THESIS

FIREFIGHTER OBSERVATIONS ON MOUNTAIN PINE BEETLE POST-OUTBREAK LODGEPOLE PINE FIRES: EXPECTATIONS, SURPRISES AND DECISION-MAKING

Submitted by

Kevin Moriarty

Department of Forest and Rangeland Stewardship

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2014

Master's Committee

Advisor: Antony S. Cheng

Chad Hoffman
Stuart Cottrell

ABSTRACT

FIREFIGHTER OBSERVATIONS ON MOUNTAIN PINE BEETLE POST-OUTBREAK LODGEPOLE PINE FIRES: EXPECTATIONS, SURPRISES AND DECISION-MAKING

Recent wildfires in mountain pine beetle (*Dendrocronas ponderosae*; MPB) post-outbreak lodgepole (*pinus contorta var. latifolia*) stands in the western United States have generated concern among stakeholders and disagreement over predicted fire behavior in the scientific literature. A study was conducted of wildland firefighters' observations of fire behavior in beetle-killed lodgepole pine forests to garner a better understanding of expected vs. observed fire behavior, with a focus on what fire behaviors surprised firefighters. Twelve MPB post-outbreak wildfires and one prescribed fire were identified in northern Colorado and southern Wyoming using USDA aerial surveys, USGS MODIS based perimeter mapping and local knowledge. Twenty-eight wildland firefighter interviews were conducted among 7 different federal, state, county, local and non-profit agencies with a total of 55 observations. Expectations, observations, surprising fire behavior and tactical decisions were categorized using qualitative coding and interpretation. Expectations were greatly based on prior wildland fire experiences rather than the scientific research results. Surprising fire behavior in the red phase included increased fire behavior in moderate conditions, increased spotting, faster crown fire transition and crown fire transition with limited or no ladder fuels. Surprising fire behavior in the grey phase included crown ignition and crown fire propagation. Observations support the increased fire behavior in MPB post-outbreak red phase and diverge from studies predicting reduced crown fire potential in red and mixed phases. Firefighters formed new expectations of active fire behavior potential in all weather conditions and MPB phases. However, respondents concluded that specific conditions of fuel, weather and topography are the main driving forces in fire behavior and MPB influence was limited to distinct events. Firefighters changed tactics by taking more indirect suppression approaches due to fire behavior and tree hazard.

ACKNOWLEDGEMENTS

I would like to thank all the agencies and organizations that were in full support of this project and the firefighters that generously donated their time to participate in interviews.

I would also like to thank my advisor Tony Cheng and committee members Chad Hoffman and Stuart Cottrell for expert advice in their fields of research.

Lastly, I would like to thank my wife Jenna and daughter Kaighin for their unconditional support and inspiration to complete a thesis.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

The lodgepole pine (*pinus contorta var. latifolia*) forests of Western Northern America have undergone significant transformation from the most recent mountain pine beetle (*Dendrocronas ponderosae*; MPB) epidemic. Mountain pine beetle has affected over 1.6 million acres of lodgepole pine forests in Northern Colorado and Southern Wyoming in the last decade. Mountain pine beetle, however, are native insects and several epidemics have been recorded in the last century (Sanfranyik et al. 2010). Regardless, policy makers, citizens and fire managers alike display great concern for the health of the forests and the potential increases in fire hazard MPB poses to neighboring communities, key watersheds and recreation areas (Schoennagel et al. 2012). Recent studies have suggested that MPB attacks result in altered fuels complexes through time that influence the probability of ignition (Jolly et al. 2012), the rate of fire spread (Page and Jenkins 2007), the probability for crown fire transition and spread, and the resistance to control (Page et al. 2013.)

However, scientific research on post-outbreak fire behavior has yielded mixed results, contributing a high degree of uncertainty and controversies concerning what actions, if any, are needed to mitigate fire hazards (Hicke et al. 2012). Some research estimates that fire behavior in the red stage of post-outbreak lodgepole (1 to 3 years since outbreak) stands will support higher rates of spread than unaffected stands and higher potential of active crown fires (Hoffman et al. 2012, Jolly et al. 2012, Page and Jenkins 2007). Others predict fire behavior to be more passive, with lower active crown fire potential in the short term (Klutsch et al. 2011, Kulakowski and Veblen 2007, Simard et al. 2011). Two factors complicate efforts to produce consistent, generalizable research about post-outbreak fire. First, the MPB outbreak was far from uniform, spanning a large variety of geographies and forest vegetation conditions, and producing varied levels of tree mortality across the landscape (Hicke and Jenkins 2008). Moreover, lodgepole pine forests are highly variable across the MBP outbreak, ranging from pure stands to mixing with various cool-moist conifer forest types (e.g., subalpine fir, Engelmann spruce) and aspen (*Populus tremeloides*); understory vegetation is also highly variable (Kaufmann et al. 2008). Hence, research results using data from Yellowstone National Park (Simard et al. 2011), for instance, may not be applicable to the central Rocky Mountains. The effect of MPB on fire behavior may change with specific conditions (Hoffman et al. 2012).

Second, fire behavior analysis in post-outbreak stands has relied on computer models that are ill-equipped to characterize and analyze the complex fuels produced by the MPB, and do not account for the complex fire-atmospheric interactions resulting from stands of trees lacking green crowns (Hoffman et al. 2012). Limited field-based observations of fire in beetle-killed stands have been documented and few experiments have been conducted (Jolly et al. 2012). While disagreement across studies is reduced when conditions are characterized with more specificity (Hicke et al. 2012), the lack of conclusive findings could potentially make decisions during firefighting operation and fuel treatments difficult to plan (Hicke et al. 2012, Jenkins et al. 2013).

Although there is a lack of well quantified experiments relating fire behavior to bark beetle caused mortality, qualitative insight from firefighters has suggested that the behavior of fire in these fuels complexes can result in surprises (Byron 2011), indicating that the observed fire behavior in these new situations might be quite different than expected. This gap between expectations and observations generates an element of surprise that increases firefighter risk (Weick 1995). Therefore, understanding how a firefighter processes and learns from these gaps is of great importance to the fire community. In addition, capturing specific conditions from observations improves the science of predicting fire behavior in post-outbreak stands.

The gap between expected and observed fire behavior may be alleviated with a wildfire case study approach. Wildland firefighters have direct observations of fire events, with many having observed multiple fires burning under different weather, fuel, and topographic conditions. Firefighters are in a unique position of observing, experiencing, and cognitively and socially processing events as they occur which could be captured or explored in a case study. Case studies of firefighter observations could become a major facet in assessing and predicting fire behavior in beetle-killed forest stands. In light of uncertain conditions, wildfire observation based case studies may provide a more nuanced understanding when, where, how, and why fire behavior in beetle-killed forests correspond to or run counter to scientific findings based on computer models.

Several researchers have suggested case studies have shown to have significant importance by both fire mangers and fire researchers (Alexander and Thomas 2003, Byram 1954, Chandler 1976, Thomas 1994, Turner et al. 1961). Case studies were prevalent in the 1950's and 1960's, but due to other priorities and limited budgets, wildfire case studies have declined in recent years (Alexander and Thomas 2003).

Documenting firefighter observations is an important component in developing a case study of a wildfire. Observational information, even if based on incomplete information due to depreciating memory, provides nuanced information on fire behavior spatially and temporally (Alexander and Thomas 2003). Case studies should also incorporate cognitive information from individual and group interactions. In addition, documenting firefighters' "mental cues" of making fire-ground decisions help surface what fire behavior firefighters might expect verses what fire behavior firefighters observe (Weick et al. 2005). Fire managers will learn from past wildfire decisions and prepare for possible surprising fire behavior. Collecting, categorizing and interpreting firefighter experiences and observations will improve the collective knowledge of how firefighters are making sense of fires in beetle-killed stands.

The exploratory approach of deconstructing and documenting firefighters' experiences and assessments of surprises will draw from a social science framework of sensemaking. Sensemaking refers to the process by which individuals ascribe meaning to an event or experience. Sensemaking occurs at both the individual and the group/community/organizational levels (Weick 1995). In this way, sensemaking provides an organized approach to examine how firefighters deconstruct and understand their experiences and observations during fires in beetle-killed forests, including unexpected fire behavior.

Sensemaking

The framework of sensemaking has been used as an analytical lens to understand why wildfire scenarios have resulted in tragic situations. Karl Weick (1993) first applied sensemaking to wildland fire by retrospectively analyzing Norman McLean's narrative of the Man Gulch fire. Research was also conducted by retrospective analysis of the circumstances on the South Canyon fire (Larson 2007). Similar retrospective analysis has been conducted in emergency type scenarios (Cohn 2006, Klein 2005, Landgren 2005). These studies apply sensemaking concepts to deconstruct the experiences and decision-making of firefighters that may have influenced the events that took place in tragic wildfire situations.

In Weicks' (1993) case study of the Mann Gulch fire, Weick concluded that the firefighters were merely forestry students with limited firefighting experience and accustomed to the "10 o'clock fire", a typical small low intensity fire that could be extinguished by 10 o'clock the next day. Naively, the firefighters entered a new encounter in which the fire was more intense than they expected. Unfortunately, the Mann Gulch fire was not a 10 o'clock fire but something of a surprise, a high intensity and fast moving fire that eventually overran and killed thirteen firefighters. In this analysis, inexperience was a crucial component to why firefighters at Mann Gulch were overrun by fire. The lack of firefighter experiences coupled with the inability to make sense of the surprising fire behavior contributed in part to the deaths of these firefighters.

Weicks' analysis of Mann Gulch, like other case studies, applied sensemaking in a retrospective analysis, remote and disconnected to the situation. However, understanding the factors that went into the surprise never really surface in the analysis. Acquiring and filtering information is a crucial step in the sensemaking process of an emergency situation (Barton and Sutcliffe 2009, Landgren 2005, Larson 2003, Weick 2005). As part of this research project, wildland firefighters are interviewed first hand, and sensemaking materializes from the interviewer as the events that took place are analyzed.

Research suggests that humans use mental shortcuts to filter and process the seemingly infinite amount of information in a given emergency situation (Barton and Sutcliffe 2009, Landgren 2005, Scott and Tretheway 2008, Weick 2005). The filtering of information may be largely driven by a firefighter's past experiences. This process is most commonly known to firefighters as situational awareness (SA). Situational awareness deconstructs the comparison between past experiences, provided information and the present situation to assemble the "situation" for further evaluation.

Experience plays a significant role in the process of situational awareness in a hazardous situation (Klein 1988). The past events are the basis for mental models. Firefighters expect fire behavior based on similar situations. Novel situations, however, may produce unexpected fire behavior and elicit an element of surprise. This surprise in behavior may lead to poor judgment or discontinuity between forces, as in the Mann Gulch tragedy. Observation based case studies provide readily available information to reduce the element of surprise.

Observing the present situation completes the process of situational awareness. Comparing expected fire behavior to the observed fire behavior creates mental cues used in future processes as the situation is continually being reevaluated. Since most decisions are based on experience, observations in unfamiliar or new situations may redirect the decision-making process (Klein 1988, Weick 1995).

Decision-making

Decision-making is the central focus of sensemaking research. Understanding what factors contribute to an individual or collective decision on the fire ground, however, is poorly understood (Klein 1988, Larson 2003, Weick 1993). Rapid decision-making requires information acquisition and processing to create meaning out of the information provided. Actions must be taken for sensemaking to occur (Weick et al. 2005). Decisions on the fire ground may have life threatening consequences. The firefighter needs to evaluate the situation and construct meaning of the information provided, especially in surprising, unexpected situations. A new element of uncertainty is added with beetle kill forests, hazardous trees and unfamiliar fire behavior.

Situational awareness is fundamental to decision-making (Klein 1988, Taynor 1990, Weick 2005). How firefighters acquire, distribute and evaluate information may be based on what they decide to be meaningful information. Mental cues are used for evaluation in the decision-making process (Barton and Sutcliffe 2009, Klein 1988, Weick 1993). Patterns of interpretation are derived from the desire to make sense of events to maintain individual and collective esteem (Weick, 1995). The situations develop meaning when the firefighter in retrospect brings pieces together to create a sensible explanation of a situation and commits to a decision (Landgren, 2005). This entire process is more commonly known to firefighters as risk assessment analysis.

Wildfire risk and hazard assessment in most research refers to the probability of wildfire and the potential of causal effect to neighboring communities. In this study however, we are looking at the risks MPB post out-break stands pose to wildland firefighter safety and the hazards the firefighter might incur. Most federal, state and local agencies have wildland fire response protocols that incorporate a risk analysis. In this process the firefighter assesses potential hazards and then discusses with other leaders before making decisions. Risk management also should be looked at long term verses short term. Most suppression activity is based on short-term hazards and may not incorporate long-term hazard potential. Wildland firefighters have been trained to assess or "size up" the situation by using standard protocols. Firefighter decisions are based on several variables including road access, terrain, weather and fuel types. Firefighters rarely make decisions without outside firefighter influence (Useem et al. 2005). When conditions permit firefighters to safely engage a fire, direct attack may be a successful strategy. However, if there are elements that warrant unsafe engagement, indirect attack may be a contingent strategy. Added hazards such as MPB may influence and modify tactics.

Project objectives

This study uses an exploratory qualitative approach of wildland firefighters' observations of fire behavior in beetle-killed forests by analyzing expectations, surprising fire behavior and decision-making. Wildfires that occurred in northern Colorado and southern Wyoming post-outbreak lodgepole pine forest stands were the focus of the study. We investigated three main question areas:

How do expectations of fire behavior in MPB compare to observations?

What surprising fire behavior was observed and why was it surprising?

How did tactics change after observing/engaging in post outbreak fire behavior?

CHAPTER 2: METHODS

Author disclosure

Before starting this research project, I worked in the field of natural resources for fifteen years and as a wildland firefighter for the last eleven. I worked on several different wildland fire crews including an engine module, interagency hotshot crew, fuels crew and a wildland fire module. During my career, I was deployed to wildfires in every western state except Hawaii and Idaho. I have also conducted prescribed fires in California, Colorado, Oregon, Texas, New Mexico and Florida.

My experience lends advantages and biases but overall it is useful in a qualitative exploratory study. I worked with several of the wildland firefighters interviewed within the study and know a few on a personal level. Additionally, I was assigned to two of the wildfires in the study (Illinois creek and Wheeler creek). My experience may influence interpretation but in response, my personal connections facilitate increased access to wildland firefighter observations and reduce barriers of reserved behavior and excessive explanation (Phillmore and Goodson 2004).

Project scope

The scope of the research encompassed wildfires in northern Colorado and southern Wyoming that are within the most current MPB lodgepole epidemic. Fires on the Arapaho-Roosevelt, Medicine Bow, Routt, and White River National Forests managed by the USDA Forest Service (USFS), and on non-federal lands in Boulder and Larimer Counties were considered for the study.   Wildfires that met this criteria were compiled using the Rocky Mountain Area Geographic Area Coordination Center (GACC) website archived wildfire database. Fire perimeters were located using the GeoMAC Viewer website, a United States Geologic Survey (USGS) MODIS based program. Fire perimeters were then overlaid with USDA Forest Health Protection Rocky Mountain area aerial detections of mountain pine beetle in lodgepole pine in the form of arc shaped files. Fire perimeters that fell within the most current northern Colorado and southern Wyoming MPB outbreak (2000-2013) in lodgepole pine were considered to be part of the study. Two distinct time periods emerged that meet the criteria of wildfires in post MPB outbreak in lodgepole forests of Northern Colorado and Southern Wyoming. Recent wildfires (2010-2012) were the focus of interviews (Figure1) but older wildfires (2001-2003) were considered. A map of all the wildfires identified is shown in appendix 1. Thirteen fires were used in the study, twelve wildfires and one prescribed fire.

Using a network-sampling approach (Scott and Carrington 2011), firefighters were identified that observed fire behavior within the context of the study (i.e. bark beetle infested lodgepole pine forests that had wildfire). These included federal and non-federal personnel. Firefighters were categorized by operational positions in the chain of command and the particular wildfires they observed. These individuals were asked to identify other individuals with direct experience in post-MPB outbreak fires who, in turn, were be asked to further identify individuals. Sampling stopped when there was complete overlap of information in the fires identified. Potential respondents were then solicited to participate in the study via email with the interview protocol (appendix 2). Candidates identified were

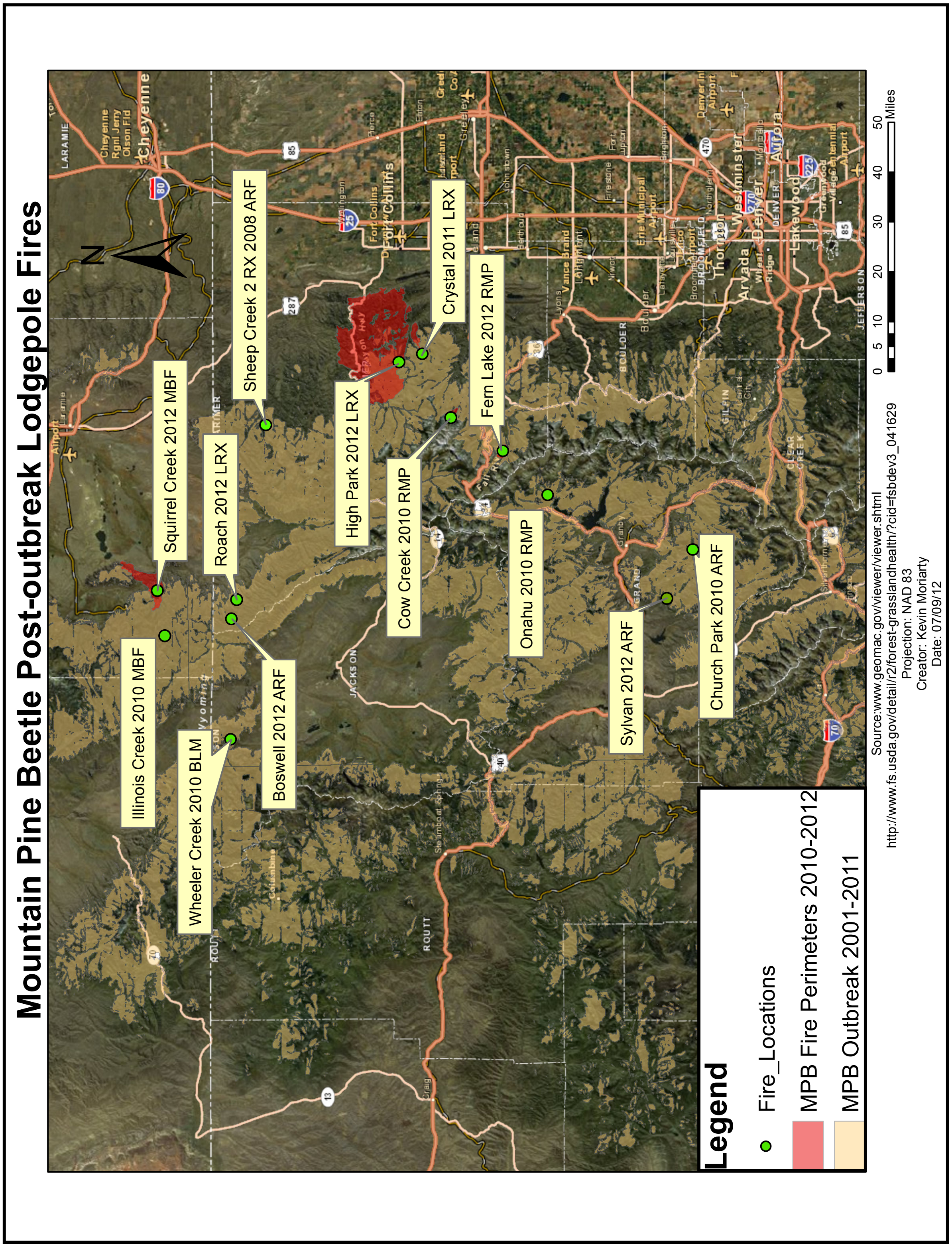

Figure 1: Northern Colorado and southern Wyoming fires in mountain pine beetle post-outbreak stands

contacted and grouped by organization and district office for ease of interviewing. Fire behavior reports, unit logs, incident action plans, photos and videos were brought to interviews. Maps and photos were gathered from online websites like InciWeb. Weather information was gathered from online the National Oceanic and Atmospheric Administration (NOAA) website that had Remote Automated Weather Stations (RAWS) data. However, most other information like incident action plans was acquired by the firefighter being interviewed. This information was provided or coordinated with the interviewee in advance.

Interview process

Interviews were conducted in person and used federal and county district offices when available. A total of 28 interviews of wildland firefighters were conducted from seven different federal, state, county, city and non-profit agencies. Interviews were conducted between October 2012 and September 2013. The average experience among firefighters interviewed was thirteen years. Corresponding photos, maps, weather and the Jenkins et al. 2008 verses Simard et al. 2011 diagram (Figure 2) was also presented in the interview. Interviews lasted around 45 minutes with some longer depending on experience and number of fires. The interviews were recorded and transferred to a hard drive and laptop for back up.

The interviews were based on a semi-structured interview question guide broken into five categories approaching events on a timeline: Introduction, Expectations, Observations, Decision Making and Big Picture. The question guide was designed to understand the sensemaking of the firefighter interviewed, what the firefighter was thinking and observing at the time and what information went into making decisions (appendix 3).

Observations were recorded and categorized by each particular wildfire. Three questions were asked to understand the expectations of fighting fire in MPB lodgepole post-outbreak stands: (1) What sources of information were used to acquire knowledge of fire behavior in post outbreak MPB? ; (2) What were firefighters expectations en-route to a particular assignment? ; (3) What they thought fire behavior would look like through time in the

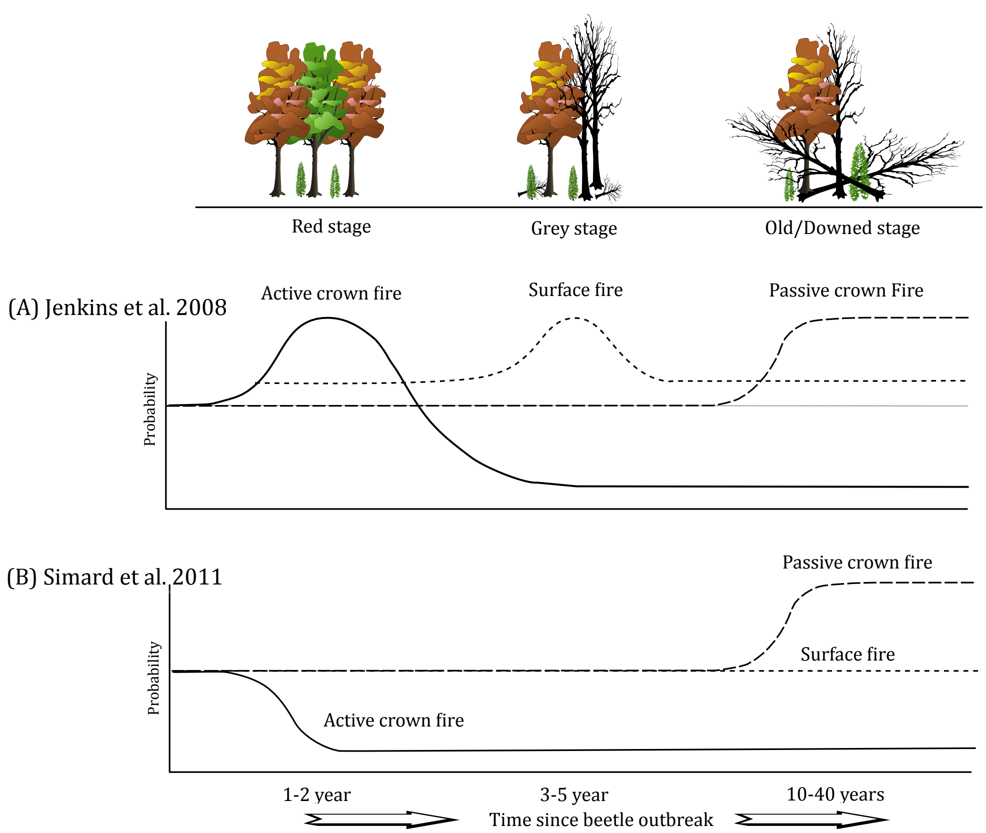

Figure 2: (A) Jenkins et al. 2008 and (B) Simard et al. 2011 net relative change in probability of different fire types relative to pre-outbreak levels (fine dotted line)

different phases of MPB, referring to the diagram in Simard et al. 2011, and which graph would they chose hypothesis or simulation (Figure 2)? Surprising fire behavior was asked with the question: “*Was there anything surprising or that stood out by the fire behavior you witnessed?”* Non-MPB surprising fire behavior was separated from surprising MPB fire behavior. Firefighters were also asked to comment on how there expectations changed after observing a MPB post-outbreak wildfire event. Each one of these questions was coded and interpreted from responses of direct interview questions.

A trial interview was conducted with a fire manager from a local agency to pin down the questions to ask and what other information should be included in the interview. Questions were asked about his observations on the recent MPB affected Salt Fire in Idaho 2011. Two themes that surfaced the trial interview were: 1) understanding environmental conditions and 2) firefighters observing multiple fires within the study. These two themes were incorporated into the interview process.

Interviews were transcribed to capture qualitative categories within the interview process. Express Scribe (Version 5.50, 2013) and Dragon Dictate (Version 3.0.3, 2013) voice command software was used for the transcription process. Each interview transcription was then exported into a word processor document.

Coding

Interviews were then coded using Glaser and Strauss Grounded Theory (Lindlof and Taylor 2011) using NVivo qualitative analysis software (Version 10, 2013). Coding was organized with similar fashion to the interview question guide with situational awareness as a 6th category. A coding tree was developed to categorize similar responses to the questions generated from the question guide and were entered into multiple sub-categories simultaneously (Table 2). Coding was broken into themes from each sub-category (not shown). A second set of coding was conducted to compile information for each wildfire within the study. Coding was also separated by individual wildfires and compiled with outside artifacts such as reports, photos and videos. The compiled MPB wildfire information initiates an ongoing database of information of MPB fires in the area.

Table 2: Coding categories and sub-categories

Coding categories and sub-categories	**Source (number of interviewees that responded in each categories)**	**Number of references in each category**
Background info		
Experience	28	82
Position on fire	28	63
Big picture		
Simard diagram	26	28
Recommendations	26	31
Source of information	27	33
Decisions		
Congruency	26	57
Major decisions	27	120
Urgency	25	42
Expectations		
Beetle kill	28	52
Organizational structure	28	52
Overall	28	71
Observations		
Fire behavior	28	133
Stand description	28	83
Surprising events	28	111
Weather	26	63
Situational awareness		
Comfort level	27	59
Overall	28	90
Past experiences	27	64

Codes were consolidated into major themes and then grouped by similar findings into six major categories (Table 2). This paper reports on the expectations and surprising fire behavior themes.

CHAPTER 3: RESULTS AND INTERPRETATION

Expectations

All but one firefighter were aware of beetle kill in the areas of the study MPB wildfires. Everyone interviewed worked within the Front Range and just east of the Continental Divide in Colorado and Wyoming. This area has the highest concentration of the MPB epidemic of anywhere in the region. Every firefighter interviewed worked in neighboring forests on cutting projects and fire management assignments. The first set of fires in MPB such as Church Park, Cow Creek and Boswell were some of the first fires interviewees had experienced fire behavior in the most recent out-break. In this situation most of the expectations were from sources other than personal experience. Hence, outside reports and anecdotal information were the main sources to form expectations.

Experience was the most utilized source of information to predict fire in mountain pine beetle from which firefighters based their expectations (Table 3). Knowledge from fellow firefighters was also very beneficial. Every federal, state and county agency sent out

Table 3: Source of fire behavior in post-outbreak MPB information
Question: *Where had you received most of your information about fire behavior in MPB post out break lodgepole stands?*

Source of MPB information response categories	Number of interviewees who responded for each category	Number of total references
Previous experience	20	23
Agency protocols and reports	17	19
Scientific research	16	19
Fellow firefighters	16	17
Hands on research	4	4

protocols of how to mitigate the risk of working in mountain pine beetle. Scientific literature was useful but mostly referred to British Columbia studies (University of Northern British Columbia conference proceedings, 2008) and experiments of fire in MPB.

Only fire managers knew of current published literature other than the British Columbia studies (University of Northern British Columbia conference proceedings, 2008). Only three firefighters were familiar with theoretical frameworks suggested within the scientific literature such as those by Jenkins et al. 2008 and Simard et al. 2011 (Figure 2). Agency protocols (USFS R2 briefing packet, 2012) were valuable to produce guidelines when approaching post-outbreak wildfires.

Based on results from qualitative coding, expectations in new MPB fire scenarios were less surprising from previously observed MPB fire behavior as firefighters referenced past experiences. Expectations of fire behavior varied due to environmental conditions and experience. Responses as to what the firefighter expected to see are summed into two basic categories: (1) Active fire with passive and active torching, and (2) Minimal fire behavior with mostly surface fire and occasional torching (Table 4). Active fire prediction expectations were from sources of information reported-experience, fellow firefighters, reports and the British Columbia studies. Experience was also a substantial factor in predicting fire behavior. Firefighters who had already been on MPB fires, especially in similar conditions, predicted active fire behavior including active crowning. Active fire behavior was also predicted from other non-MPB conditions including seasonal drought, high temperatures, low relative humidity and high surface winds.

Expectations of minimal fire behavior were rooted from study fires burning in moderate weather and fuel conditions. Firefighters expected minimal fire behavior on Church Park and Illinois Creek, wildfires that occurred in the fall with moderate temperatures and fuel conditions. Wildfires that occurred during drought conditions (Fern Lake and Roach) were expected to have active fire behavior but observations of active crown fire exceeded expectations.

Table (4): Expectations of fire behavior
Question: *What were your expectations of fire behavior en-route to a particular MPB wildfire?*

Expectation of fire behavior response categories	Number of interviewees who responded for each category	Number of total references
Knowledge of beetle kill in the	24	36
No knowledge of beetle kill in	4	4
Prediction of active fire	21	34
Prediction of minimal fire	13	20
Unfamiliar with area	2	2

Fourteen out of twenty six firefighters agreed with the prediction of increased fire behavior in the red stage (Table 5). These firefighters would reference the observations of their own and logically describe how active fire would occur from drier fuels and less preheating in the red stage. Conversely, firefighters who agreed with no change or decreased fire behavior in the red phase emphasized the dependency of wind to achieve active crown fire. Under normal conditions with light winds, fire would remain on the surface or only achieve passive crown fire. Firefighters also commented on the reduced bulk density being a factor of reduced active crown fire potential.

Firefighters who agreed with increased surface fire in the grey phase referred to observations of increased surface fuels and regeneration of lodgepole and fir species. Three sources observed active crown fire in the grey stage, contrary to either model. Based on observations, firefighters concluded that active crown was possible in red and mixed phases, regardless of condition.

Everyone was in full agreement with both models in the old phase but responses emphasized increased fire intensity from dead and downed 1000-hour fuels and increased regeneration understory. Results favor increased fire behavior in red and mixed phases and diverge from reduced potential of active crown fire.

Firefighters who disagreed with either model emphasized that each wildfire and forest stand was condition specific. Firefighters in disagreement struggled with normalizing the situation in which MPB wildfires would have in similar conditions and behavior. Firefighters in disagreement were aware of the assumptions and limitations of MPB fire behavior modeling but emphasized too much variation of condition in MPB stands to commit to supporting either hypothesis.

Table 5: Expectations of fire behavior through time in each of the MPB phases (Figure 3)

Question: "This is a paper published in 2011 by Martin Simard. Simard did some fire behavior prediction modeling using MPB post-outbreak lodgepole stands in Yellowstone. Prior to this paper, the general hypothesis of fire behavior in MPB lodgepole is displayed in this top graph. Simard however concluded a fairly different set of fire behavior outcomes through the different phases. Would you agree with either of these hypotheses or would you formulate your own opinion?"

MPB phase prediction respondent categories	Number of interviewees who responded for each category	Number of total references
Hypothesis trends	14	17
Neither model	9	10
Simard's simulation	7	7

Observations

General information was organized in a matrix of beetle-kill wildfires (Table 6) based on firefighter interviews, reports and other documents. Wildfire information like size and location was generated from in GACC archives but more detailed information like stand description, MPB phase and mortality, fuel loading, topography and weather variables was generated through the qualitative coding process.

Table 6: Wildfires information collected from interviews, reports and related documents

Fire	Date	Location	Size (acres)	MPB Phase	% MPB Mortality	Stand Description	Fuel loading and conditions	Topography	Weather Variables	Number of observations
Cow Creek	2010, June 25	40.475, -105.566	1200	Green to red	0%-50%	Mostly lodgepole, spruce-fir	Needlecast, grass, 1000 hour	Remote and rugged, drainages, ridgetops	Early summer, warming conditions	5
Boswell	2010, August 12	40.96 -106.15	43	Mostly red	50%-90%	Mostly lodgepole, sage openings	Needlecast, grass, moderate 1000 hour	Drainages, remote	Pre-frontal winds, moderate conditions	6
Wheeler Creek	2010, August 13	40.959 -106.50	2	Mixed	70-100%	Mostly lodgepole, douglas fir	Needlecast, 1000 hour, slashpiles	Flat, small ridge	Moderate conditions	2
Illinois Creek	2010, September 7	41.104 -106.2	120	Mostly red	50%-90%	Lodgepole, spruce	Needle cast, limited 1000 hour	Relatively flat, small drainages	Strong wind during crown fire, moderate conditions	7
Onahu	2010, September 18	40.26 -105.79	30	Mostly grey	80-100%	Mostly lodgepole, most of fire perimeter was in grass	Grass, standing dead	Flatter meadow with small drainage	Late summer, dry conditions	1
Church Park	2010, October 3	39.946 -105.817	473	Mixed	50%-80%	Lodgepole, spruce, subalpine fir, aspen	Needlecast, grass, moderate 1000 hour	Hillside and ridgtops	Pre-frontal winds, moderate conditions	4
Crystal	2011, April 3	40.537 -105.381	2940	Grey	10%-20%	Small amount of lodgepole, mostly ponderosa	Needlecast, grass, 1000 hour	Ridgetops	80 mph winds	3
Sylvan	May 2012	39.996 -106.091	0.5	Downed	90-100%	Mostly lodgepole, Sub-alpine fir	Needlecast, grass, heavy downed 1000 hr	Small drainage and ridge	Moderate conditions with some wind gusts	1
High Park	2012, June 20	40.589 -105.404	87284	Red	50%-80%	Significant stand in mostly lodgepole	Needlecast, limited 1000 hour	Large drainages, hillsides and ridgetops	Multiple wind events, drought conditions	7
Squirrel Creek	2012, July 2	41.12 -106.069	10921	Red	50%-70%	Small portion of MPB lodgepole	Needlecast, limited 1000 hour	Flatter terrain, small drainages and ridges	Multiple wind events, drought conditions	3
Roach	2012, August 27	40.946 -106.095	117.2	Mixed	60%-90%	Lodgepole stands, some aspen and spruce-fir	Needlecast, 1000 hour fuel	Flatter terrain, small drainages and ridges	Drought to moderate conditions	5
Fern Lake	2012, October 9th	40.359 -105.662	3498	Mostly grey	40%-60%	Mixed lodgepole, spruce, subalpine fir, limberpine	Needle cast, grass, heavy dead and downed 1000 hour	Steep rocky remote sub-alpine terrain	Multiple wind events, drought to moderate conditions, snow event	10
Sheep Creek 2 Rx	2008-2011, Various dates	40.882 -105.534	~150	Mostly Red	70 -80%	Mostly lodgepole	Needlecast, limited downed 1000 hour	Moderate drainages and ridgetops	Within RX prescription	1

Coding was not used too in depth for general fire observations in MPB and did not differ from observations of non-MPB stands. In short, fire behavior observations such as surface fire, passive crown fire and active crown fire were observed on all thirteen fires. No new types of fire behavior were observed like independent crown fire.

Surprising fire behavior

Overall firefighters were not necessarily surprised by fire behavior but perhaps perplexed in the sensemaking process of observations, in most cases under novel conditions. Few

Table 7: Surprising fire behavior in MPB post-outbreak lodgepole phases

Surprising fire behavior	Red	Grey	Downed	Wildfire observations	Number of observers
Increased fire behavior from expected	x	x	x	Boswell, Cow Creek, Fern lake, High park, Illinois Creek, Roach, Squirrel Creek	19
Increased spotting	x			Boswell, Illinois Creek, Squirrel Creek, High Park, Fern Lake, Roach	9
Faster crown fire transition	x			Boswell, Fern Lake, High Park, Illinois Creek, Sheep Creek 2RX	7
Lack of perimeter growth	x	x		Boswell, Illinois Creek, Roach	6
Crown fire transition with limited or no ladder fuels	x			Illinois Creek, High Park, Sheep Creek 2 RX	4
Active crown fire propagation	x	x		Fern Lake, Roach, Boswell	3
Active fire behavior in standing dead		x		Onahu	1
Intense heat			x	Sylvan, Wheeler creek	2

firefighters had seen fire behavior in post outbreak stands before observations of the study fires. Some behavior like increased crowning and spotting and faster transition was known but never experienced. This behavior made sense as firefighters put together what they learned and what they observed. The larger the gap from expected to observed behavior, the larger element of surprise. The following are the main themes coded of surprising fire behavior (Table 7).

The most surprising fire behavior that firefighters observed were passive and active torching in conditions that they would not expect these observations to occur. Nineteen firefighters observed fire behavior that exceeded expectations, with the most surprising behavior associated with moderate fuel and weather conditions. Observations of active fire behavior in moderate conditions were not something firefighters expected.

> *FF12: " The transition from the surface fire to group torching or single tree torching initiated really fast. Considering the environmental conditions that we had (Rh 32, Temp 50F,). Normally if there were conditions of 15% Rh with a dry of 70F, I could see that initiation like it did and faster than what it did. But to be able to burn under those conditions and not lose your fire per se, I think that's what's significant about what this points out, how flammable it is, at such a low intensity moderate condition." (Illinois Creek 2010)*

Contrary to increased fire behavior in moderate conditions, firefighters were also fairly surprised at how certain MPB wildfires would have limited perimeter growth if there were no driving factors to sustain active crown fire like wind, slope or continuous fuel.

> *FF03: "Well just that what we have been told was a really active crown fire you know potential of the fire getting up and moving into lodgepole. It was pretty clear that there was a lot of mortality. Just really trying to look at where the fire edge was? At least where the crown fire edge was and trying to figure out why or why not it didn't advance into those places. But I concluded pretty fast that it still needed the slope and a continuous run of fuel. So that, I figured that out pretty fast that it wasn't a grass model that would spread in every direction in canopies, it still needed an alignment." (Salt 2010)*

Active crown fire runs that would promptly drop to the forest floor were an observation on four fires in the study. Wildfires that seemed to have large growth potential would still need distinct conditions to maintain active crown fire. Initial observations left firefighters perplexed at lack of perimeter growth.

> *Interviewer: "Because it wasn't exceptionally hot temperatures or dry or windy?"*
> *FF06: "Nothing was real crazy. I guess that it was a surprise was seeing the sustained crown fire. There wasn't a huge wind on it. It's always breezy to the top of the mountains in Wyoming. Not abnormally high winds or anything. Other than that, the other surprise to me was once it laid down, it was done. When you see that fire behavior, when you first pull up and you kind of think, you're in for it. The next couple days if it keeps doing this, it's a pretty big fire. But after the second day or the third day it never did much. So I was surprised by that." (Roach 2012)*

Besides the two themes of overall surprise, firefighters were also surprised in certain conditions in each particular phase (Table 8). Several firefighters had observations of increased spotting fire behavior including short range spotting just outside the fire front like on Wheeler Creek and longer rage spotting like on Boswell. Firefighters expected spotting potential to increase but were still perplexed at how much the spotting increased in the red stage. Increased spotting potential created more complex and hazardous conditions on most fires within the study.

> *FF12: "Just, reinforced what I've been seeing with these fires as far as all the spotting and the spotting getting out in front. Having to chase all that stuff from the little quarter sized stuff of to the helmet size in a jackpot the fuels on the fire and having to manage all that in addition to the main fire. But yeah, that's it. I think were to see more of that. I think that's just more of that material available in the convection column of the fire." (Wheeler Creek 2010)*

Six firefighters observed faster transition from surface fire to crown fire in the red phase. Observations occurred on High Park, Illinois Creek, Boswell, Fern Lake and Sheep Creek 2 prescribed burn. Most firefighters expected quick transition but still perplexed at how fast surface fire transitioned to crowns. Faster crown transition, however did not affect suppression tactics and only acknowledged to crews for firefighter safety.

FF24: "We knew that if it got in the red needles that it would obviously torch out and spread. But I guess I was surprised how fast it happened, the initiation.

Interviewer: so really fast initiation?
FF24: yeah, almost instantaneously. (High Park 2012)

Observations of fire moving from the surface to crown with limited or no ladder fuels were surprising to a few firefighters. Observations included fire moving directly up the boles of trees or directly to the crown with wind flow. Crown fire initiation with limited ladder fuel contradicts conventional wisdom taught in agency training and was considered surprising fire behavior by four firefighters.

FF04: "Once it got into the crowns, it moved pretty well but like I said, there's not much taken down. The transition from latter fuels… but there's nothing in this red needle. So typically…the conception that I've had after all the beetle stuff came out….is how is it going to get into the crowns, once it gets there? Yeah-red needle trees, those are going to burn pretty well. But it has to get to the crowns. The regeneration maybe? The fire did have some latter fuels to get up into the crowns. That was still a ways; you know 100 acres away from the initial push. Once the heat started going, the red needles, even the bowls of the trees. Where I'm standing on this one it didn't need ladder fuels to carry ground to crown transition." (Illinois creek 2010)

Firefighters observed active crown fire propagation in mixed stands of grey and red phases. Few studies have concluded such behavior, although observations were fairly limited. Observations occurred on the Roach, Boswell and Fern Lake fires by three firefighters who found surprising fire behavior that was not taught as conventional wisdom.

FF04: "I think on the three fires we just talked about you got a pretty good mix between red and gray, some a little heavier on gray. And it didn't seem to me to really…the gray stage didn't seem to really make a difference to really less likely go to a crown fire then the red. They all show that ability to do it for short amounts of time but both those phases, red and gray later on showed kind of the resistance to getting back up there and making that transition. I think this we will see on this time frame, couple years down the road." (Boswell 2010, Illinois Creek 2010, Roach 2012)

One firefighter observed fire activity that exceeded expectations in standing dead (grey phase) when fire establishing itself by either ignition of small limbs or in the crotches of limbs. This fire behavior also diverges from most fire prediction models that do not include standing dead fire behavior integrated into other fuel conditions.

> *FF25: "Like we discussed before the recording, minimal residence time around the base of the dead lodgepole. The tree was easily ignited and like we talked earlier watching embers get lifted, lofted in the opportune places with into crotches of trees. Within thirty minutes of visible flame, the tree was falling in half. And we later surveyed the tree after we felled it. And it was pretty well dried and rotten in on the inside. It wasn't punky but drier than punky. It wasn't powdery yet. The outside of the tree was still fairly solid. But the inside was started to decay out and become rotten and status solid wood." (Onahu 2010)*

Most literature and firefighters are in consensus in predicting high intensity surface fire once MPB affected trees begin to fall. However, all but one wildfire in the study was in the red or grey phase at the time of observations. On the Sylvan wildfire, a small wildfire in the downed phase, one firefighter was still surprised how intense fire behavior was and how difficult the fire was to suppress. Fires with excessive dead and downed from MPB are fairly novel to the firefighters interviewed and were compared to the intensity in pile burning. Wildfires in this phase will likely occur in jackstraw conditions and could be quite problematic.

> *FF10: "Now when the trees fall putting more stuff on the ground. I think it's can be a very intense fire, it's not a crown fire but extremely hot. And the Sylvan fire that we had took us two hours for two sawyers to get aligned to the actual fire and actually find it. It was jack straw like you would not believe. It was difficult without cutting your way in. It took us forever to try and to find the fire. And we're just climbing over stuff and it was ridiculous, it was horrible. And that jack straw stuff, if it hasn't been treated, you can get starts in the grasses that might've been there with the original stand. You get that grass cured and all those dead trees all over the place. You think about the wind pushing through that. It's a pretty intense fire. So… You know… It may… Single and multiple tree torching at times for the most part it's can be a very intense fire." (Sylvan 2011)*

Factors forming new expectations

Firefighters who had experienced MPBs fires within the study directly referred to previous MPB fires comparing fire behavior and hazard. Most agreed on the high potential for active fire behavior and expected quicker crown fire transition and spotting in the red and mixed stands. Firefighters also expected that each MPB wildfire was condition specific and standard fire engagement protocol would be appropriate on the wildfires within the study. Most firefighters expected an increased hazard of fire engagement due to MPB related mortality. Firefighters would refer to the agency protocols and thinning work in MPB post-outbreak lodgepole stands. In summary, expectations of MPB hazard did not change regardless of experience.

Decisions - Change in tactics

Three categories of fire behavior in beetle-killed lodgepole stands contributed to changing tactical decision-making: 1) increased spotting 2) faster transition time from surface fire to crown fire and 3) intense heat. Firefighters were consistently surprised at the increased spotting potential in red phases of post-outbreak stands. Faster transition time required increased awareness. Intense heat from fallen trees contributed to affecting fire behavior. In the latter two categories, firefighters could not engage directly because of increased danger to their safety. Observations of increased spotting along with increased fire behavior and intense heat resulted in more indirect attack and aircraft operations regardless of topography and accessibility.

Mountain pine beetle affected trees as non-fire hazard also played a significant role in the decision-making process. Tree-fall hazard was one of the biggest concerns in mitigating risk on the MPB fires within the study. Tree safety zones were established and utilized in windy situations. Mop-up requirements were greatly reduced when high winds were present; firefighter exposure to tree-fall was limited to non-windy conditions. One tree strike incident occurred on the Roach Fire in 2012. Firefighters on the scene planned an efficient evacuation and a written report was generated and distributed throughout the region. This incident was the only MPB related accident report within the three-year time span of the study fires.

Firefighters were in agreement of less engagement in mountain pine beetle post-outbreak fires. Observations of active crown fire, quick crown fire transition, increased spotting and tree fall hazards influenced more indirect approaches and use of aircraft. Protocols for wind speeds were also established and put in incident action plans. On the three largest wildfires: High Park, Squirrel Creek and Fern Lake, firefighters would comment on non-regional Type 1 interagency wildland fire management teams wanting to aggressively approach the fire and not fully considering the MPB hazard. During all three wildfires, non-regional team decision-makers eventually utilized advice by local resources and employed more indirect attack strategies.

Firefighters listed many recommendations on how to approach MPB fires for other managers. Recommendations were grouped into different categories and listed in Table 8. The most frequent recommendation response was a heightened awareness of a complex hazardous situation. Three major themes surfaced from responses: heightened awareness, less engagement and hazard mitigation.

Table 8: Firefighter recommendations in MPB post outbreak stands

Recommendations	Number of responses by firefighters
Heightened awareness	18
Less engagement	11
Mitigating tree hazard	10
Bigger boxes	4
Epidemic complexity	4
Needs more study	4
Same risk analysis	4
Experienced local crews	3
Consider long duration RH	3
Use of aviation	3
Increased buffers	2
Similarity to burning a pile	2
Use of dozers	2
Use of natural features	2
Burning at night	1
Consider previous epidemic	1
Plan for worse case	1
Use different models	1

The beetle-kill wildfires in Colorado and Wyoming used in this study were in remote rugged locations and already had increased hazard complexity due to topography and access limitations. With the addition of MPB induced mortality, firefighters need a higher awareness of fire behavior and tree fall hazard. The tree-fall hazard is one more variable to be aware of and manage in order to suppress fire safely and effectively.

> *FF19. "I could tell you how we are approaching them now. The risk management thing is huge. My district ICs, for the past couple years I have a talk with them at the beginning of the season every year and just emphasize the fact that risk management starts and stops with them. I'm not the one that IA's (initial attack) these things. And they are. I think it's critical that that they evaluate not only the fire behavior, we've always done that but the snag hazard is huge. It becomes problematic. What you do when you got one snag burning when you got a 2 mile hike? What do you do? They have to make that decision. And I told them I will support their decision on that and they know I don't like drama either and for some reason they don't want to engage I will support that."*

Most firefighters agreed in less engagement of suppression and mop-up phases. Potential active fire behavior and tree strike hazard induced more indirect attack and thorough size up. Mop-up standards were generally reduced to ensure firefighter safety and avoid potential tree strikes. Most agencies had protocols or adopted protocols from partnering agencies. Standards were also discussed in morning briefings and put into incident action plans.

> *FF22: I think that the beetle letter that we've received from the forest FMO is really good. There's no need to get into the mop up stages, you know even during the initial attack stages. There is no need to get into the interior of these things. Just because of the high probability of something falling over and that's probably the biggest thing."*
>
> *Interviewer: so not so not so much an aggressive direct attack immediately and maybe?*
> *FF22: yeah, size it up and see what it's doing and if there is wind on it. It's got a pretty good potential to make a mess and move around pretty fast.*

Firefighters first line of approaching MPB fires was mitigating the tree hazard by use of experienced crews, mechanical equipment and aircraft. Bulldozers were used on several fires to create control lines. Feller bunchers were used on High Park to conduct a multi-division burnout operation adjacent to high MPB mortality lodgpole stands. Aircraft was also found to be very useful on most of the wildfires in the study. Retardant and water drops were used frequently. On the High Park Fire, aerial ignitions were used on MPB ridge tops while interagency (Type I) hotshot crews conducted burnouts from the bottom. Interagency hotshot crews were used and recommended in direct attack, burnout and snagging operations in several wildfires in the study.

> *"Interviewer: so you are using not only shot crews but local shot crews.*
> *FF11: we were not putting in the type two crews up in the mountain pine beetle. Also putting in the mountain pine beetle meant stuff in the IAP (incident action plan). But to have the superintendents up there, those folks that can cut those kinds of trees. This was big. Also have an ability to be empowered to pull out of there when the winds got to a certain point."*

Firefighters' recommended tactics generally remained unchanged between fires in non-beetle-killed and beetle-killed stands; MPB-affected trees were simply regarded as one more hazard that needed to be mitigated by firefighters during an incident. The tree-fall hazard was the greatest concern and firefighters recommended a more thorough tactical plan than instantaneous direct attack. Fire management teams on Fern Lake went through several sand tabling exercises to approach the wildfire with MPB, but also steep rugged remote terrain and downed logs in an area that had not burned in over 300 years. MPB affected trees was just one of many mitigation issues to engage in suppression. Because of so many hazards, management teams took a monitoring approach and used minimal ground troop engagement.

CHAPTER 4: DISCUSSION AND IMPLICATIONS

Expectations

Experience has been found to be an essential factor in hazardous situation response (Jeong and Brower 2008, Klein et. al. 1988, Landgren 2005, Putman 1995, Weick 1993). In comes as no surprise that firefighter trainings and command systems are experienced based models (Klein et al. 1988). Older and more qualified firefighters provide situational training based on their own experiences and experiences of others. The firefighters participating in this study had a wealth of situational experiences in neighboring lodgepole stands and on wildfires within the recent MPB outbreak.

Most expectations were based on personal experience and discussions with other firefighters while scientific literature had little impact. Recent surveys show scientific research to be utilized by fire management officers and ecologists but operational firefighters to a lesser extent (Wright 2010). Our results support the underutilization of scientific research among operational firefighters. Two main limiting factors that may explain why firefighters are underutilizing science are lack of time and experience (Wright 2010). During this interview process firefighter time was invaluable. Scheduling interviews was difficult because of time constraints. Most employees relied on technical reports to synthesize information rather than finding direct sources. Firefighters also explained how experience in the short term holds more robust value to fire behavior prediction then any simulation or model. Synthesized reports of research and case studies of observed fire behavior may be the best sources of outside information for fire behavior prediction in an operational setting.

Firefighters were unable to explain why the crown fire predictions between the two models in Simards' et al. 2011 diagram (Figure 2) are different. According to current reviews, one reason Simards' simulation differs from the hypothesized trends is because the model uses a reduced bulk density in the canopy but does not account for the lost needle in the surface fuel (Hicke et al. 2012, Moran and Cochran 2012,). The diagram is used to emphasize the variation in MPB fire behavior prediction within published literature. Since only one firefighter had seen this diagram or read the associated journal papers, answers during the interview process were primarily based on personal experiences and other outside information of MPB wildfires within the study. Since every wildfire within the study exhibited active crown fire in mostly red and mixed phases with limited ladder fuels, hypothesized trends of increased fire behavior logically made sense with the most respondents.

Observations compared to expectations

Because fire behavior prediction was largely based on experience, the majority of firefighters predicted active fire behavior because of past wildfires in similar non-post outbreak conditions and factored in a drier environment. However, firefighters were surprised because observations exceeded expectations. Fire behavior like increased spotting and faster crown transition was more prevalent than expected. Firefighters who predicted a wildfire with more surface fire did so because of previous wildfires in moderate conditions. In these situations, firefighters were often surprised by increased fire behavior on certain fires in moderate conditions. Firefighters still did not expect the increased fire behavior they were observing, although they assumed conditions would be dry. As previously explained, surprise develops from the gap between expectation and observation. Results conclude firefighters create expectations of fire behavior in beetle-kill fires and reduce surprises through their ongoing, accumulated experiences. Results support other studies of similar context (Klein 1988.)

Surprising fire behavior relevant to current research

The Simard et al. 2011 diagram was used as a tool to show the variation in current research. Similar to this variation, there was also a variation in prediction choice of fire behavior in post outbreak stands. Results of prediction were largely driven from the ample amount of condition variation between observations.

Firefighters who choose Simards' et al. 2011 simulation emphasized the need for wind and slope to achieve active crown fire - variables not explained in the diagram. Firefighters commented on reduced bulk density in mostly red and mixed phased canopies but also factored increased red needle and other surface fuel. However respondents concluded increased needle surface fuel would not generate enough intensity for active crown fire propagation without wind and slope as overriding factors. Respondents who choose neither prediction concluded that fire behavior in post-outbreak stands could be anything from creeping surface fire to active crown fire depending on fuel, weather and topography conditions.

Surprising observations of limited perimeter growth supports how specific conditions associated the fire environment can result in surface fire spread or active crown fire regardless of added tree mortality from MPB outbreaks. Lodgepole canopies in red phase may be more flammable from reduced fuel moisture content and chemical changes but limiting factors like low surface fire intensity and non-continuous fuel strata may override perimeter growth and active crown fire propagation (Hoffman et al. 2012, Jenkins et al. 2012, Jolly et al. 2012). Most firefighters compared MPB wildfires to similar fires in the same forest type and concluded that perimeter growth is still limited by fuel breaks, weather and topography.

Observations of increased spot fires relate to the increased amount of dry fuels in the post-outbreak canopy and availability and lofted in the convection column or transferred by wind flow (Jenkins et al. 2012, Jolly et al. 2012). Faster transition from surface to crown fuel results from changes in fuel, moisture and chemistry of canopy fuels (Jenkins et al. 2012, Jolly et al. 2012). The drier canopy strata would require less preheating and lower surface fire intensity to transition fire into the crown (Hoffman et al. 2012). Direct wind flow and fire movement up tree boles may explain crown fire with limited surface fuel strata. In lodgepole MPB red phase, canopy pre-heating time is reduced and requires lower surface fire intensity and lower surface fuel height for fire crown transition (Jolly et al 2012, Page et al. 2012). Drier tree boles may also assist in fire transition into the crown, a phenomenon not accurately accounted for in Van Wagner (1977) based crown fire models.

Firefighter observations within the study region and in other regions are consistent with predictions of increased fire behavior in the red phase (Hicke et al. 2013, Jenkins et al. 2013). Predictions of MPB influence having no effect or reduced fire behavior in other published literature, however, runs counter to firefighter observations within the study. (Klutsch et al. 2011, Kulakowski and Veblen 2007, Simard et al. 2011)

Dry standing dead lodgepole could perpetuate crown fire propagation for short bursts but empirical evidence is limited (Schoennagel et al. 2011). Limbs and bark dry enough potentially ignite to propagate crown fire in a mixed stand where there is green, red and grey MPB phases, considering basal area and stand density in a closed lodgepole stand. With limited observations active crown fire behavior in mixed MPB stands should be further investigated.

Most research is in consensus with expecting high intensity surface fire. The bigger question will be as these fires become more prevalent, what will be an effective approach to engaging fires with "jack straw" conditions in Colorado's and Wyoming's beetle-killed lodgepole pine forests (Jenkins et al. 2013)? Current research concludes that fire behavior prediction models under-predict crown fire behavior and are not designed for MPB stands (Cruz and Alexander 2010, Jenkins et al. 2012, Hoffman et al. 2012). Fire behavior prediction uses an either-or model of beetle-kill conditions: solely red-phase vs. solely grey phase. In reality, there's a mix; also, not always pure, even-aged lodgepole pine (e.g., Simard et al), but mixed ages and species complicate fuels characterization. Combining advances in fire behavior modeling, firefighter observations, and rigorous experimental fires in different MPB-affected forest conditions is necessary to improve knowledge and tactical decision-making.

Change in tactics

Our study provides examples how suppression tactics have changed to more indirect tactics because of increased fire behavior and falling tree hazards resulting from the MPB outbreak. Firefighters will need to adjust aggressive tactics and pay explicit attention to the higher risks associated with increased available fuel and tree fall. New strategies may result in larger fire sizes due to lack of direct attack and reliance on indirect perimeter backfiring, air support, and heavy machinery for ground support.

An illustrated example is the Fern Lake fire that burned in Rocky Mountain National Park in the December 2012, which was surprising given the weather and season. A combination of drought, substantial dead and down 1,000 hours fuels and the most recent MPB outbreak resulted in a 14,000 acre, 3-month event that carried through the winter – an event never recorded in Rocky Mountain National Park history. Fern Lake had several factors that contributed to observed fire behavior but could represent the next generation of wildfire in the most recent MPB outbreak as trees fall to the forest floor.

Study limitations

Retrospective sensemaking analysis is often used in tragedy fires (Church 2011, Larson 2003, Putman 1995, Weick 1993). Recalling information from the past unfortunately does not accurately describe environmental and fire conditions and falls short of empirical evidence. Retrospective accounts; however, provide more situational information than just studying post effects (Alexander and Thomas 2003). Firefighters were asked to recall fires up to three years from time interviewed and accurate fire behavior parameters were difficult to capture. Larger themes like the presence or absence of active crown fire, and moments of surprise were much easier to describe and incorporate into fire prediction models.

Future studies

Further research is needed to understand conditions firefighters are observing on MPB wildfires. Management of wildfires does not incorporate consistent data collection of fire behavior and conditions. Unless an injury or mortality has occurred most fire behavior information from a wildfire is rarely published. The cost of recorded observations and condition documentation is minimal compared to the cost of suppression. Protocols should be established within regional federal and state wildfire management plans to acquire certain information, not just fire behavior but also the conditions under which fire behavior is observed. Fire effect monitors and field observers, the operational position to collect this information, should be incorporated in every wildfire.

Scientific field experiments would be tremendously useful in fire behavior prediction but data collection is also fairly limited. Data could be entered into a national database and summarized to short reports and attached to incident management plans and other related documents. Information could be accessed from a multi-agency support system such as WFDS or LANDFIRE, but geared towards prescribed and wildfire information including observations of fire behavior and conditions. Scientific briefs (findings of published literature) could be stored by region, fuel type and conditions and utilized by managers and scientists and available to the general public. A more cataloged approach of wildfire information may improve information transfer between managers and scientists. This research emphasizes the value of on-the-ground observations to improve fire behavior prediction under certain conditions using a categorized case study approach.

Our study also brings up several questions relevant to fire management and fire research. Are current fire management plans adapted to these beetle-killed wildfires? Can scientists quantify the variation of conditions and fire behavior in which these fires occur? Are fire management protocols considering long-term goals of forest health or making decisions based on political and social consequences? Stakeholders agree there will be plenty of wildfires in the western United States in the short term. As wildfires get larger and fuel conditions steer further away from the historic range of variability, novel surprising fire behavior may persist. The more we can learn about fire behavior and associated conditions, the better-prepared lawmakers, fire managers and scientists will be to take appropriate action and adjust research accordingly.

LITERATURE CITED

Alexander, M.E., and D.A. Thomas. 2003. Wildland fire behavior case studies and analyses: value, approaches, and practical uses. *Fire Management Today* 63 (3):4-8.

Barton, M. A., K. M. Suttecliffe. 2009. Overcoming dysfunctional momentum: Organizational safety as a social achievement. *Human Relations* 62, 1327 Bigler C., D. Kulakowski, Thomas T. Veblen 2005. Multiple disturbance interactions and drought influence fire severity in rocky mountain subalpline forests. *Ecology* 86(11)

Byram, G.M. 1954. Atmospheric conditions relating to blowup fires. Station Paper No. 35. Asheville, NC: USDA Forest Service, Southeastern Forest Experiment Station.

Byron, E. 2011. Firefighters warn new fires may burn in mysterious ways. *Helena Independent Record*, May 5, 2011.

Chandler, C.C. 1976. Meteorological needs of fire danger and fire behavior, In: Baker, D.H. Foseberg, M. A., tech. coords. Proceeding of the Fourth National Conference on Fire and Forest Meteorology: Nov. 16-18:St. MO. Gen Tech. Rep. RM-32. Fort Collins, CO USDA Forest Service, Rocky Mountain Forest and Range Experiment Station:38-41

Church, S., F. Romero, I.Erskine, L. Evans, D. Camper, A. Pertrilli. 2011. Salt FireFacilitated learning analysis. USDA Forest Service. Wildland fire lessons learned Center. Available from http://wildfirelessons.net/documents/Salt_Fire_FLA.pdf

Cohn J. Patrica, M. S. Carroll. 2006. Evacuation behavior during wildfires: Results of the case studies, *West J. Appld. For*. 21(1):39-48

Hicke, J.A. and J.C. Jenkins. 2008. Mapping lodgepole pine stand structure susceptibility to mountain pine beetle attack across the western United States. Forest Ecology and Management 255(5-6):1536-1547.

Hicke J. A., M. C. Johnson, J. L. Hayes, H. K. Preisler. 2012. Effects of bark-beetle caused tree mortality on wildfire. *For. Eco. And Mgnt*. 271, 81-89

Hodgson, R.W. 2007. Emotions and sense making in disturbance: community adaptations to dangerous environments. *Human Ecology Review* 14 (2):233 242.

Hoffman C. M.,P. Morgan, W. Mell., R. Parsons, E. Strand, S. Cook. 2012. Surface fire intensity influences simulated crown fire behavior in lodgepole pine forests with recent mountain pine beetle-caused mortality. *For. Sci. 11-114*

Jenkins M. J. , J. B. Runyon, C. J. Fetttig, W. G. page and B. J. Bentz. 2013. Interactions Among the mountain pine beetle, fires, and fuels. *For. Sci. 60(x):000-000*

Jenkins M.J., W.G. Page, E.G. Herbertson, M.E. Alexander. 2012. Fuels and fire behavior dynamics in bark beetle-attacked forests in Western North America and implications for fire management. *For. Eco. and Mngt. 275,23-34*

Jenkins M.J., E. H. Hebertson, W. G. Page, C.A. Jorgeson. 2008. Bark beetles, fuels, fires and implications for forest management in the Intermountain West. *For. Eco. and Mngt. 254,16-34.*

Jolly M. W., R. A. Parsons, A. M. Hadlow, G. M. Cohn, S. S. McAllister, J. B. Popp, R. M. Hubbard, J. F. Popp. 2012. Relationships between moisture, chemistry, and ignition of Pinus contorta needles during the early stages of mountain pine beetle attack. *For. Eco. and Mngt.* 269, 52-59

Kaufmann M.R., G.H. Aplet, M. Babler, W.L. Baker, B. Bentz, M. Harrington, B.C. Hawkes, L. Stroh Huckaby, M.J. Jenkins, D.M. Kashian, R.E. Keane, D. Kulakowski, C. McHugh, J. Negron, J. Popp, W.H. Romme, T. Schoennagel, W. Shepperd, F.W. Smith, E. Kennedy Sutherland, D. Tinker, and T.T. Veblen. 2008. The status of our scientific understanding of lodgepole pine and mountain pine beetles – a focus on forest ecology and fire behavior. GFI technical report 2008-2. The Nature Conservancy, Arlington, VA.]

Klein, G.A., R. Calderwood and A. Clinton-Cirocco. 1988. Rapid Decision Making on the Fire Ground. *Research Institute for the Behavioral Science*

Klutch G. J., M.A. Battaglia, D. R. West, S, L.Costello and J.F. Negrón. Evaluating potential fire behavior in lodgepole pine-dominated forests after a mountain pine beetle Epidemic in North-Central Colorado. 2011. *West. J. Appl. For. 26(3)*

Kulakowski D., D. Jarvis. 2011. The influence of mountain pine beetle outbreaks and drought on severe wildfires in northwestern Colorado and southern Wyoming: A look at the past century. *Forest Ecology and Management*. 262

Landgren, J. 2005. Supporting fire crew sensemaking enroute to incidents, I*nt J. EmergancyManagement*, Vol. 2, No. 3, pp. 176-188

Larson, G.S. 2003. A "worldview" of disaster: organizational sensemaking in a wildland firefighting tragedy. *American Communication Journal* 6 (2):Online (http://www1.appstate.edu/orgs/acjournal/holdings/vol6/iss2/articles/lason.pdf)

Lindlof T.R. and B.C. Taylor. 2011. Qualitative Communication Research Methods. Thousands Oaks, CA: Sage Publications

Moran J. and M. A. Cochrane. 2012. Do mountain pine beetle outbreaks change the probability of active crown fire in lodgepole forests? Comment. *Ecology* 93(4) 2012, pp 939-941

Safranyik, A.L. Carroll,J. Régnière, D.W. Langor, W.G. Riel, T.L. Shore, B.Peter, B.J. Cooke, V.G. Nealis, S.W. Talyor. 2010. Potential for range expansion of mountain pine beetle into the boreal forest of North America. *Can Entomol.* 142 415-44

Schoennagel T, T.T. Veblen, J.F.Negron, J. M. Smith. 2012. Effects of mountain pine beetle on fuels and expected fire behavior in lodgepole pine forests, Colorado, USA. PLoS ONE 7(1): e30002.doi:10.1371/journal.pone.0030002

Scott C. W., A. Tretheway. 2008. Organizational discourse and appraisal of occupational hazards: Interpretive repertoires, heedful interrelating, and identity at work. *Journal of Applied Communication Research* 36, 3, 298-317

Scott, J. and P.J. Carrington (Eds.). 2011. The SAGE handbook of social network analysis. SAGE publications.

Page, W.G., M. E. Alexander, M.J. Jenkins. 2013. Wildfire resistance to control in mountain pine beetle attacked lodgepole pine forests. *Forest Ecology Chronicle* 86 (6)

Page, W. G. and M. J. Jenkins and J.B. Runyon. 2012. Mountain pine beetle attack alters the chemistry and flammability of lodgepole pine foilage. *Can. J. For. Res.* 42:1631-164

Page, W., and M.J. Jenkins. 2007. Predicted fire behavior in selected mountain pine beetle-infested lodgepole pine. *Forest Science* 53 (6):662-673.

Phillmore, J. and L. Goodson. 2004. Qualitative research in Tourism: Ontologies, Epistemologies and Methodologies (Contemporary Geographies of Leisure, Tourism and Mobility). Taylor and Francis e-library

Putnam, T. 1995. The collapse of decisionmaking and organizational structure on Storm King Mountain. *Wildfire* 4 (2):40-45.

Simard, M., W.H. Romme, J.M. Griffin, and M.G. Turner. 2011. Do mountain beetle outbreaks change the probability of active crown fire in lodgepole pine forests? *Ecological Monographs* 81 (1):3-24.

Talyor, J.R. 1993. Rethinking the thoery of organizatioanl communication: How to read an organization. Norwood, NJ: Ablex Publishing

Thomas, D. 1994. A case for fire behavior case studies. Wildfire. 3(3)45,47

Turner, J.A.; J. W. Lillywhite, Z. Pieslak, 1961 Forecasting for fire services. Tech. Note No. 42 Geneva, Switzerland: World Meteorological Organization: 12

United States Forest Service. 2012. Region 2: Fire operations guidance in bark beetle stands. Arapahoe-Roosevelt/Rocky Mountain National park briefing packet.

University of Northern British Columbia. 2008. Mountain pine beetle: from lessons learned to community-based solutions. Conference procedings.

Van Wagner, C.E. 1977. Conditions for the start and speread of crown fire. *Can J. For Res.* 7:23-34

Weick, K. 1993. The collapse of sensemaking in organizations: the Mann Gulch disaster. *Administrative Science Quarterly* 38 (4):628-652.

Weick, K., 1995. Sensemaking in organizations. Thousand Oaks, CA: Sage Publications

Weick, K., K.K. Sutcliffe, D. Obstfeld. 2005. Organizing and the Process of Sensemaking. *Organisation Science*, 16, 409-421

Wright, V. 2010. Influences to the suceess of fire science delivery: Perspectives of fire/fuels science users. Final Report to the Joint Fire Science Program. Project#04-4-2-0

APPENDIX 1

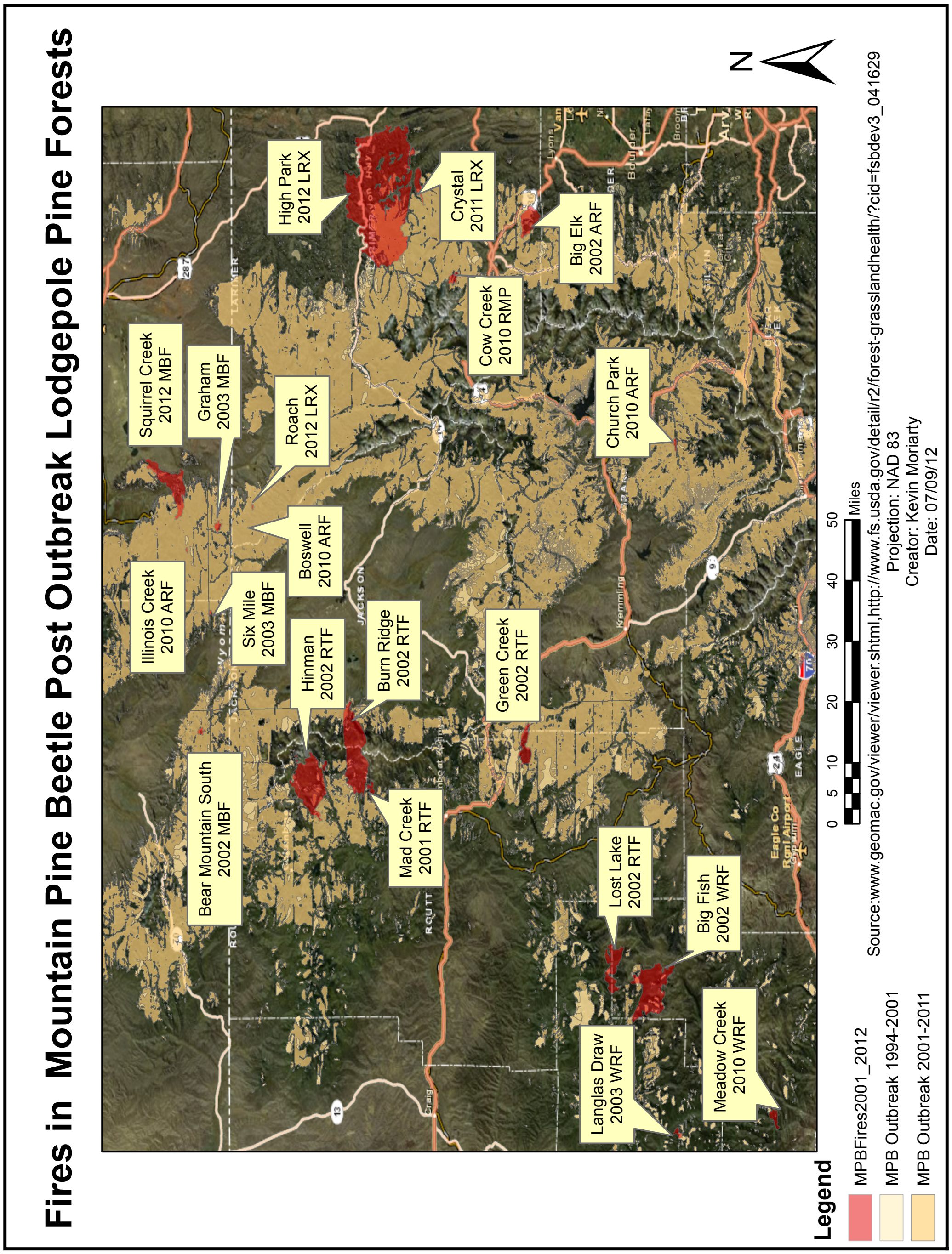

Figure 2: Mountain pine beetle fires in northern Colorado and southern Wyoming

APPENDIX 2

Colorado State University

INTERVIEW RESPONDENT COVER LETTER

Department of Forest and Rangeland Stewardship
Fort Collins, Colorado 80523-1472 USA
Telephone (970) 491-6911
FAX (970) 491-6754
http://welcome.warnercnr.colostate.edu/frws-home/index.php

[DATE]

Dear *[NAME]*:

The mountain pine beetle infestation affecting lodgepole pine forests in Colorado and Wyoming raise concerns over new kinds of unexpected fire behavior. These concerns affect how managers plan for and respond to fires burning in beetle-killed forests. Current scientific research relies on computer models to predict fire behavior and have produced conflicting, uncertain results. At the same time, fire managers and firefighters have been documented as observing surprising fire behavior.

We are conducting a research project to inventory and document the observations of fire operations personnel of wildfires burning in beetle-killed lodgepole pine forests in Colorado and Wyoming. This research will focus on the fire behavior fire managers and firefighters expected to observe and the actual observation. We are also interested in how those expectations and observation are communicated among the wildland fire community in order to understand how managers prepare for and respond to beetle-killed forest fires.

You have been identified as a potential participant in this study because of your position relating to wildland fire management and your direct experience in beetle-killed forest fires based on recommendations from your unit's Fire Management Officer and Incident Commanders. We are asking you to participate in a face-to-face interview to share your observations and knowledge. This interview is expected to take no more than 90 minutes of your time.

By documenting the observations of fire managers and fire operations personnel of beetle-kill forest fires, we hope to contribute to a better understanding and explanation about the conditions and factors that contribute to surprising fire behavior in beetle-killed forest stands. In turn, we hope that this information helps managers better plan for and respond to beetle-kill forest fires in ways that protect firefighter safety, public safety, and natural resource values.

We will be following up this letter with an e-mail in within the next five business days to gauge your willingness to participate. Should you voluntarily wish to participate, we will schedule an in-person interview that fits your schedule and send you the interview questions in advance so you have time to prepare your responses.

All survey responses will be kept anonymous and all identifying characteristics will be removed to safeguard your anonymity. This project complies with human research protection guidelines set out by the Regulatory Compliance Office at Colorado State University. For more information on these guidelines, contact Janell Barker, Human Research Administrator at 970-491-1655.

We would greatly appreciate your participation in this project. This is an opportunity for you to express your perspectives on beetle-kill forest fires.

If you have any questions, please contact Kevin Moriarty at knmoriarty@hotmail.com or 415-450-5673 or Dr. Tony Cheng at tony.cheng@colostate.edu or 970-491-1900. If you have any questions about your rights as a volunteer in this research, you may contact Janell Barker, Human Research Administrator, at 970-491-1655.

Thank you for your time and consideration in participating in this project.

Sincerely,

Tony Cheng
Associate Professor

Kevin Moriarty
M.S. student

NON-USFS RESPONDENT COVER LETTER

Department of Forest and Rangeland Stewardship
Fort Collins, Colorado 80523-1472 USA
Telephone (970) 491-6911
FAX (970) 491-6754
http://welcome.warnercnr.colostate.edu/frws-home/index.php

[DATE]

Dear *[NAME]*:

In planning for the future of the National Forests, the USDA Forest Service (USFS) seeks to reach forest management objectives while meeting community needs. Stewardship end results contracting, or stewardship contracting, is a recently established voluntary mechanism for the USFS to provide enhanced opportunities for resource management and community development.

We are conducting a research project to understand the role of collaboration in reaching forest management and community objectives with regard to U.S. Forest Service stewardship contracts and agreements. This research will focus on the factors influencing the varying levels of collaboration in stewardship contracting efforts and the associated outcomes. It will address the following questions: 1) To what extent does stewardship contracting reach its intended policy goal of meeting both forest management objectives and community needs? 2) What is the role of collaboration in meeting this policy goal? 3) And what factors influence the use of collaboration in stewardship contracting?

You were referred to us by *(NAME OF USFS RESPONDENT/ OTHER)* because of your involvement with *(Name of Stewardship Contract)* on the *(NATIONAL FOREST).* We would like you to participate in an internet-based survey to share your experiences with this stewardship contract/ agreement. This survey is expected to take no more than 30 minutes of your time. The survey will ask questions about your experience and opinions on USDA Forest Service stewardship contracts/ agreements. You will also be asked to voluntarily refer other individuals who you think should be contacted as part of this research because of their involvement with this stewardship contract/ agreement.

By identifying the outcomes associated with varying levels of collaboration and the factors influencing differing levels of collaboration, this research intends to help USFS officials, congressional representatives, forest and community practitioners better understand the implementation of stewardship contracting and the role of collaboration in reaching forest and community objectives.

We will be sending an email with a link to the internet-based survey to you within the next five business days. You will be able to access this link for two weeks, until *(DATE)*. You will also be able to save your responses and return to edit and/or complete the survey if you are unable to complete it in one session.

If you are unable or unwilling to participate in this research, please contact Kathie Mattor at katherine.mattor@colostate.edu or 970-402-1206. Otherwise we will be sending the survey link and email reminders to you. If you are unable to participate we request a referral of an alternate individual associated with this stewardship contract/ agreement.

All survey responses will be kept anonymous and all identifying characteristics will be removed to safeguard your anonymity. This project complies with human research protection guidelines set out by the Regulatory Compliance Office at Colorado State University. For more information on these guidelines, contact Janell Barker, Human Research Administrator at 970-491-1655.

We would greatly appreciate your participation in this project. This is an opportunity for you to express your perspectives on collaboration and stewardship contracting.

If you have any questions, please contact Kathie Mattor at katherine.mattor@colostate.edu or 970-402-1206 or Dr. Tony Cheng at chengt@warnercnr.colostate.edu or 970-491-1900. If you have any questions about your rights as a volunteer in this research, you may contact Janell Barker, Human Research Administrator, at 970-491-1655.

Thank you for your time and consideration in participating in this project.

Sincerely,

Dr. Antony Cheng	Katherine Mattor, M.S.
Associate Professor	Ph.D. Candidate

APPENDIX 3

Figure 3: Interview Question Guide

Ice Breaker Questions
What is your background in wildfire? How did you get involved?
What was your position on this wildfire?

Fire Expectations
What do you expect in terms of fire behavior before you engaged this wildfire?
What did you expect in terms of fire organization and fire personnel?
What was going through your mind when you found out the fire was in beetle kill?
Where did you get your information on fire behavior in MPB forests?

Fire Observations
What were your observations in terms of fire behavior (rate of spread, flame length, flame height (explain)?
How much MPB mortality was there? Was it in the red phase or gray phase?
Anything unusual or surprising that you witnessed?
Have you seen fire behavior like this before?
Anything else?

Sense-making
What was going through your head when you had your initial observation?
Did you reference your observations with past experiences?
Did you feel comfortable that you could engage the fire?
How did you assess the situation? What factors did you incorporate?
What was there urgency to make decisions?
How was everyone else on the fire line making sense of the situation? Was there assessment congruent with yours?

Decision Making
What major decisions did you make after a size up? (direct attack, indirect attack, burnout)
What was the decision based on?
Was the decision congruent among forces?
What influence did your decision have on the fire behavior?
What influence did your decision have on fire personnel?

Big Picture
What else about the fire was important?
What else do fire mangers need to know that you learned from this fire?
What do you learn that you can use in the future?