) and Habitat Type Group 2b ($G=21.654$, $df=5$, $p=0.0006$) were the most important predictor variables.

Several explanations may be identified as to why the nine other candidate independent variables did not enter the model during regression procedures. The variables considered in this study may be classified as those describing fire behavior, fire ecology, and stand structure and condition.

Four variables, Aspect, Elevation, Slope, and Position on Slope have been used to describe fire behavior (Rothermel 1983). In this study's model, Aspect was the only fire behavior variable entering in the model. Elevation may not have been an important variable in this study due to narrow range and average elevations observed (minimum =3000 ft, maximum=6100 ft, and mean of 4800ft). Although there was a wide range of Slope observations (10-70%) the average slope was 33%, just above Rothermel's (1983) observed increased fire behavior value. Sixty-eight percent of the stand Position on Slope values were in the middle and upper zones. There may not have been enough observations in the other classes to be able to detect a difference in stand replacement fire based on stand slope position. The variable Aspect may have entered the model due to its influence on long term drought conditions rather than fire behavior.

Three variables, Habitat Type, Fire Group, and VRU may be used to describe the fire ecology or ecological process of a stand. The majority of the stands (72%) were of the Fire Group 9 and 11 (Fischer and Bradley 1987). Fire Group 9 contains all of the subalpine fir habitat types while Fire Group 11 contains all of the western hemlock and western redcedar habitat types. Ecologically speaking, both groups have similar mean fire intervals and characteristically have stand replacement fires during drought conditions (Fisher and Bradley 1987). Sneck (1977) estimated the mean fire interval for subalpine fir stands to be approximately 117 to 146 years while Arno and Davis (1980) calculated the interval to be 50 to greater than 200 years for hemlock and redcedar. Grouping of the habitat types into two Fire Groups may have hidden the explained variability of stand replacement fire. Thus, Habitat Type Group 2b, with 5 classes, allowed the variability in stand replacement fire to be captured in the model. Part of the VRU classification was based on the ecological Fire Groups. Thus, VRU may not have entered the model for the same reasons the variable Fire Group did not enter.

Six variables, Age, Equipment Type, Forest Type, Reforestation Method, TPA, and Type of Treatment (Fuel and Harvest) may be used to describe stand structure or condition at the time of the wildfire. Age may not have entered the model due to the stand selection criteria for this study. The focus of this study was on very young stands (<20 years old). Thus, the stand may not have developed structurally in a way that would have allowed a determination of risk to stand replacement fire. Likewise, Forest Type probably did not enter the model because the trees were too young to have developed their species specific resistance to stand replacement fire. For Equipment Type and Type of Treatment (Fuel or Harvest) the determining factor identified in the logistic model was not the arrangement or quantity of residual fuel produced. Rather that the fire hazard was reduced by accomplishing a type of fuel treatment. It did not matter to the wildfire, that resulted in a stand replacement fire, if the harvest was a clearcut, seed tree, or shelterwood cut as long as the residual fuels were treated so that the fire hazard was reduced. The lack of relationship between Regeneration Method and stand replacement fire may be explained by the inclusion of TPA in the final model. The method of regeneration may not have been as important as the amount or resulting TPA. The high TPA in stands that did not experience stand replacement fire indicates there was adequate regeneration to out-compete the fine fuel vegetation that contributes to fire hazard. The practice of natural regeneration can be used, without increasing risk to stand replacement fire, as long as adequate regeneration is obtained in the stand.

Model validation tests showed that there was evidence of a dependency between observed and predicted Z-values ($\chi^2 = 32.4$, df=2,$p<0.001$). Overall, the model predicts outcomes correctly 79 percent of the time. The model had the best performance when predicting the occurrence of stand replacement fire when stand replacement fire was observed (88 percent correct). However, the model did not predict the non-occurrence of stand replacement fire as well (61 percent correct) when stand replacement fire did not occur. The majority of the misclassifications (62 percent) were due to over-predicting the occurrence of stand replacement fire.

A similar study conducted on the Klamath National Forest in ponderosa pine and Douglas-fir habitat types found some of the same independent variables to be significant predictors. Six variables: Grasses, Forbs, Elevation, Site Prep None, Site Prep Machine Piled, and Damage in Adjacent Stand, were the most significant ($p=0.0001$)

(Weatherspoon and Skinner 1995). The amount of Grasses, Site Prep None, and Damage in Adjacent Stand were positively correlated with fire damage class while the other variables were negatively correlated. The authors note that the strongest relationship was between the damage in the adjacent stand and damage in the regeneration stand (Skinner and Weatherspoon 1996).

In this study, I did not have a measure of grasses, forbs, or damage in adjacent stand. Inclusion of these variables in the model may improve prediction capabilities. Weatherspoon and Skinner (1995) also examined Elevation, Slope, Aspect, and Initial Density of Planted Trees as possible independent variables similarly to this study. However, slope was not found to be a significant predictor variable in either study. This study showed aspect to be a significant predictor variable while their study yielded elevation as a significant predictor variable. Although Weatherspoon and Skinner (1995) did not find Initial Density of Planted Trees to be significant, this study identified TPA as a significant predictor variable. The discrepancy may be due to stand development at the time of the fire rather than regeneration attempts made by planting.

In this study, TPA was found to be negatively correlated with stand replacement fire and was significant at $p=0.0002$. Landrum and Hermit (1996) proposed a Stand Resiliency Index (SRI) based on TPA and quadratic mean diameter (QMD), as a way to calculate fire hazard. A low SRI is based on the premises that as TPA decreases and QMD increases, the stand will be more likely to survive a stand replacement fire. They suggest that stands that have been thinned or have a lower TPA are less likely to have crown contact with ladder fuels, and thus be more resistant to crown fires that are stand replacement in nature.

While Landrum and Hermit (1996) explored the SRI relationship for mature stands, logistic regression analysis in this study showed that as the TPA of a stand increased, the regeneration stand became less likely to have stand replacement fire. Furthermore, the 2-sample t-test for the difference in mean TPA between stands that experienced the stand replacement fire and those that did not was significant ($p<0.001$). The difference in mean TPA between stands experiencing replacement fire and those that did not was 246. Stands that did not experience a stand replacement fire had a mean TPA of 666 and 95% confidence limits of 539 and 793. Stands that did experience a stand replacement fire had a mean TPA of 420 and 95% confidence limits 378 and 462. These results suggest that regeneration stands with a higher mean TPA are able to compete with, and therefore, shade out the fine fuel vegetation. As suggested by the Weatherspoon and Skinner (1995) model results, these fine fuels may enhance fire spread and stand replacement effects.

All Aspect categories, except southeast and northeast, were positively correlated with the stand replacement fire while Aspect was significant at $p=0.0004$ in the model. Three out of the seven Aspect categories were significant when compared to the reference category east. Most notably, the southwest aspect had an odds ratio of about 22. This means that the southwest aspect is 22 times more at risk of having a stand replacement fire compared to the east aspect, which had the least occurrence of a stand replacement fire. South, north, west, and northwest were approximately 9,8,7, and 3 times more at risk to having a stand replacement fire.

Results obtained from ANOVA procedures indicate a significant difference ($p<0.05$) in mean log (TPA) across Aspect categories. A graph of mean TPA by Aspect category showed that there was a decreasing trend in mean TPA from the northerly to southerly aspects. Tukey HSD multiple comparison test indicated that only two aspect pairings, south to north and south to northeast, had significantly different mean log (TPA) ($p<0.006$). This suggests that the southerly aspects are harsher and more difficult to regenerate. Shearer (1982 and 1989) and Ferguson (1994) obtained similar results when they examined regeneration success on different aspects. These differences in mean TPA indicate that there is a trend between Aspect and TPA.

The variable Fuel Treatment was positively correlated with the stand replacement event and was significant at $p=0.0285$. The category None was approximately 11times more at risk, while the Burn category was 3 times more at risk for having a stand replacement fire compared to Piled and Burned stands. These results suggest that it did not matter how the fuels were treated, rather, what made the difference was that a fuel treatment was applied.

Weatherspoon and Skinner (1995) also observed the importance of fuel treatment in harvested stands. In their study, all stands that had untreated fuels were burned completely and severely. They also found that no site preparation had a positive correlation, machine pile had a neutral and broadcast burning had a negative correlation with fire damage in regeneration stands. Furthermore, the wildfire damage in broadcast burned stands decreased from the edge inward while the damage to machine piled stands was spotty (Weatherspoon and Skinner 1995).

A significant difference (F value=3.601, df=2, $p<0.03$) in mean log (TPA) was detected across Fuel Treatment categories based on one-way ANOVA results. The Tukey HSD multiple comparison test indicated that for stands that were Piled and Burned mean log (TPA) was higher and significantly different ($p<0.03$) from that of stands that were Burned. While stands that were Piled and Burned had the highest mean log (TPA), there was not a significant difference between the mean log (TPA) for Piled and Burned, and No Fuel Treatment stands. There was also no significant difference in mean log (TPA) between stands that were Burned and No Fuel Treatment. The lack of significant difference between mean log (TPA) for Piled and Burned and No Fuel Treatment stands may be due to the high variability in No Fuel Treatment TPA observations. These results suggest that Piling and Burning may be a more effective site preparation treatment for increasing TPA.

Several authors point out the importance of effective site preparation and fuel treatment for germination, seedling survival, and growth. For many conifer species, germination and seedling survival is best on surfaces where duff has been removed providing exposed mineral soil (LeBarron and Jemison 1953, Roe and DeJarnette 1965, Parker and Johnson 1988, Graham et al 1988). Seedlings are able to survive competition from other vegetation when there is adequate humus layer removal and penetrable mineral soil (Hetherington 1965, Graham et al 1989). Removal of competing vegetation is not only important for seedling survival but also for growth (Dumroese et al 1997). However, shade provided by larger logs (Gray and Spies 1997) and residual organic matter, such as decaying wood, is important for regeneration (Harvey 1982). Thus, there is a balance between too much and not enough site preparation and fuel treatment effort for providing seed germination and seedling survival.

While there is evidence for the need to have effective site preparation and fuel treatment, there are varying opinions on the preferred method for removing competition in regeneration stands. Williamson (1976) as well as LeBarron and Jemison (1953) state that broadcast burning eliminates brush competition and dense patches of slash that inhibit regeneration. However, Roe et al. (1970), found that burning may not be enough to destroy the competing vegetation and that additional site preparation measures may be needed. Piling and burning may provide better control of competing vegetation (Van Lear and Waldrop 1991). The preferred method may depend on the regeneration circumstances and not on any "best" method for all cases.

There are several advantages of broadcast burning compared to piling and burning. Van Lear and Waldrop (1991) noted that with broadcast burning there is more residue and decreased soil erosion, less soil compaction, more herbaceous growth, and that broadcast burning can be done more quickly. Eramian and Neuenschwander (1989) found less compaction and greater infiltration rates and seedling growth in broadcast burned compared to pile and burned stands. A study conducted by Holdorf (1982) on the Kootenai National Forest showed that at critical levels of compaction, soil bulk density affected seedling survival. When 60 percent or more of a harvested area was compacted beyond the critical bulk density, stocking standards were difficult to attain. Minore (1986) also found decreased site quality and lower measured and potential heights of seedlings on piled and burned stands compared to broadcast burned stands. Due to decreased site quality from piling and burning, care should be taken in the ash capped soils found in northern Idaho and northwest Montana (Eramian and Neuenschwander 1989, Ferguson 1994).

Care should also be taken when considering the size of the piles to be burned. Roe et al. (1970) recommend that burn piles should not be large and that burning are confined to the smallest area possible with minimal dozer work. Burning slash in large piles creates too much heat and sterilizes the soil, creates a deep layer of ash, and prevents plant growth (Roe and DeJarnette 1965). Some logs, tops and other slash should be left for soil protection (Roe et al. 1970).

There are advantages and disadvantages to conducting some type of burning compared to none at all. Reinhardt et al. (1994) found greater height for planted seedlings and greater number of natural regeneration seedlings in burned units. However, natural regeneration seedlings where greater in height in unburned units. Hetherington (1965) also found the greatest number of seedlings per unit area in burned compared to unburned stands.

The Habitat Type Group 2b categorical predictor variable was significant in the model ($p<0.0006$) and all coefficients were positively correlated with stand replacement fire with the exception of the Subalpine Fir/ Menziesia category which was negatively correlated.

The Subalpine Fir/Sitka Alder habitat type had low occurrence and, in regards to this study, is assumed to have some resistance to a stand replacement fire. Thus, the Subalpine Fir/Sitka Alder habitat type was used as the reference category for logistic regression modeling. Results indicate that the Western Hemlock/Queencup Beadlily and Western Redcedar/Queencup Beadlily habitat types have the greatest risk (approximately 30 and 17 times respectively) of a stand replacement fire compared to Subalpine Fir/Sitka Alder habitat type. The model results suggest that the Western Hemlock/Queencup Beadlily and Western Redcedar/ Queencup Beadlily habitat types are the most at risk to a stand replacement fire. There was not a significant difference (p>0.05) in mean log (TPA) across the Habitat Type Group 2b classes based on one-way ANOVA results.

The cause for the increased risk to stand replacement fire might be due to the presence of bracken fern (*Pteridium aquilinum*) associated with cedar-hemlock stands. Bracken fern is prevalent in the early through mid-successional stages of cedar-hemlock stands (Zack and Morgan 1994) and will decrease with canopy closure (Mueggler 1965). Bracken fern is also significantly associated with soils high in potassium and south slopes (Mueggler 1965).

Agee and Huff (1987) observed a peak in bracken occupation following disturbance by year nineteen and a "deep fluffy litter layer" of accumulated bracken (Agee and Huff 1987). Cedar-hemlock stands that have bracken litter are highly flammable and bracken fern has been considered to cause many reburns (Issac 1940, Haeussler and Coates 1990).

Bracken fern has many growth mechanisms that enhance its presence and survival following disturbance. A deeply rooted stem and rhizomatous growth allows the plant to survive cutting and severe burns (Cody and Crompton 1975, Lyon and Stickney 1976, and Stickney 1986). Regeneration occurs mainly from vegetative growth but it can colonize new areas, such as a logging site or burned soil, by spores (Haeussler and Coates 1990)

Bracken fern also possesses many characteristics that enable effective plant competition. Allopathic phytotoxins kill or decreases seed germination, reduce seedling vigor, or causes seedling mortality of other plants (Ferguson and Boyd 1988). Stickney (1986) found that bracken fern was able to retard tree and shrub development during the first decade after disturbance. Issac (1940) also observed that bracken fern out competed and eliminated tree seedlings, and persisted throughout the life of the stand when other herbaceous plants disappeared.

Growth and competition mechanisms of bracken fern allow the plant to thrive when disturbance occurs. Site preparation treatment, such as bulldozer or fire, which may damage the roots and stimulate rhizomatous growth should be avoided (Newton 1976). Mechanical site preparation will cause bracken fern to expand rapidly if it is present before logging. If bracken fern is not present, it can colonize new areas by spore reproduction (Coates et al. 1990). However, rhizomatous growth may be diminished by severe fires (Morgan 1989). Whittle et al. (1997) found the lowest severity class had the lowest percent cover of bracken fern. Ferguson and Boyd (1988) recommend that minimal site preparation is used and that hot burns or excessive scarification increases bracken fern spread. Haeussler and Coates (1990) also note that bracken fern favors sites with high mechanical disturbance or deep hot burns.

Methods of controlling bracken fern are limited. Some success has been achieved from repeated cutting (Haeussler and Coates 1990). Successful control of bracken fern has been achieved by using the herbicide Asulam or Glyphosate during frond emergence (Coates et al 1990 and Newton 1976).

Although the presence of bracken fern in cedar-hemlock stands may explain the difference in habitat type and mean TPA across the independent variable categories, I did not directly measure the quantity of grass, herbs, or forbs. Thus, I can not draw conclusions about the effect of bracken fern on regeneration stand risk to stand replacement fire in this study. Further research needs to be conducted on the effects of site preparation and the early serial stages of the various habitat types to clearly determine their relationship and the appropriate fuel treatment for a given habitat type. This study indicates that some habitat types and stands on southerly aspects are more susceptible to a stand replacement fire while stands with high mean TPA are less susceptible to stand replacement fire. Adequate lowering of the fire hazard can be achieved with either burning or piling and burning the fuel created by harvesting as long as the fuel treatment is accomplished. Fire hazard may be increased in those cedar-hemlock stands that have bracken fern.

Management Implications

The results from this study provide evidence to support the following management implications to timber harvesting in the moist habitat types that posses relatively long fire intervals that burn infrequently on the Kootenai National Forest.

1. Southerly aspects appear to be harsher and more at risk to stand replacement fire following harvesting activities. Regeneration may be more difficult on the southerly aspects, thus allowing fine fuel vegetation to increase fire hazard.

2. Cedar-hemlock regeneration stands are at the greatest risk to stand replacement fire under the fire conditions that were observed during 1994. The presence of bracken fern following timber harvesting may create a fire hazard during the early successional stages of these cedar-hemlock stands.

3. Ensuring the accomplishment of fuel treatments prior to regeneration efforts seemed to abate fire risk in regeneration stands. The month of the year and type of fire treatment are not as important as accomplishing treatment.

4. Regeneration stands in mixed of high intensity habitat types that have a higher mean TPA are less at risk for stand replacement fire. These stands may have been able to out-compete the fine fuels that carry fire into the stand.

5. For forests possessing the ecological characteristics of the Kootenai, four variables, Aspect, Habitat Type Group 2b, Fuel Treatment and log (TPA), can be used as a risk assessment for regeneration stands experiencing stand replacement fire as a result of wildfire.

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APPENDIX I

Definition of Variables

Definition of variables in study data set. Oracle code descriptions are from Timber Management Control Handbook 1996.

Fire 1994—The two fire codes in the Oracle database. 4250 is a stand replacement fire and for study purposes was considered to have the event (value of 1). 4981 is a wildfire that effectively reduces existing fuels, but does not change the character of the existing stand. For study purposes, a stand coded 4981 was considered a non-event (value of 0).

Aspect—The eight cardinal directions on a compass.
N = North
NE = Northeast
E = East
SE = Southeast
S = South
SW = Southwest
W = West
NW = Northwest

Elevation—in hundreds of feet.

Elevation Group—Elevation in hundreds of feet by percentile.
0-45
>45-48
48-53
>53

Fire Group—Habitat types placed in fire groups as defined by Fischer and Bradley 1987.
4 =Warm, dry Douglas-fir habitat types
6 =Moist, Douglas-fir habitat types
7 =Cool habitat types usually dominated by lodgepole pine
8 =Dry, lower subalpine habitat types
9 =Moist, lower subalpine habitat types
11 =Moist grand fir, western redcedar, and western hemlock habitat types.

Forest Type—based on the majority of tree numbers up to 5.0 inches dbh and on basal area over 5.0 inches dbh.
DF =Douglas-fir
PP =Ponderosa Pine
WP =Western White Pine
SAF =Spruce-Subalpine Fir
WH =Western Hemlock
L =Western Larch
LP =Lodgepole Pine

Fuel Treatment Group 1—based on combined outcomes of primary and secondary fuel treatments.

Pile/Burn =those stands that have either been dozer (4984) or mechanically piled (4983) then piles burned (4975 or 4977).
Burn =those stands that have been either understory (4980) or broadcast burned (4978).
None =those stands that did not have any fuel treatment prior to 1994. Includes stands that were piled but not burned.

Fuel Treatment Group 2—based on combined outcomes of primary and secondary fuel treatments.

Pile/Burn =those stands that have either been dozer (4984) or mechanically piled (4983) then piles burned (4975 or 4977).
Burn =those stands that have been either understory (4980) or broadcast burned (4978).
Pile = Includes stands that were piled but not burned
None =those stands that did not have any fuel treatment prior to 1994.

Primary Fuel Treatment—the first fuel treatment conducted in a stand.

4984 =Dozer Piling
4983 =Mechanical Piling
4982 =Lopping

Secondary Fuel Treatment—the second fuel treatment conducted in a stand.

4975 =Burn Dozer Piles
4977 =Burn Mechanical Piles
4978 =Broadcast Burn
4979 =Jackpot Burn
4980 =Understory Burn

<u>Habitat Type</u>—Habitat Types based on Pfister et al. 1977.

ADP CODE	**HABTAT ABBREVIATION**	**FULL SCIENTIFIC NAME**
250	PSME/VACA	*Psuedotsuga menziesii* *Vaccinium caespitosum*
260	PSME/PHMA	*Psuedotsuga menziesii/* *Physocarpus malvaceus*
283	PSME/VAGL/XETE	*Psuedotsuga menziesii* *Vaccininum globulare* *Xerophyllum tenax*
292	PSME/LIBO/CARI	*Psuedotsuga menziesii* *Linnaea borealis* *Calamagrostis rubescens*
310	PSME/SYAL	*Psuedotsuga menziesii* *Symphoricarpos albus*
312	PSME/SYAL/CARU	*Psuedotsuga menziesii* *Symphoricarpos albus* *Calamagrostis rubescens*
320	PSME/CARU	*Psuedotsuga menziesii* *Calamagrostis rubescens*
322	PSME/CARU/ARUV	*Psuedotsuga menziesii* *Calamagrostis rubescens* *Arctostaphylos uva-ursi*
323	PSME/CARU/CARU	*Psuedotsuga menziesii* *Calamagrostis rubescens* *Calamagrostis rubescens*
350	PSME/ARUV	*Psuedotsuga menziesii* *Arctostaphylos uva-ursi*
520	ABGR/CLUN	*Abies grandis* *Clintonia uniflora*
521	ABGR/CLUN/CLUN	*Abies grandis* *Clintonia uniflora* *Clintonia uniflora*
530	THPL/CLUN	*Thujia plicata* *Clintonia uniflora*
531	THPL/CLUN/CLUN	*Thujia plicata* *Clintonia uniflora* *Clintonia uniflora*
570	TSHE/CLUN	*Tsuga heterophylla* *Clintonia uniflora*
571	TSHE/CLUN/CLUN	*Tsuga heterophylla* *Clintonia uniflora* *Clintonia uniflora*

ADP CODE	HABITAT ABBREVIATION	FULL SCIENTIFIC NAME
620	ABLA/CLUN	*Abies lasiocarpa* *Clintonia uniflora*
624	ABLA/CLUN/XETE	*Abies lasiocarpa* *Clintonia uniflora* *Xerophyllum tenax*
625	ABLA/CLUN/MEFE	*Abies lasiocarpa/* *Clintonia uniflora* *Menziesia ferruginea*
661	ABLA/LIBO/LIBO	*Abies lasiocarpa* *Linnaea borealis* *Linnaea borealis*
663	ABLA/LIBO/VASC	*Abies lasiocarpa* *Linnaea borealis* *Vaccinium scoparium*
670	ABLA/MEFE	*Abies lasiocarpa* *Menziesia ferruginea*
690	ABLA/XETE	*Abies lasiocarpa/* *Xerophyllum tenax*
691	ABLA/XETE/VAGL	*Abies lasiocarpa* *Xerophyllum tenax* *Vaccinium globulare*
692	ABLA/XETE/VASC	*Abies lasiocarpa* *Xerophyllum tenax* *Vaccinium scoparium*
730	ABLA/VASC	*Abies lasiocarpa* *Vaccinium scoparium*
731	ABLA/VASC/CARU	*Abies lasiocarpa* *Vaccinium scoparium* *Calamagrostis rubescens*
732	ABLA/VASC/VASC	*Abies lasiocarpa* *Vaccinium scoparium* *Vaccinium scoparium*
740	ABLA/ALSI	*Abies lasiocarpa* *Alnus sinuata*

Habitat Type Group 2a—grouping based on n>5 observations.
740 =ABLA/ALSI
670 =ABLA/MEFE
624 =ABLA/CLUN/XETE
620 =ABLA/CLUN
571 =TSHE/CLUN/CLUN
570 =TSHE/CLUN
531 =THPL/CLUN/CLUN
Other =all other habitat types observed

Habitat Type Group 2b—grouping based on n>5 observations as well as phases.
740 =ABLA/ALSI
670 =ABLA/MEFE
624/620 =ABLA/CLUN/XETE & ABLA/CLUN
571/570 =TSHE/CLUN/CLUN & TSHE/CLUN
531 =THPL/CLUN
Other =all other habitat types observed

Habitat Type Group3—grouped by habitat series.
Douglas-fir
Hemlock
Redcedar
Grand Fir
Subalpine Fir

Habitat Type Group 4—grouping based on n>9 observations.
741 =ABLA/ALSI
620 =ABLA/CLUN
570 = TSHE/CLUN
Other =all other habitat types observed

Harvest—the regenerative cutting that has taken place in a stand.
4111 =Clearcutting Patch
4113 =Clearcutting Stand
4114 =Clearcutting With Reserves
4131 =Shelterwood Seed Cut
4132 =Seed Tree Seed Cut
4133 =Shelterwood Seed Cut With Reserves
4141 =Shelterwood Removal Cut
4149 =Seed Tree Cut With Reserves

Harvest Group—regenerative cutting grouped by type.
Clearcutting
Seed Tree
Shelterwood

Harvest Equipment Type—the equipment used to accomplish harvesting.

Dozer
Skyline
Ground Base Skidder
Ground Lead Yarder

Reforestation Method-natural regeneration or planting.

Reforestation Year—year in which stand initiation activities took place.

Slope—in percent.

Position On Slope—the position of the stand relative to the proximal ridge.

Valley Bottom
Lower
Middle
Upper
Ridge

Vegetative Response Unit—the VRU that made up the majority of the stand.

2S	=Moderately Warm and Dry South
3	=Moderately Warm and Moderately Dry
4N	=Moderately Warm and Moist North
4S	=Moderately Warm and Moist South
5N	=Moderately Cool and Moist North
5S	=Moderately Cool and Moist South
7N	=Cool and Moist North
7S	=Cool and Moist South
9	=Cool and Moderately Dry

APPENDIX II

Additional Multivariate Regression Results

Results of multivariate regression analysis using the prediction data set (n=135). $R^2 = 0.329$.

Variable	D	G-statistic	df	p-value
Position on Slope	-77.326	18.062	4	0.0012
log (TPA)	-72.874	9.157	1	0.0025
Fuel Treatment	-70.652	4.714	2	0.0947

Model containing Vegetative Response Unit Variable (n=135). $R^2 = 0.393$.

Variable	D	G-statistic	df	p-value
Position on Slope	-73.354	18.606	4	0.0009
Vegetative Response Unit	-70.652	13.203	8	0.1051
log (TPA)	-70.067	12.032	1	0.0005

Model containing Aspect variable (n=135). $R^2 = 0.471$.

Variable	D	G-statistic	df	p-value
Aspect	-68.295	19.572	7	0.0066
Position on Slope	-65.342	13.666	4	0.0084
Fuel Treatment	-61.429	5.839	2	0.0540
log (TPA)	-61.061	5.105	1	0.0239

Model containing Habitat Type Group 2b variable (without Aspect)(n=135). $R^2 = 0.398$.

Variable	D	G-statistic	df	p-value
Habitat Type Group 2b	-70.652	13.942	5	0.0160
Position on Slope	-69.650	11.938	4	0.0178
log (Tpa)	-69.153	10.943	1	0.0009

Frequency distribution of the number of stands and TPA.