HUMAN IMPACTS TO FIRE REGIME IN INTERIOR ALASKA

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ABSTRACT

A thorough analysis of human impacts on interior Alaska's fire regime demonstrates that human activities have effects in populated areas. Two approaches were used to determine impacts: I examined three regions with very different populations, and also one large region to analyze suppression, ignition, and vegetation interactions. The Fairbanks Region, with a large human population and an extensive road system, differs from two other regions with low human populations and few roads. In the Fairbanks Region, humans have impacted fire regime by causing more fires in certain fuel types and doubling the length of the fire season. The Fairbanks Region, with a higher level of suppression than the other two regions, has less area of land burn, even after controlling for fuel type and a higher number of human ignitions. In areas designated for high protection, there is less area burned and more human caused starts. For interior Alaska as a whole, human ignitions and suppression have only a minor effect on fire regime, and climate strongly influences the total area burned. However, in populated areas and areas designated for high protection, human ignitions account for most of the area burned, and less area burns overall due to suppression.
**CONTENTS**

Signature Page ................................................................................................................................i
Title Page ........................................................................................................................................ii
Abstract .........................................................................................................................................iii
Table of Contents .........................................................................................................................iv
List of Figures ...............................................................................................................................vi
List of Tables ................................................................................................................................ix
Acknowledgments .........................................................................................................................x
Introduction .....................................................................................................................................1
    Human Impacts to Fire Regime in Interior Alaska .................................................................1

Chapter 1: A Comparison of Fire Regimes in Three Regions of Interior Alaska .................7
    Abstract ....................................................................................................................................7
    Introduction ............................................................................................................................7
    Methods ...................................................................................................................................8
    Results ...................................................................................................................................14
    Discussion ..............................................................................................................................21
    Figures ...................................................................................................................................28
    Tables ...................................................................................................................................47
    Literature Cited .......................................................................................................................48

Chapter 2: Interactions among Fuels, Suppression, and Ignition in Interior Alaska .......52
    Abstract ....................................................................................................................................52
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>52</td>
</tr>
<tr>
<td>Methods</td>
<td>55</td>
</tr>
<tr>
<td>Results</td>
<td>57</td>
</tr>
<tr>
<td>Fuel-type effects on fire number and size</td>
<td>57</td>
</tr>
<tr>
<td>Fire-management effects on fire number and size</td>
<td>59</td>
</tr>
<tr>
<td>Seasonality effects on fire number and size</td>
<td>61</td>
</tr>
<tr>
<td>Effects on area burned</td>
<td>62</td>
</tr>
<tr>
<td>Discussion</td>
<td>63</td>
</tr>
<tr>
<td>Effects of fuel type</td>
<td>63</td>
</tr>
<tr>
<td>Effects of seasonality</td>
<td>66</td>
</tr>
<tr>
<td>Effects of human activities</td>
<td>67</td>
</tr>
<tr>
<td>Figures</td>
<td>69</td>
</tr>
<tr>
<td>Literature Cited</td>
<td>80</td>
</tr>
<tr>
<td>Conclusions</td>
<td>84</td>
</tr>
<tr>
<td>Ecological and Societal Consequences of Human Impacts on Fire Regime</td>
<td>84</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

1.1 Proportional distribution of management options in each study region .............28
1.2 Map of fires in Alaska from 1950-2000, and the three study regions and the large Interior Region ................................................................................................................29
1.3 Total area burned in the three study regions from 1990-1999 and from 1950-2000 ..................................................................................................................................30
1.4 Proportion of fires caused by human activity in the three study regions from 1990-1999 and from 1950-2000 ................................................................................................................31
1.5 Total number of fires per month per million ha that were caused by lightning or by human activities in the three study regions from 1950-2000 ........................................32
1.6 Percentage of the total region area burned per month from 1950-2000 due to lightning or human activities in the three study regions .................................................33
1.7 Frequency distribution of final sizes of fires caused by lightning or human activities in the three study regions from 1990-1999 ..............................................................34
1.8 Compositional cover of the major vegetation types present in the Interior Region (8a. 1991), and the composition of the vegetation that actually burned (8b. 1992-2001) ..................................................................................................................................35
1.9 The proportion of each vegetation type in the Interior Region that burned between 1992 and 2001 .........................................................................................................................36
1.10 Vegetation cover type for three regions (1991) .....................................................37
1.11 Proportion of each vegetation type burned within the three regions (1992-2001)................................................................................................................................38
1.12 Compositional cover of the major fuel types present in the Interior Region (12a. 1991), and the composition of the fuels that actually burned (12b. 1992-2001)................................................................................................................................39
1.13 The proportion of each fuel type in the Interior Region that burned between 1992 and 2001..........................................................................................................................40
1.14 Composition of major fuel types in the three regions in 1991.........................41
1.15 Proportion of each fuel type burned within the three regions (1992-2001)........42
1.16 Frequency distribution of June-July precipitation (1.16a) and temperature (1.16b) observed in 1-km pixels in three regions.................................................................43
1.17 Average June-July temperature from GIS data compared to 1950-2000 temperatures recorded from RAWS weather stations in three regions ..................44
1.18 Relationship between average June temperature and percentage of the study region burned in each year from 1950-2000 in three regions.........................45
1.19 Relationship between initial attack size and final fire size...............................46

2.1 Large and small fires within each management option in interior Alaska (1986-2001).........................................................................................................................69
2.2 Total number of lightning- and human-caused final fire size distribution within fuel type (1992-2001)..................................................................................................................70
2.3 Lightning- and human-caused final fire size distribution per unit area within fuel type (1992-2001)..................................................................................................................71
2.4 Frequency distributions (total number of fires) of final fire size in relation to management option (1992-2001) .................................................................72

2.5 Frequency distributions (fires/million ha) of final fire size in relation to management option (1992-2001) .................................................................73

2.6 Frequency distribution (fires/million ha) of final size of lightning-caused fires in the Boreal Spruce fuel type: A comparison of Limited versus Full and Critical management options (1986-2001) .................................................................74

2.7 Proportion of total area burned by lightning-caused fires of differing final sizes in the Boreal Spruce fuel type: A comparison of Limited versus Full and Critical management options (1986-2001) .................................................................75

2.8 Frequency distribution (number of fires) of final sizes of fires caused by lightning or human activities occurring during each month of the fire season (1950-2001) ..............................................................................................................76

2.9 Total hectares burned per month due to lightning- and human-caused fires (1950-2001) ..............................................................................................................77

2.10 Proportion of each fuel type burned within each management option (1992-2001) ..............................................................................................................78

2.11 Total hectares burned per fuel type within each management option (1992-2001) ..............................................................................................................79
LIST OF TABLES

1. Area, population density, and fire statistics of study regions (1990-1999).............47
2. Fire statistics of study regions (1950-2000).................................................................47
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INTRODUCTION

There is increasing public and scientific concern that humans are modifying the environment around them by changing species composition (Chapin et al. 2000) and land cover (Turner et al. 1990) to an extent that this affects even regional climate (Pielke et al. 2002). Most studies of human impacts have focused on areas where human populations are large, and human impacts are obvious. In this study I examine human impacts on the fire regime of interior Alaska. Alaska has the lowest human population density of any state in the United States and is thought to have a fire regime that is not strongly affected by people (Kasischke et al. 2000, Kasischke et al. In press). There are vast areas in interior Alaska with few or no roads and human population densities similar to those occurring 200 years ago. In contrast, the Fairbanks region has more than 95% of the population and road system of interior Alaska. This contrast enabled me to compare human impacts on the fire regime among areas that differed substantially in population density and road access.

Wildfire is the dominant form of disturbance in the boreal forest of interior Alaska. The fire regime of this region is thought to be determined primarily by climate and vegetation (Viereck 1973, Kasischke et al. in press). Mountain ranges to the north and south block marine moisture sources, so interior Alaska has a continental climate with hot dry summers and low relative humidity (Mock et al. 1998, Fleming et al. 2000, Hinzman et al. in press). This climate is characterized by high summer temperatures with little night cooling, long periods with minimal precipitation, and intensive convection.
producing frequent thunderstorms that provide a natural source of ignition (Dissing and Verbyla 2003). Together these factors contribute to a high frequency of fires in interior Alaska (Kasischke et al. In press).

The Canadian Forest Fire Danger Rating System has classified North American boreal vegetation into fuel classes that differ in fire probability. The broad types are Boreal Spruce (C2), Mixed Hardwood/Spruce (M1/M2), Open Tundra, Shrub/Grass (O1a/O1b), and Boreal Lichen (C1) (National Interagency Fire Center [NIFC] 1992, Van Wagner et al. 1992). About 40% of interior Alaska consists of broad valleys and rolling hills with large areas of continuous black spruce (*Picea mariana*) forest with an understory of feather mosses and lichens (Yarie and Billings 2002). The Boreal Spruce (C1) fuel type is extremely flammable, dries quickly in response to low humidity, and support extensive fire spread (Viereck 1973, Yarie 1981, Johnson 1992). The Canadian Forest Fire Danger Rating System ranks this as one of the most fire-prone fuel types for several reasons (Van Wagner et al. 1992, Johnson 1992, NIFC 1992, Anderson 1982). The high resin content of black spruce and understory evergreens supports burning at relative humidities up to 30%. Once ignited, fire spreads readily along the ground through the moss, lichen and evergreen shrubs. Fire also moves directly into the canopy which is continuous (a ladder fuel) from the ground surface to the crown. The burning of resinous cones in the crown produces firebrands that create spot fires, allowing the fire to cross vegetation and water barriers and to spread rapidly during periods of severe fire weather. Even during rainy periods, the thick organic layer can support a smoldering fire for weeks, which can then spread rapidly as soon as the relative humidity decreases. For
all of these reasons, the Boreal Spruce (C2) fuel type produces fires that can burn for weeks, months or even over winter in peat mounds or berm piles from land clearing and trail construction.

Mixed Hardwood/Spruce fuel types, including white spruce (*Picea glauca*), poplar (*Populus balsamifera*), birch (*Betula papyrifera*), and aspen (*Populus tremuloides*) (classified as M1[before green-up] or M2[after green-up]), also burn but may be less prone to extensive fires because they are less homogeneous on the landscape, are less flammable during the main fire season, have a thinner soil organic mat to support smoldering, and lack the ladder fuels that allow fire to spread to the canopy (Van Wagner et al. 1992, NIFC 1992, Anderson 1982). However, these forests are particularly prone to human-caused fires in spring before the lightning season, when the grass litter of the understory is dry enough to burn and spread fire readily. In addition, nearly all interior Alaskan vegetation will burn during severe fire years, which account for most of the area burned (Kasischke et al. 2002).

The third extensive fuel type in interior Alaska consists of open ecosystems such as Open Tundra (O1a), and Shrub/Grass (O1b) fuel types (NIFC 1992, Van Wagner et al. 1992). Wind readily penetrates to the ground layer of these treeless (or nearly treeless) vegetation types (McFadden et al. 1998), which can dry rapidly enough to support fire spread through shrubs, grasses, mosses and lichens. These are termed 20-minute fuels because they burn readily after drying for only 20 minutes (NIFC 1992, Anderson 1982). The major exception is tundra above 1000 m elevation, which has insufficient fuel and remains too wet to carry fire. This fuel type is also prone to early season human-caused
fires, where old fields, now covered in grass and shrubs, ignite and spread through dry grasses and shrubs.

The Boreal Lichen (C1) fuel type consists of open park-like black spruce with well drained soils. There is continuous ground-dwelling lichen with an organic layer that is shallow or absent. This Fuel type is less likely to have extensive fires because of limited ground and ladder fuels available. The shallow soil organic layer prevents fires from persisting within the ground layer during rainy periods, reducing the likelihood of long-standing fires that continue burning after rains have stopped and ground fuels have dried.

In summary, most interior Alaskan vegetation types can burn, given the right circumstances, but they differ in the range of climatic conditions and seasons in which they are most fire-prone.

In the 1980’s, Alaska’s fire-prone boreal forest was classified into four management options (Roessler 1997, Gotholdt 1998). There are Limited, Modified, Full, and Critical management options, ranging from monitoring a Limited fire, to taking immediate action on a high-priority Critical fire, where hundreds of thousands of dollars can be spent in a few days to stop or contain the fire. Since the top priority in suppressing wildfire is the protection of human life and property, these management options are distributed in patterns that reflect human settlement. About 1% of Alaska’s land is under the Critical management option, 16% under Full, 16% under Modified and 60% under Limited management option (http://agdc.usgs.gov/data/blm).
The general pattern consists of land designated as Critical or Full located around human settlements. Usually Critical and Full lands are surrounded by a buffer of land classified as Modified. Fires on Modified land may or may not be fought, depending on resource availability and threats to human life and property. After July 13th of each year all the Modified land is usually converted to the Limited classification. However, in dry years the date of reclassification may be postponed. Limited suppression lands are located in areas with little or no settlement. Most of the fires on Limited lands are only monitored. There may be suppression in the form of cabin protection, in which firefighters burn fuels around the cabin but otherwise let the fire continue on its natural course (Roessler 1997, Gotholdt 1998).

Many factors can affect the fire size distribution of a region, the percentage of land burned, and the seasonality of fire. These factors include human suppression, human ignitions, vegetation composition, and weather. In order to improve our understanding of the possible impacts of these variables on landscape patterns of burning, I compared these variables and their relationship to fire size distribution, percentage of land burned, and seasonality of fire regimes in three large regions of interior Alaska. Several regression models were utilized in order to better understand the relationship between percent of land burned and air temperature, with a focus on how humans may affect that relationship.

In this thesis, I use two approaches to analyze the impact of people on the fire regime of interior Alaska. In chapter 1, I compare a densely populated region (the city of Fairbanks and the surrounding road system) with two sparsely populated regions (Galena
and Yukon Basin). These three regions are then compared with a large region that represents most of interior Alaska and includes the three smaller regions. These regional comparisons allow an evaluation of the overall impact of human activities on the fire regime of interior Alaska. These regions differ, however, in many properties, including vegetation and the extent to which fire suppression is applied, making it difficult to assess the relative importance of fire, fuel type, human ignitions, and fire suppression in explaining regional variation in fire regime. In chapter 2, therefore, I analyze the fire regime of interior Alaska separately for each 1 km pixel to explore the interactions among human ignition, fuel type, and suppression policy. The general conclusion section is a brief summary of human impact on the fire regime of interior Alaska and its implications for Alaskan residents and fire managers.
CHAPTER 1: A Comparison of Fire Regimes in Three Regions of Interior Alaska.

Abstract

A thorough analysis of human impacts on interior Alaska’s fire regime demonstrates that human activities have a large effect on fire regime in areas occupied by people. The Fairbanks Region, which has a large human population with road influences, differs from two other regions with low human populations and only local roads. Alaska’s land is separated into four management options designated for different levels of protection: Critical, Full, Modified and Limited, going from high level of protection to low protection. In the Fairbanks Region, humans have impacted the fire regime by causing more fires in certain fuel types and doubling the length of the fire season. Despite the increased number of fires in the Fairbanks Region, much of the Fairbanks Region receives a high level of suppression. Therefore, less area of land burns in the Fairbanks Region, even after controlling for fuel type. For Alaska as a whole, human ignitions and suppression have only a minor effect on fire regime, and climate strongly influences the total area burned. However, in areas where people live, human ignitions account for most of the area burned, and climate has no significant effect on area burned.

Introduction

Although human activities may affect regional fire regime, there has not been a thorough analysis of the effects of human activities on the fire regime of interior Alaska.
In this chapter I explore the direct human impacts, such as ignitions and suppression, on interior Alaskan fire regimes by comparing three areas that differ in population density and road access. Questions of importance in this study are: How do people influence the frequency of ignitions? How do ignitions and fire suppression interact to influence the fire regime? How effective are suppression efforts in stopping or controlling the spread of fires? Part of the answers to these questions lies in understanding human societies and decision-making processes that influence the ignition and suppression of fires. I also consider some indirect human impacts mediated by historical changes in land use.

**Methods**

I selected three regions of interior Alaska that differed substantially in population density, but had relatively similar climate and vegetation. One region (the Fairbanks Region) is the only region in interior Alaska with a large population (>55,570 people). The other two regions (Galena and Yukon Basin) have small populations (1,450 and 2,366 people, respectively). I also selected a mega-region that included most of interior Alaska, including all three smaller regions. Examination of this mega-region provided an overall view of the fire regime in interior Alaska. I chose the Yukon Basin Region (11,473,010 ha) by selecting the Tanana Fire Management Zone, then removing the upper part of the zone below Arctic Village, which consists mainly of rocky tundra in the Brooks Range with almost no fire activity. The Galena Region (12,810,214 ha) was a rectangle centered on Galena with approximately the same area as the Yukon Basin
Region. The Fairbanks Region (6,444,503 ha) was the smallest rectangle I could define that included all of the most highly populated areas and the connecting road network. This region was about half the size of the other two regions but had 50-fold higher human population density (Table 1). Larger regions for the Galena and Yukon Basin Regions were used in order to have adequate sample sizes for some of the analyses. Although these three regions differ in size, this does not impact the analytical results, which are all expressed as percentage of total land area. Together, these three regions account for 35% of the area in interior Alaska. Regions centered in the Galena area and the upper Yukon Basin reflect a relatively natural fire regime where human influences are largely localized around villages. In these regions there are no roads extending beyond the villages.

Alaskan lands are classified into four fire management options. These are “Full” and “Critical” lands, where fires are attacked as soon as possible; “Modified” lands, where suppression is applied only during the time of greatest fire danger (typically before July 13); and Limited lands, where fires are monitored but seldom suppressed (General Introduction, http://agdc.usgs.gov/data/blm). The Fairbanks Region has twice as large a proportion of land classified under the Full, Critical, and Modified management options as do the other two regions (Fig. 1.1). Most of the Yukon Basin and Galena Regions are under Limited protection, with Full protection only around the villages and along rivers where there are individually owned Native allotments.

I compared fire history data for these three regions from 1990 to 1999. I restricted the analyses to this 10-year time period to avoid complications associated with changes in management options and fire detection efficiency that occur over longer time
intervals. The management options were stabilized in 1991 with the establishment of the Alaska Wildland Fire Management Plan (Roessler 1997). I also included some analysis of the entire fire record (1950 to 2000) to determine whether regional differences observed during the decade of intensive study were representative of the longer fire record. I have less confidence in the absolute values of fire statistics in earlier portions of the fire record because of lower detection efficiency, less accurate mapping of fire perimeters, and periods of missing data (Murphy et al. 2000). Relative differences among regions should, however, still be valid.

The Geographic Information System (GIS) fire scar database (http://agdc.usgs.gov/data/blm) contains only fires larger than 400 hectares from 1950-1986 and fires larger than 40 hectares from 1987 to 2001. For all analyses I used a combination of the tabulated database of all fires (including smaller ones) from the Alaska Fire Service and the GIS database in order to include as many of the recorded fires as possible.

Fire statistics were obtained for these three regions from the tabulated wildland fire database for Alaska maintained by the Alaska Fire Service. This database contains data on all fires that occurred in these areas since 1950, including their sizes at initial attack, whether they were fought, the final fire size, the presumed cause of the fire (lightning or human), and the management option for the land where the fire started. There are several limitations to this fire history record. The fires represented by the record are only the ones that were detected, and fires may be detected less efficiently in remote areas than in the more traveled areas. Also, the record only includes fires that
were still burning when first detected. The fires that had burned out before detection are left out of the record. Both of these facts would result in a lower representation of small fires in more remote areas. These small fires would have very little impact on analysis of area burned.

Another limitation of the fire history database is that the perimeter of the fire is only an estimate of area burned, since most fires have green islands and fingers of unburned vegetation along the outside perimeter. The actual area burned has not been measured or analyzed here. However, if fires from all regions are mapped in the same way, this comparison among regions should be meaningful.

Since 1981 the location and timing of lightning strikes have been monitored by triangulation from at least 2 ground-based lightning detector sensors in interior Alaska (Dissing and Verbyla 2003). Fires are assumed to be caused by people when no lightning strikes are recorded at the fire location for up to approximately 5 days prior to first detection of the fire or if there is good evidence of human influence. Location is also important in classifying the cause of fire because, if the fire is far from the road or river system, it is most likely assumed to be lightning-caused, and, if it is on the road or river system, it is more likely to examined for evidence of human influences. There were no lightning detector sensors prior to 1981, so the cause of fires was assumed to be lightning unless there was evidence of human influences observed. Fires in remote areas are usually recorded only if seen by aircraft. If the lightning-strike network indicates a large number of lightning strikes in an area during the prime fire season, detection planes fly
the area to check for fires. However, in remote areas small fires are less likely to be detected.

The start date recorded for a fire is the date of its discovery even if the fire began burning several days previously. This could affect the results because fires are likely to be discovered later in remote areas than in more traveled areas. However since the analysis is integrated over a monthly time period rather than short intervals, the comparisons among regions should not be strongly affected.

Other GIS data were obtained from the Wildland Fire Dataset for Alaska maintained by the Bureau of Land Management, Alaska Fire Service (http://agdc.usgs.gov/data/blm). This database includes maps of management options and fire scars. Vegetation cover and fuel type data were obtained from the Forest Health Monitoring Clearinghouse website, where Fleming (1997) developed a classification using the phenology of a vegetation index (AVHRR/NDVI) collected during the 1991 growing season. I used Arc View and Fleming’s 1-km resolution vegetation map, derived from the AVHRR data, to determine the proportion of major vegetation types in each region. I compared the vegetation available to burn with the area of each vegetation type that actually burned for 1992-2001, i.e., the decade after 1991 imagery was collected, to develop the map.

The statewide vegetation map was converted to four different fire fuel types by the Alaska Fire Service (R. Burgan pers. comm.), Boreal Spruce (C2), Mixed Hardwood/Spruce (M1/M2), Open Tundra, Shrub/Grass (O1a/O1b) and Boreal Lichen (C1) (http://agdc.usgs.gov/data/projects/fhm/#P). I compared the area of each fuel type
that burned from 1992-2001 with the area available to burn, as described above for vegetation.

Climatic data for the three regions were obtained from two sources: Remote Automated Weather Stations (RAWS) and maps of the average monthly climate of Alaska (Fleming et al. 2000). Data from three to six RAWS weather stations within each region were used to calculate the average June temperature for each year since 1950; however for later years data were available for only some of the stations within a region. Figure 1.2 shows the locations of RAWS stations used. RAWS stations are deployed in lowland areas where weather is most supportive of fire. The RAWS are owned and operated by multiple agencies such as the United States Fish and Wildlife, the National Park Service, the United States Forest Service and the Bureau of Land Management.

To estimate the geographic variation in climate within each region, I used a 1-km resolution map that was interpolated spatially based on elevation and the 30-year averages for air temperature and precipitation in June and July in each region (Fleming et al. 2000). These data were used to calculate the frequency distributions of temperature and precipitation in June and July for each region.

I compared several aspects of the fire regimes among the three regions for all fires that occurred during the 10-year study period. These data included the number of human-versus lightning-caused fires per month, the percent of total area burned, and the frequency distribution of fire sizes. Effectiveness of suppression in the Fairbanks area was evaluated by comparing the initial attack size to the final fire size. I compared the seasonal pattern of human and lightning-caused fires to explore human impacts on the
length of the fire season. I examined interactions between climatic and human impacts on fire regime by testing whether the correlation between annual area burned and June temperature (the climatic parameter that shows the best correlation with interior Alaskan fire regime; P. Duffy and S. Rupp pers. comm. Department of Forestry, University of Alaska Fairbanks.) differed between the Fairbanks Region and the other two regions with low human population density. For these correlations I used mean values of June temperature and annual values of total percentage of area burned for each region from 1950 to 2000.

Results

The Fairbanks Region, with 50-fold greater population density than the other two regions (Table 1), differed markedly from these regions in fire regime. The Fairbanks Region had a large number of small fires, whereas the Yukon Basin and Galena Regions had fewer but larger fires (Fig. 1.2, Table 1). For example, from 1990-1999, the Fairbanks Region had 8.4-fold more fires per unit area than the other two regions, but the average fire size in the two remote regions was 30-fold larger than in the Fairbanks Region (Table 1). The net result of this difference in fire regime was that the total area burned in the Yukon Basin Region was four-fold greater than in the Fairbanks Region (Fig. 1.3). Similarly, over the entire 50-year fire record (1950 to 2000), 2.5-fold more area burned in the Yukon Basin Region than the Fairbanks Region. For both data sets, the Galena Region was intermediate, with the percentage area burned being more similar
to the Yukon Basin than to the Fairbanks Region. Ten percent of the Yukon Basin Region burned in a single year (1950). This was 75% of all the land that burned during the 50-year fire record, indicating a large variance in annual area burned.

There was no consistent difference among the three regions in the density of lightning-caused fires. From 1990-1999 the Fairbanks Region had 9% greater density of lightning fire starts than did the other two regions (Table 1), but over the entire fire record (1950-2000) the Fairbanks Region was intermediate between the Yukon Basin and the Galena Regions in number of lightning fires (Table 2). This suggests that regions of the interior differ from year to year in their relative frequency of lightning fires, perhaps explaining why the regions with most intense fire activity change from one year to another.

In contrast to the lightning fires, there was a dramatic and consistent difference in the number of human-caused fires between the Fairbanks Region and the other two regions. The Fairbanks Region had 60-fold greater density of human-caused fires than did the two more remote regions from 1990 to 1999 (Table 1). In the Fairbanks Region, 83% of all fires were human-caused, whereas only 17% of fires were human-caused in the Yukon Basin Region, and 4% were human caused in the Galena Region (Fig. 1.4). Similar patterns were evident over the entire fire record, with 83% of fires being caused by human activity in the Fairbanks Region but only 25% and 8% of fires caused by humans in the Yukon Basin and Galena Regions, respectively (Fig. 1.4).
Most lightning-caused fires begin in June and July, after soils have dried following snowmelt but before late-summer rains begin (Fig. 1.5). Human-caused fires extended the length of the fire season. In the Fairbanks Region, for example, human-caused fires began in March, two months before the beginning of the natural fire season, and continued through October, two months after the end of the natural fire season (Fig. 1.5). Human-caused fires peaked in May in the Fairbanks area, at least a month before the peak in the number of lightning fires. In the Yukon Basin and Galena Regions, there were too few human-caused fires to detect their impact on the seasonality of fire regime.

Most of the land that burned in the Galena and Yukon Basin Regions resulted from fires that began during June, with July being the second most important month of fire starts (Fig. 1.6). Lightning caused most of these fires. However, in the Fairbanks Region, the largest land area burned in May, primarily due to human-caused fires, with June being the second most important month of fire ignitions, primarily due to lightning ignitions (Fig. 1.6).

Seventy-nine percent of the fires in the Fairbanks Region were less than 0.4 ha, and there were only a few large fires (Fig. 1.7). In contrast, only 28% of the fires in the Yukon Basin Region and 13% in the Galena Region were less than 0.4 ha. One percent of the fires in the Fairbanks Region became larger than 400 ha, as opposed to 19% in the Yukon Basin Region, and 17% in the Galena Region. Overall, in the Galena and Yukon Basin Regions there were fewer small fires and more fires that were greater than 20 ha, possibly due to less suppression efforts. Even in the Fairbanks Region, most small fires
were clustered near the city of Fairbanks and the outlying road network, with the large fires located farther from populated areas (Fig. 1.2).

To explore the possibility that factors in addition to human activity might contribute to the large differences in fire regime between the Fairbanks Region and the other two regions, I compared these three regions (and the mega-region representing interior Alaska) with respect to vegetation type, fuel type, and climate. The Interior Region contained 58% Open & Closed Spruce Forest/Shrub bog mosaic, which was the most flammable vegetation cover type; an additional 20% of the region was mixed Spruce Woodland & Broadleaf Forest, which was second in flammability; Tall & Low Shrub/Lichen Tundra, the third most flammable vegetation cover type, accounted for an additional 15% of the vegetation (Fig. 1.8a). In summary, 93% of this large region consisted of flammable vegetation cover types. Not surprisingly, the most flammable vegetation type (Open & Closed Spruce Forest/Shrub bog mosaic) accounted for most (72%) of the area burned (Fig. 1.8b). The percentage of each vegetation type that burned within this Interior Region was consistent with its presumed flammability, ranging from 5.8% of the most flammable vegetation type burned per decade (Open & Closed Spruce Forest/Shrub bog mosaic) to 2.4% of the least flammable fuel types (Fig. 1.9).

All three regions had a high proportion of flammable vegetation types (90-99%; Fig. 1.10). However, vegetation differences among regions probably contributed to regional differences in area burned. The Fairbanks Region, which had the smallest proportion of Open & Closed Spruce Forest/Shrub bog mosaic, also had the smallest proportion of area burned (2.5% of total area or 9.4% of the area of flammable vegetation
per decade) (Fig. 1.11). In contrast, the Yukon Basin Region, which had the largest proportion of Open & Closed Spruce Forest/Shrub bog mosaic, had the largest proportion of area burned (10% of total area or 12.9% of the area of flammable vegetation per decade). In the most flammable vegetation type (Open & Closed Spruce Forest/Shrub bog mosaic), the Fairbanks Region did not differ consistently from the other two regions in the percentage of this vegetation type (about 6%) that burned (Fig. 1.11). However, a much smaller percentage of the other flammable fuel types (Spruce Woodland & Broadleaf Forest and Tall & Low Shrub/Lichen Tundra) burned in the Fairbanks Region than in the other two regions. These comparisons show that vegetation differences contributed to, but did not fully explain, the large differences in fire regime among the three study regions.

The vegetation classification that I used (Fleming, 1997) is not an unambiguous indicator of flammability, because the satellite images that formed the basis of the classification cannot differentiate among certain vegetation types that differ substantially in flammability and capacity to support fire spread (e.g. black and white spruce forests). The 24 vegetation types in the original vegetation map can, however, be combined into fuel types which best represent vegetation differences in flammability (NIFC 1992). These fuel types serve as inputs to fire behavior models (Anderson 1982).

Nearly half (46%) of the Interior Region consisted of the most flammable fuel type, Boreal Spruce (C2), which includes closed and open black spruce forests with an understory of feather mosses and evergreen shrubs (Fig. 1.12a). This fuel type accounted for 58% of the area burned (Fig. 1.12b). The percentage of each fuel type that burned
ranged from 5.8% of the highly flammable Boreal Spruce, to 4.9% of the Mixed Hardwood/Spruce (M1/M2) fuel type, to 2.3% of the least flammable fuel types (Fig. 1.13).

The three regions differed in proportions of fuel types. The Fairbanks Region had less of the two most flammable fuel types (C2 and M1/M2) than the more remote regions (Fig. 1.14), but more of the Open Tundra, Shrub/Grass (O1a/O1b) than the other two regions. Regional differences in these open fuel types are difficult to interpret. In the Fairbanks Region this fuel type probably includes extensive grasslands and mixed fuel types that are products of human disturbance and prone to early-season burning. These grass fields account for many of the early-season fires in the Fairbanks Region, because the standing dead litter burns readily before the growth of fresh grass. However, the Open fuel type in the Yukon Basin and Galena Regions is primarily tundra that does not burn as readily early in the season, but supports fire later in the season after fuels have dried.

The Fairbanks Region did not differ consistently from the other two regions in the percentage of the most flammable fuel type (C2) that burned (Fig. 1.15). However, a smaller percentage of other flammable fuel types (M1/M2, C1, and O1a/O1b) burned in the Fairbanks Region than in the other two regions.

In summary, the fuel-type analysis supports the conclusion of the vegetation analysis. Regional differences in fuel types probably contributed to, but did not fully explain, the large differences in fire regime among the three study regions. There was a reduction in area burned in the Fairbanks Region primarily in those vegetation/fuel types
of intermediate flammability, rather than in the most flammable vegetation/fuel types (Fig. 1.11, 1.15).

I compared regions with respect to two sources of climatic data: RAWS stations, which are deployed in the most fire-prone areas, and a GIS climate map (Fleming et al. 2000), which is a 30-year average of temperature and precipitation for each 1-km² pixel of each region, allowing an assessment of climate variability within regions.

Precipitation data, which were available only from the climate maps, indicated that a larger proportion of the Fairbanks Region received more precipitation during the months of June and July than did the Yukon Basin or Galena Regions (Fig. 1.16a). This could partially explain the smaller proportion of area burned in the Fairbanks Region (Fig. 1.3) than in the other two regions. Data from both the climate map (Fig. 1.16b) and the RAWS stations (Fig. 1.17) indicated that the Fairbanks Region was similar in temperature to the other two regions. The warmer temperatures at the RAWS stations than the average climate of the region (Fig. 1.17) reflects the lowland locations of RAWS stations.

To determine whether human activities affected the sensitivity of fire to climate, I analyzed the relationship between percent of land burned and average June temperature, using the 50 years of RAWS weather data and the 50-year fire-scar record. Several RAWS stations were located within each region studied (Fig. 1.2). Regressing the average June temperature against the log of annual percent of area burned, I found that area burned increased exponentially with June temperatures in the Galena and Fort Yukon Regions \( (p<0.001, r^2=0.27, F=35.2, n=98) \) (Fig. 1.18). The difference between a
linear analysis and exponential analysis was very small, with the exponential analysis fitting slightly better. Residuals from this regression were randomly distributed with respect to temperature. In contrast, area burned showed no significant relationship to temperature in the Fairbanks Region (p=0.85, r²=0.07, F=3.8, n=50), suggesting that factors other than June temperature accounted for most of the inter-annual variation in area burned in this more densely populated region.

In the Fairbanks Region, where a large number of fires were attacked, I tested the effectiveness of fire control by comparing the initial attack size with the final fire size (Fig. 1.19). Ninety-seven percent of the fires that were attacked when smaller than 0.4 ha stayed less than 0.4 ha, and none became larger than 2 ha, indicating that small fires were effectively suppressed. If the fire was staffed at less than 4 ha, it remained less than 4 ha 84% of the time. If the fire was staffed when it was larger than 4 ha, the final fire size was less predictable and ranged from 8 ha to 4000 ha; the final fire size was seldom less than 20 ha. This suggests that for fires larger than 4 ha, the final fire size depended substantially on factors other than initial attack size, including variables such as wind, fuel type, slope, topography, relative humidity, duff moisture, natural barriers, and suppression effort.

Discussion

The more densely populated Fairbanks Region had a radically different fire regime than did the other two regions. Only 25% as much area burned in the Fairbanks
Region as in the Yukon Basin Region even though there were 7.9 times more ignitions per unit land area in the Fairbanks Region. To the extent that difference in area burned can be ascribed to human activities, these results indicate that fire suppression had much greater impact on fire regime than did the increased ignitions, just as in the continental United States, where a policy of fire suppression has substantially reduced the area burned (Pyne 2001).

One reason that fire suppression has a greater impact on fire regimes in the Fairbanks Region than elsewhere is that a larger proportion of the fires are fought because more of the land is classified in the Critical, Full, and Modified protection categories; consequently suppression activity is more intense. This difference in classification reflects the tendency for land to be put into high priority protection in areas with roads, houses, or other valuable resources. Human settlement therefore strongly increases the amount of fire suppression in an area. Fire suppression may also be more effective in the Fairbanks Region than elsewhere in interior Alaska because of greater road access and proximity to abundant resources to fight fires. Also, fires may more often be in fuel types (Mixed M1/M2 and Open O1a/O1b) that allow more effective suppression. Regardless of the causes, it is clear that fire suppression has been effective in the areas where it is applied, probably by putting out most fires before they become too large to contain effectively.

In addition to the direct human effects on ignition and suppression, human activities may have reduced the area burned in the Fairbanks Region indirectly, if greater burning and other disturbances during the gold rush in the early 20th century caused
vegetation changes that reduce fire probability (Lutz 1959). Hills near creeks and rivers were frequently logged to provide fuel for steamboats or to thaw the ground (Roessler 1997). There was also a high fire frequency in the early 20th century (Fastie et al. 2003), which may have resulted from fires that were accidentally or purposefully set by gold miners (Graves 1916). These human disturbances may contribute to the higher proportion of mid-successional mixed forests in the Fairbanks Region than in the Yukon Basin and Galena Regions (Fig. 1.10). However this vegetation difference could not by itself account for the difference in overall percent burned (Fig. 1.11).

Fuel type (Fig. 1.14) and ignition source (Fig. 1.5) may interact to affect the fire size distribution in the Fairbanks Region (Fig. 1.7). Lightning fires are distributed broadly throughout the interior Alaska (Gabriel and Tande 1983; Dissing and Verbyla 2003), whereas human-caused fires are concentrated around towns and roads (Fig. 1.2). The fuel types around these towns and roads are more likely to be early successional vegetation that is less flammable and less likely to spread and form large fires, especially when suppression is attempted. This may partially explain the small average fire size in the Fairbanks Region (Fig. 1.7, Table 2).

In general, a fire that is caused by humans is likely to be reported immediately, be fairly accessible to fire crews, occur in a high-protection area, be attacked at a small size, and perhaps occur in fuel types that are less supportive of extreme fire behavior. Together these factors explain why the numerous human-caused fires in the Fairbanks Region do not lead to a large total area burned. Because human-caused fires are more likely to start under conditions unfavorable for fire spread and to remain small until the fire is staffed,
they are relatively easy to contain and extinguish at a small size. On the other hand, fires that are lit under dry windy conditions are more likely to exceed 2 ha before they are staffed and are also more likely to grow to large size after the initial suppression efforts begin. There are therefore many reasons and interactions that explain the positive relationship between initial attack size and final fire size (Fig. 1.19). Once a fire becomes large, whether ignited by people or lightning, it is difficult to contain and could become large and burn many different fuel types. Under these circumstances the final fire size depends mainly upon fire weather.

Not all fires are staffed with the objective of putting them out. Many remote cabins, native allotments and villages are protected from approaching fire by burning out the area around the property, allowing the fire to continue burning. This form of fire management could increase the fire size and might contribute to the larger fire sizes in the Yukon Basin and Galena Regions.

The only climatic factor that I analyzed that could contribute to regional differences in fire regime was the greater proportion of the Fairbanks Region that received high precipitation (Fig. 1.16a). Precipitation shows no correlation with area burned in interior Alaska (Duffy and Rupp unpubl.), and temperature, which does correlate with area burned in remote regions (Fig. 1.18), was similar among regions (Fig. 1.17), so it seems unlikely that climate alone can explain regional differences in fire regime.

There was a strong positive relationship between mean June temperature and annual percent of land burned in the Yukon Basin and Galena Regions, but not in the
Fairbanks Region (Fig 1.18). Perhaps suppression in the Fairbanks Region minimizes fire spread to a significant degree during warm weather, so the percent of land burned does not correlate with June temperatures.

Fire suppression appears to be the major cause of the reduction in area burned in the Fairbanks Region. There was a low density of large fires in the Fairbanks Region, and most of these were in areas of Limited suppression south and west of the city (Fig. 1.2).

Although I restricted my analysis to the 1990-1999 time period, where quality assessment shows the fire record to be excellent (Murphy et al. 2000), errors and biases in the fire record could have contributed to some of the differences in fire regime that I observed among regions. The less frequent air traffic over the Yukon Basin and Galena Regions than over the Fairbanks Region could lead to a lower detection efficiency and partially explain the smaller number of fires observed in these remote regions. This potential bias seems unlikely, however, to completely explain the 8.5-fold difference in number of fires. In addition, large fires, which account for most of the area burned (Kasischke et al. 2002), are probably reported with similar efficiency and accuracy in all regions, so regional differences in total area burned are most likely accurate.

In summary, there may be a bias toward under-reporting of fire number in remote regions, but our general conclusion remains robust: the Fairbanks Region had more small fires, a smaller proportion of the total area burned, and a larger percentage of human-caused fires than did the more remote regions.
There are limits to the effectiveness of suppression. Under conditions of severe fire weather with strong winds, aircraft are grounded for safety reasons, and suppression efforts are ineffective without air support. Under these conditions some fires in zones designated for active suppression will escape. Consequently, fire suppression cannot eliminate fire risk in populated areas. It may, in fact, increase the probability of larger fires in the future, as late-successional flammable vegetation becomes a larger proportion of the landscape (Chapin et al. 2003). Fire suppression was least effective in the most flammable fuel type (Boreal Spruce, C2), a late-successional type that is likely to become more common over the long run, if suppression is effective in reducing area burned.

My results suggest that human activities have substantial impacts on fire regime in interior Alaska but that these effects are not uniformly distributed. In areas remote from towns and the road network, fire suppression has relatively small effects, and lightning-caused fires account for the largest number of fires and about 90% of the area burned (Kasischke et al. in press). These remote regions, including most of the Galena and Yukon Basin Regions, are typical in most of the boreal forest in interior Alaska. In areas near towns and along the road network, however, most fires are lit by people, and fire suppression has a substantial impact in reducing the area burned by putting out fires and preventing them from spreading.

In conclusion, there are human impacts on the fire regime of interior Alaska, but they are mostly concentrated along the road system and around towns along these roads. The villagers and users of cabins in remote parts of interior Alaska appear to have little effect on percent of land burned, seasonality of fire regime, number of ignitions, or
locations of fires. However, in areas along the road system, human impacts have
decreased the overall land area burned, increased the number of small fires, doubled the
length of the fire season, and changed the locations of fires.

The importance of human activities in altering the fire regime of Alaska depends
on the region, the processes considered, and the time scale of concern. For area-
dependent processes such as carbon sequestration, the overall impact of human activities
on fire regime in interior Alaska remains relatively small. The two-thirds of interior
Alaska that I did not study have a largely natural fire regime similar to that of the Yukon
Basin and Galena Regions. Fire suppression has, however, had huge effects on processes
and characteristics that more directly influence human welfare because these human-
environment interactions, by definition, are concentrated in areas where people live and
travel. These include risks to life, health, and property from fire and changes in
ecosystem services, such as wildlife habitat, berries, firewood availability, and
recreational opportunities. In these relatively small areas, where fire suppression has
increased the fire return interval by reducing the annual area burned (Fig. 1.3), the
resulting increase in the proportion of the landscape occupied by late-successional
flammable vegetation will augment the long-term risk of fire, particularly if the strong
warming trend of the late twentieth century continues into the future. Mitigation of this
risk will require a careful re-evaluation of current policies, which emphasize fire
suppression over fuel reduction in populated areas and which encourage settlement in
fire-prone areas.
Fig. 1.1. Proportional distribution of management options in each study region.
Fig. 1.2. Map of fires in Alaska from 1950-2000, and the three study regions and the large Interior Region.
Fig. 1.3. Total area burned in the three study regions from 1990-1999 and from 1950-2000.
Fig. 1.4. Proportion of fires caused by human activity in the three study regions from 1990-1999 and from 1950-2000.
Fig. 1.5. Total number of fires per month per million ha that were caused by lightning or by human activities in the three study regions from 1950-2000.
Fig. 1.6. Percentage of the total region area burned per month from 1950-2000 due to lightning or human activities in the three study regions.
Fig. 1.7. Frequency distribution of final sizes of fires caused by lightning or human activities in the three study regions from 1990-1999.
Fig. 1.8. Compositional cover of the major vegetation types present in the Interior Region (8a. 1991), and the composition of the vegetation that actually burned (8b. 1992-2001).
Fig. 1.9. The proportion of each vegetation type in the Interior Region that burned between 1992 and 2001.
Fig. 1.10. Vegetation cover type for three regions (1991).
Figure 1.11. Proportion of each vegetation type burned within the three regions (1992-2001).
12a. Fuel type composition

- Water: 21%
- Boreal Lichen (C1): 46%
- Open Tundra, Shrub/Grass (O1a/O1b): 5%
- Mixed Hardwood/Spruce (M1/M2): 28%
- Boreal Spruce (C2): 0%

12b. Composition of fuel types burned

- Water: 58%
- Boreal Lichen (C1): 11%
- Open Tundra, Shrub/Grass (O1a/O1b): 2%
- Mixed Hardwood/Spruce (M1/M2): 0%
- Boreal Spruce (C2): 29%

Figure 1.12. Compositional cover of the major fuel types present in the Interior Region (12a. 1991), and the composition of the fuels that actually burned (12b. 1992-2001).
Fig. 1.13 The Proportion of each fuel type in the Interior Region that burned between 1992 and 2001.
Fig. 1.14. Composition of major fuel types in the three regions in 1991.
Fig. 1.15. Proportion of each fuel type burned within the three regions (1992-2001).
Fig. 1.16. Frequency distribution of June-July precipitation (1.16a) and temperature (1.16b) observed in 1-km pixels in three regions.
Fig. 1.17. Average June-July temperature from GIS data compared to 1950-2000 temperatures recorded from RAWS weather stations in three regions.
Fig. 1.18. Relationship between average June temperature and percentage of the study region burned in each year from 1950-2000 in three regions.
Fig. 1.19. Relationship between initial attack size and final fire size.
Table 1. Area, population density, and fire statistics of study regions (1990-1999).

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<tr>
<th>Characteristic</th>
<th>Fairbanks</th>
<th>Yukon Basin</th>
<th>Galena</th>
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<tr>
<td>Area (ha)</td>
<td>6,444,503</td>
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<td>418</td>
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<td>Average Fire Size (ha)</td>
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<td>Total Starts (#/Million ha)</td>
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<tr>
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<td>Human -caused fires (% of total)</td>
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<td>17%</td>
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Table 2. Fire statistics of study regions (1950-2000).

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<th>Plot</th>
<th>Human starts (#/million ha)</th>
<th>Lightning starts (#/million ha)</th>
<th>Total starts (#/million ha)</th>
<th>Area Burned (ha)</th>
<th>%burned since 1950</th>
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<td>3,394,706</td>
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Literature Cited


CHAPTER 2: Interactions Among Fuels, Suppression, and Ignition in Interior Alaska.

Abstract

An analysis of human impacts on interior Alaska's fire regime demonstrates that human activities have effects in populated areas. I analyzed the fire regime of interior Alaska for individual 1-km pixels to explore the interactions among cause of ignitions, fuel type, and suppression category. Land designated for high suppression priority, (Full or Critical), differs from Limited lands where little or no suppression is applied. In the Full and Critical lands, humans have altered fire regime by causing more fires in certain fuel types and increasing the length of the fire season compared to Limited lands. The Full and Critical lands have less area of land burned, even while controlling for fuel type, and there is a larger number of human ignitions. There are more large fires per unit area in Limited lands compared to Full and Critical lands. Since most of interior Alaska is classified as Limited, human ignitions and suppression have only a minor effect on fire regime, and climate strongly influences the overall area burned. However, in populated areas and areas designated for suppression, less area burns, and human ignitions account for a large proportion of burned area.

Introduction

The recent occurrence of extensive fires in the western United States (U. S.) has focused considerable scientific interest and public concern on how human activities have
influenced fire regime (Pyne 1982, Pyne 2001). People have altered fire regime through ignitions (increasing fire frequency), suppression (decreasing fire area), and vegetation modification resulting from past suppression and other land-use changes. It is virtually impossible to assess the relative importance of these factors in the continental U. S., because most fires have been suppressed (Pyne 2001), so we lack an appropriate control for comparisons.

Interior Alaska provides a unique opportunity to assess human impacts on fire regime, because fire is the main disturbance type (Viereck 1973, Johnson 1992, Kasischke et al. 2002), and regions within interior Alaska differ substantially in human ignitions and suppression. Fire is important because it causes long-term fluctuations in the structure and functioning of ecosystems by altering the structure of populations, communities, and ecosystems through changes in physical environment or resource availability (Chapin et al. 2000). Most studies on the fire regime of Alaska have focused on natural factors influencing fire, because most of the area burned in interior Alaska results from lightning-caused fires (Kasischke et al. 2002, in press). However, the human impact on the Alaskan fire regime has never been carefully analyzed, so little is known about the magnitude and consequences of human impacts on fire regime (Gabriel and Tande 1983, Murphy et al. 2000). Understanding the dynamics of the fire regime, direct and indirect human impacts, and how these impacts will change as the human population grows are essential to understanding the long-term trajectory of vegetation cover and climate in Alaska (Chapin et al. 2000, Johnstone et al. in press), particularly in those parts of Alaska most intensively used by people and structured by people.
The fire regime in Boreal forests is affected by multiple interacting variables (Johnson 1992). In this chapter I focus on the interactions of vegetation, management options for suppression, and the source and season of ignition. Vegetation determines the fuel types available to burn. Certain types are more flammable than others. Fire policy in Alaska differs radically from that in the continental U.S., where federal policy dictates that all fires should be suppressed (Pyne 1982, 2001). The management options in interior Alaska are Critical, Full, Modified, or Limited, going from highest priority for suppression (Critical and Full) to no suppression in Limited lands (Roessler 1997, Gotholdt 1998, http://agdc.usgs.gov/data/blm, Chapter 1). These management options span the full range of potential human impacts on fire regime. Ignition occurs from either lightning or human activities. I examined the interaction among these variables to determine size, timing, and frequency of fires in the Interior Region.

The specific questions I addressed were: Do different management options within the same vegetation type burn differently? What impact does season have on the frequency distribution of fire size, and how does this interact with human- versus lightning-caused fires? What management options and fuel types contribute most to total area burned? My study provides an analysis of the interactions among vegetation, climate, and fire season. This is essential to understanding where humans affect the fire regime most strongly and how human impacts may alter future vegetation trajectories in interior Alaska’s boreal forest.
Methods

The study area consisted of a 44,852,000 ha region that occupied most of interior Alaska between the Alaska and Brooks Ranges and between the Canadian border and Seward Peninsula (Fig. 2.1). Within this area I analyzed the fire size distribution based on fuel type, management option, and month of year. This is identical to the Interior region used in Chapter 1.

Fire data were obtained for the study area from the National Database system located at Alaska Fire Service. This database contains data on all fires that occurred in this area since 1950, including the cause of the fire, the discovery date, and the management option of the land that burned, resources sent to fires, initial attack size of fire (i.e. size when suppression activities began), and final fire size. This database includes information about fires less than 0.4 ha (1 acre) in size, in contrast to the GIS database at the Bureau of Land Management (BLM) web site (http://agdc.usgs.gov/data/blm), which contains only fires larger than 400 hectares from 1950 to 1986, and fires larger than 40 hectares from 1987 to 2001. For all analyses I used a combination of the tabulated database of all fires (including smaller ones) from Alaska Fires Service and the GIS dataset in order to include as many of the fires that were recorded as possible. Data for management options within the Interior region were obtained from the BLM website (http://agdc.usgs.gov/data/blm).

Data on vegetation distribution were based on a 1 km-resolution vegetation map derived from Normalized Difference Vegetation Index (AVHRR/NDVI) data collected

Location and timing of cloud-to-ground lightning strikes are monitored by triangulation from lightning detectors in interior Alaska (Dissing and Verbyla 2003). Fires were assumed to be human-caused if no lightning strikes were recorded at the fire location for approximately 5 days prior to first detection of the fire or if there was good evidence of human influence. Prior to 1981, there were no lightning detectors, so fires were assumed to be lightning-caused if no evidence of human influences was found. Limitations of all data used are discussed in Chapter one.

I examined fire size distribution within each category of fuel type, management option, and month in which the fire started. In assessing the influence of fuel types, I restricted my analyses to the 10-year time period (1992-2001) after 1991, the year in which satellite imagery was collected to produce the vegetation map from which the fuel type map was derived (Fleming, 1997, http://agdc.usgs.gov/data/projects/fhm).
I analyzed the relationship of management option to final fire size distribution using data from 1986, the year in which management options were first designated, to 2001. This analysis was based on a map of the management options in 1991. The shifts in management options that occurred between 1986 and 1991 were too small to significantly affect my conclusions.

I analyzed fire size distribution with respect to month of fire start, using data from 1956 to 2000, once again choosing the longest time period available in order to maximize sample size.

To assess the overall effect of fuel type and management option on area burned in the Interior Region, I looked at which management options burned most within each fuel type. I then looked at the proportion of each management option that burned within different fuel types relative to what was available to burn.

Results

Fuel-type effects on fire number and size

The most common size range of lightning-caused fires was 0.4-4.0 ha (Fig. 2.2). Above this size threshold, there was an exponential decrease in number of fires as fire size increased. Fires smaller than 0.4 ha were also less frequent than those of 0.4-4.0 ha. In most of these fire-size categories, about 50% of the lightning-caused fires occurred in the fuel type (Boreal Spruce) that was most flammable and most abundant; 25-35% of the fires occurred in the Mixed Hardwood/Spruce, about 15% in Open Tundra, Shrub/Grass,
and less than 5% in Boreal Lichen fuel type. Very small fires (<0.4 ha) occurred less commonly in Boreal Spruce (37% of the total) than was observed with larger fires (Fig. 2.2).

The pattern of fire distribution among fuel types, when analyzed per million hectares (Fig. 2.3), differed somewhat from the pattern described above because the fuel type that was most flammable (Boreal Spruce) was also most abundant (58% of the study area). In general, Boreal Spruce and Mixed Hardwood/Spruce supported the most frequent lightning-caused fires per unit of land area (Fig 2.3). Intermediate and large fires (>4 ha) tended to occur primarily in Boreal Spruce, the fuel type generally considered to be most flammable (Wagner et al. 1992). In contrast, small fires (<4 ha) tended to occur primarily in Mixed Hardwood/Spruce. There were very few large fires within Open Tundra or Boreal Lichen, although small fires occurred frequently in these fuel types (Fig. 2.3). These results suggest that fires that started in the most flammable fuel types were more likely to burn large areas.

Human-caused fires differed strikingly from natural fires in both their typical size and in the fuel types where they occurred. Most (78%) human-caused fires were less than 0.4 ha in size (Fig. 2.2), and these occurred predominately in moderately flammable fuel types: Mixed Hardwood/Spruce, and Open Tundra, Shrub/Grass) (Fig. 2.2). Higher densities of human-caused fires occurred in Mixed Hardwood/Spruce and Open Tundra, Shrub/Grass fuel types, and these were mostly <0.4 ha and 0.4-4 hectares in size (Fig. 2.3). These two fuel types were ignited most frequently by people because (1) they are early successional stages that occur commonly after human disturbance and are therefore
more abundant in populated areas, and (2) people carry out activities that lead to fire (escaped campfires and brushfires; Gotholdt 1998) more frequently in deciduous forests and grass fields than in black spruce forests. The human-caused fires larger than 40 ha in size were primarily in Boreal Spruce or Mixed Hardwood/Spruce fuel types. The very few large (>400 ha) human-caused fires that occurred were predominantly in the highly flammable Boreal Spruce fuel type. These results indicate that human-caused fires were more likely to start and to remain small in less flammable fuel types than was the case for lightning-caused fires. However, human-caused fires, like those caused by lightning, were more likely to become very large (>400 ha) in highly flammable vegetation.

Within the Interior Region most (89%) small fires (<0.4 ha) were human-caused, but human ignitions were of negligible importance for fires larger than 4 ha in size and therefore accounted for only a minor proportion (4.6%) of the total area burned in the Interior Region from 1992-2001 (Fig. 2.2).

*Fire-management effects on fire number and size*

Within Interior Region most (57%) lightning-caused fires occurred on Limited lands (68% of the study area) (Fig. 2.4). This was particularly true for large fires (>400 ha), where 80% of large lightning-caused fires occurred on Limited lands, whereas only 4% of these fires occurred on Full and Critical lands (17% of the land area). On Limited lands 30% of lightning-caused fires exceeded 400 ha in size, and 50% of fires remained less than 4 ha in size. In contrast, on Full and Critical lands only 4% of lightning-caused fires exceeded 400 ha in size, and 75% remained less than 4 ha in size.
In contrast to lightning-caused fires, most (80%) human-caused fires occurred on Full and Critical lands (Fig. 2.4), because this was where human activity was concentrated, even though these land categories accounted for only 17% of the study area. On Limited lands 12% of human-caused fires exceeded 400 ha, and 60% remained less than 4 ha in size (Fig. 2.4), indicating that human-caused fires were 2.5-fold less likely to get large than lightning-caused fires in the absence of suppression. On Full and Critical lands, only 0.6% of human-caused fires exceeded 400 ha in size, and 94% remained smaller than 4 ha. Together these data indicate that fire suppression greatly reduced the number of large fires and kept most fires quite small. Fire suppression was more effective in reducing fire size of human-caused than of lightning-caused fires, in part because human-caused fires occurred in less flammable vegetation types (Fig. 2.2).

The effectiveness of fire suppression in altering fire regime is best evaluated by looking at the number and size of fires per unit area of each management option (Fig. 2.5). On a unit-area basis, most large lightning-caused fires (>400 ha) occurred on Limited and Modified lands, whereas most fires remained small (<0.4 ha) on Full and Critical lands, where suppression was most active. This pattern was even more pronounced with human-caused fires, where large human-caused fires occurred only in Limited lands, and small fires were 100-fold more likely to occur on Full and Critical lands than on Limited lands. These results clearly demonstrate that fire suppression or some other characteristics of Full and Critical lands greatly reduced the probability of large fires. Visual inspection of the fire maps (Fig. 2.1) also shows that most large fires
occurred on Limited lands, whereas small fires were concentrated in areas receiving
maximum suppression effort (Full and Critical lands).

When looking only at lightning-caused fires in the Boreal Spruce fuel type (to
eliminate differential effects of ignition source and fuel type) there is even clearer
evidence of suppression effects. Many more large fires occurred in Limited lands, and
more small fires occurred in the Full and Critical lands (Fig. 2.6). Suppression kept most
fires in Full and Critical lands from getting large. As a result, a much smaller proportion
of the land burned in the Full and Critical lands than in Limited lands (Fig. 2.7).

Seasonality effects on fire number and size

Most (85%) lightning-caused fires began in June and July (Fig. 2.8), after soils
dried from snowmelt, and convective thunderstorms (which produce lightning with only
scattered rain) were frequent (Dissing and Verbyla 2003), but before the summer rains
began. Some lightning-caused fires also began in May and August, but these generally
remained small.

Human ignitions extended the length of the fire season by two months and moved
the peak fire season to May in areas with high human populations which are classified as
Full or Critical. Most of these spring fires were ground fires that occurred in Open
Tundra, Shrub/Grass or Mixed Hardwood/Spruce fuel type. They burned dead grass litter
before new green leaves (with higher moisture content) emerged. Most (85%) early
spring, late summer, and fall fires (months of April, May, August and September)
remained smaller than 4 ha. Almost all large human-caused fires began in May or June, and there were only a few of them.

**Effects on area burned**

An analysis of total area burned integrates the information presented above on fire size and fire number. Fires that began in June and July accounted for most (92%) of the area burned in the Interior Region (Fig. 2.9). For this 50-year time period lightning-caused fires accounted for 91% of the area burned. Only for fires that started in May did human ignitions account for a significant proportion of the area burned.

Management categories differed in proportion of fuels burned per unit area (Fig. 2.10). For all fuel types a larger proportion of Limited land burned except for the relatively high proportion of Mixed Hardwood/Spruce that burned in Modified lands. All other suppression categories showed the same ranking of fuel types burned: Boreal Spruce > Mixed Hardwood/Spruce > Open Tundra, Shrub/Grass ≥ Boreal Lichen. This analysis, which includes all fires, shows a less pronounced difference in proportion of area burned per management option (Fig. 2.10) than when only lightning-caused fires are considered (Fig. 2.3), because of the large number of human-caused fires in the Mixed Hardwood/Spruce fuel type. However, there still are differences among protection categories, because less land burned in high-protection areas, regardless of fuel type.

Fuel types differed substantially in their contributions to total area burned, due to differences in both flammability and abundance, with Boreal Spruce accounting for 58% of the area burned, Mixed Hardwood/Spruce 29%, Open Tundra, Shrub/Grass 11%, and
Boreal Lichen 2% (Fig. 2.11). About 80% of the area burned for each of these vegetation types occurred in Limited lands (68% of the land area), and about 9% of the area burned occurred on Critical and Full lands (17% of the land area) (Fig. 2.11).

**Discussion**

My results clearly show that fuel type, season and source of ignition, and fire management all affect the fire regime in interior Alaska. By stratifying the Interior Region according to these controlling factors, I can consider each of these factors separately and in combination. I first discuss the effects of natural factors (fuel type and seasonality) and then the impacts of human activities.

**Effects of fuel type**

On a unit area basis, most lightning-caused fires start in those fuel types that fire managers have classified as being most flammable (Johnson 1992, Wagner et al. 1992): Boreal Spruce (C2) > Mixed Hardwood/Spruce (M1/M2) > Open Tundra, Shrub/Grass (O1a/O1b) > Boreal Lichen (C1) (Fig. 2.2). This ranking of number of lightning-caused fires is a logical consequence of ecosystem differences in flammability. Most Boreal Spruce (C2) is dominated by black spruce (*Picea mariana*), which is highly flammable because of its fine twigs and needles, high resin content, low moisture content, and ladder-like structure that carries fire into the canopy (Viereck 1973, Johnson 1992, Kasischke et al. 2000, Wagner et al. 1992). Fire is carried through the Boreal Spruce fuel
type primarily in the understory, which consists of a flammable matrix of mosses, evergreen shrubs, and a fibrous organic mat, all of which dry quickly during hot, dry weather. The large continuous stands, which are typical of black spruce, support fire spread.

The Mixed Hardwood/Spruce (M1/M2) fuel type consists of patches of black and white spruce (Picea glauca), which are flammable for the reasons described above, and hardwoods (primarily aspen, Populus tremuloides, and paper birch, Betula papyrifera), which are less flammable than spruce, because of higher leaf moisture and less understory moss, evergreen shrubs, and organic accumulation. This fuel type is particularly prone to spring fires before leafout, when dry grass and litter burns readily.

The Open Tundra, Shrub/Grass fuel type consists of open tundra (O1a), which has generally low flammability because of high moisture content and small fuel loads, and grass meadows (O1b), which are quite flammable in spring because of dry leaf litter, but less flammable during the growing season because of the high leaf moisture content. Finally, the Boreal Lichen (C1) fuel type is least flammable because of its small fuel load and lack of a thick surface organic mat to carry the fire, however this fuel type is still capable of supporting fire spread under the right conditions.

Variation in lightning strike density contributes to differences among fuel types in number of fires (Dissing and Verbyla 2003). Open Tundra (O1a) and Boreal Lichen (C1) have a low fire frequency in part because they occur most commonly at high elevations where lightning strike density is low (Reap 1991, Dissing and Verbyla 2003). In addition, Boreal Spruce (C2) has a higher lightning strike density than other fuel types at a given
elevation (Dissing and Verbyla 2003) because its dark, structurally complex canopy absorbs more radiation (low albedo), and its low stomatal conductance causes most energy to be transferred to the atmosphere as sensible heat, which generates convective uplift and air-mass thunderstorms (Baldocchi et al. 2000, Chapin et al. 2000, Chambers et al. 2003, Dissing and Verbyla 2003).

Under conditions of severe fire weather, when most large fires occur, any boreal vegetation will support fire spread (Kasischke et al. 2002), although tundra is less fire-prone than forest (Wein 1976), so I would expect to see small differences among fuel types in large fires. Consistent with this expectation, the two forested fuel types (Boreal Spruce and Mixed Hardwood/Spruce) were similar in the number of fires per million hectares larger than 4000 ha, with open fuel types (Open Tundra, Shrub/Grass and Boreal Lichen) having fewer large fires (Fig. 2.3). Nonetheless, there were substantial differences among all fuel types in number of fires per unit area across a wide range of fire sizes, indicating that vegetation differences in flammability and/or lightning strike density had a strong effect on fire regime, particularly under conditions of moderate fire weather (small-to-intermediate fire sizes). If high-latitude warming causes large fires to become more frequent (Kasischke et al. 2002), I expect the nature of forest vegetation (spruce vs. hardwood) to have less influence on fire regime than at present but that forested vegetation will continue to be more fire-prone than tundra.

Large fires form a positive feedback system that promotes further increase in fire size. This is because there is more perimeter of the fire exposed to unburned vegetation,
so it is more likely to burn into flammable fuels and continue to burn. Also large fires create their own winds that drive fire spread (Johnson 1992).

Fuel types differ more strongly in total area burned (Fig. 2.11 and Fig. 2.2) than their flammability (Fig. 2.3) would suggest, because the most flammable vegetation types are most widespread in the Interior Region. Because of these differences in flammability and spatial extent, the area of Boreal Spruce fuel type that burns is twice as great as that of the next most flammable fuel type (Mixed Hardwood/Spruce) and 24-fold greater than the least flammable fuel type (Boreal Lichen) (Fig. 2.11).

Effects of seasonality

Lightning ignitions peak during June and July, when fuels are driest (Wilmore 2001), and thunderstorms are most frequent (Dissing and Verbyla 2003). Before June, soils are typically still wet from snowmelt, because soils have not thawed sufficiently to allow drainage from the soil organic mat. After July, med-late summer rains increase fuel moisture, and lightning strike density declines, minimizing the number of lightning-caused ignitions. Mixed Hardwood/Spruce and Open Grasslands are the major exception to this generalization because fire in these fuel types is carried primarily by grass and tree litter, which is driest in May before new leaves emerge. There is therefore an interaction between fuel type and month of ignition.

Fires of different sizes were surprisingly similar in their month of fire start in that most fires started in the months of June and July (Fig. 2.8). Large fires therefore differed from small ones primarily in the length of time that they burned, rather than the month in
which they started. In dry years, fires often continue burning until late August or September (Kasischke et al. 2002).

**Effects of human activities**

Between 1992-2001 even though human ignitions accounted for 62% of the fires in my study area, they accounted for only 4.6% of the total area burned (Fig. 2.2). Over a longer time period (1950-2001) they accounted for 9% of area burned (Fig. 2.9). Most (80%) of the area burned occurred in Limited lands (Fig. 2.11), which have an essentially natural fire regime because they are far from human activities and have minimal human impact from ignitions or suppression. This supports earlier conclusions (Kasischke 2000) that human activities have little effect on the area burned in interior Alaska.

There are several reasons why human ignitions are less effective than lightning in burning Alaskan forests: (1) Most (80%) human-caused fires occur on lands designated for fire suppression (Fig. 2.4) and are therefore likely to be put out at a small size, because they are often reported right away, are accessible to fire crews, and are attacked at a small size with large amounts of fire-fighting resources. (2) About 55% of human-caused fires are lit outside of the peak (June-July) season of lightning-caused fires (Fig. 2.8) and are therefore less likely to encounter dry fuels and spread over large areas. (3) Finally, people often light fires in Mixed Hardwood/Spruce (M1/M2) and Open Grass (O1b) fuel types (Fig. 2.2), which are less flammable than Boreal Spruce where lightning-caused fires predominate. Human ignitions often lead to fires in Mixed Hardwood/Spruce and Open Grass because these fuel types are products of disturbance.
(Viereck et al. 1993) and therefore occur more often near populated areas. Second, these fuel types are preferred for home sites and recreation, compared to boggy permafrost- and mosquito-dominated black spruce forests.

In Limited lands, where suppression activities are minimal, lightning-caused fires were 2.5-fold more likely to exceed 400 ha and 20% less likely to remain less than 4 ha compared to human-caused fires (Fig. 2.5), suggesting that factors other than fire suppression (i.e., season and fuel type) contribute substantially to the small size of most human-caused fires. Although human activities have a relatively small effect on the total area burned in the Interior Region, they have a substantial impact on the fire regime in Critical and Full lands (Fig. 2.6 and Fig. 2.7), where these effects are concentrated. The net effect of human activities has been to reduce the proportion of area burned nearly seven-fold in areas designated for suppression, compared to Limited lands (Fig. 2.7).
Fig. 2.1. Large and small fires within each management option in interior Alaska (1986-2001).
Fig. 2.2. Total number of lightning- and human-caused final fire size distribution within fuel type (1992-2001).
Fig. 2.3. Lightning- and human-caused final fire size distribution per unit area within fuel type (1992-2001).
Fig. 2.4. Frequency distributions (total number of fires) of final fire size in relation to management option (1992-2001).
Fig. 2.5. Frequency distributions (fires/million ha) of final fire size in relation to management option (1992-2001).
Fig. 2.6. Frequency distribution (fires/million ha) of final size of lightning-caused fires in the Boreal Spruce fuel type: A comparison of Limited versus Full and Critical management options (1986-2001).
Fig. 2.7. Proportion of total area burned by lightning-caused fires of differing final sizes in the Boreal Spruce fuel type: A comparison of Limited versus Full and Critical management options (1986-2001).
Fig. 2.8. Frequency distribution (number of fires) of final sizes of fires caused by lightning or human activities occurring during each month of the fire season (1950-2001).
Fig. 2.9. Total hectares burned per month due to lightning- and human-caused fires (1950-2001).
Fig. 2.10. Proportion of each fuel type burned within each management option (1992-2001).
Fig. 2.11. Total hectares burned per fuel type within each management option (1992-2001).
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Geographic patterns and dynamics of Alaskan climate interpolated from a sparse


CONCLUSIONS

Ecological and Societal Consequences of Human Impacts on Fire Regime

In the short term, fire suppression minimizes risks to human life and property, reduces health risks from smoke. Fire suppression also provides wages for fire fighters, which are important to the economy of rural communities, and provides important career and social experiences that lead to other job opportunities.

The long-term effects of fire depend on the changes in ecosystem services that result from fire (Chapin et al. 2003). Early successional vegetation enhances mushroom production for 2-4 years after fire, berries for 2-20 years after fire, and moose and furbearers between 10 and 30 years after fire. Conversely, firewood and timber products are reduced for 30-50 years after fire. The less flammable deciduous vegetation that develops after fire reduces fire risk to adjacent property owners for about 30-60 years in black-spruce-dominated lowlands and about 80-100 years in white-spruce-dominated uplands (Yarie 1981). Over the long term, the reduction in area burned resulting from fire suppression increases the aerial extent of late-successional Boreal Spruce, which increases the potential for larger fires in the future (Chapin et al. 2003). This in combination with the large number of lightning strikes in this vegetation type (Dissing and Verbyla 2003) could create a situation in which nature takes control, and large fires eventually burn the area, regardless of the suppression efforts applied. On the other hand, numerous small human-caused fires near populated areas and land clearing activities
break up areas of continuous vegetation and act as fuel breaks that prevent development of vast expanses of late successional flammable vegetation.

Human-induced changes in fire regime can have important effects on the successional trajectory by keeping the fires smaller in size and causing fires earlier in the season when the organic duff moisture is high. White spruce, birch, and aspen must disperse into a burn from surviving individuals or from adjacent unburned areas (Johnson 1992, Zasada 1992). Although human-caused fires are likely to be small and therefore close to seed sources, large fires often contain unburned islands that act as seed sources (Johnson 1992). Human-induced changes in fire size will therefore probably have small effects on post-fire successional trajectory.

Human impacts on fire severity could have strong effects on post-fire succession. Fires caused in early spring by humans generally do not burn down to mineral soil and therefore produce an organic seedbed that is unfavorable for most boreal trees (Zasada 1986, 1992). Deciduous trees (birch and aspen) and understory shrubs generally survive these spring fires and resprout from roots or stumps. Low-severity fires in Mixed Hardwood stands often produce hardwood stands with very few spruce, whereas low-severity fires in black spruce forests can produce open shrublands or forests with very low densities of black spruce. These successional trajectories are quite different than those that occur after more severe fires (Flinn, and Wein 1977, Foote 1983, Viereck and Dyrness 1979). Humans may also change the vegetation trajectory by setting fires in young black spruce forests, where cones have not yet matured enough to produce viable
seeds, eliminating the heavy recruitment that normally occurs from semi-serotinous cones, and shifting vegetation cover to weeds and deciduous shrubs (Johnstone 2003).

Overall, the results suggest that land managed for a natural fire regime (Limited) supports more large fires, and a larger percent of the area has burned than in areas with active fire suppression (Chapter 1). When the analysis is controlled for fuel type and ignition source, the relationship is even more pronounced (Chapter 2). The areas classified as Full and Critical have many more fires than Limited lands, because these lands are usually located near human populations. Therefore suppression is even more successful than the difference in area burned would suggest. My results support the idea that the higher levels of suppression in Full and Critical lands have decreased the overall percent of land burned and reduced the number of large fires. Continued suppression could increase the area of late-successional flammable vegetation in the future, increasing the risk of large fires in forests adjacent to communities and roads. In addition to increasing future fire risk, this vegetation change could alter most ecosystem processes and even the regional climate. My study shows that fire suppression has altered fire scar sizes and the percent of land burned over time and that human-caused fires have lengthened the fire season and altered the fuel types where fires occur. Future studies of the long term impacts of human suppression and ignition will need to look more closely at seed recruitment and vegetation regeneration in fires that differ in month of start, vegetation type, and size.

My analysis shows that Alaska's management strategy of concentrating suppression activities in zones close to people reduces the conflict among potentially
competing objectives of fire management. This strategy has maintained a natural fire regime over a large portion (68%) of interior Alaska, with natural fires accounting for 91% of the area burned. Thus human activities have probably had minimal impact on those aspects of ecosystem function that depend on the total aerial extent of fire, such as carbon sequestration and energy feedbacks to climate. At the same time, suppression has greatly reduced the occurrence of large fires and the total area burned in areas designated for suppression and thus reduced risks to life and property. Thus any fuel buildup that may have occurred due to fire suppression is probably restricted to a relatively small area (Critical and Full lands). Alternative policy options, such as prescribed fire or thinning, can then be focused on these relatively small accessible areas of land, whose management is of greatest concern to people.

In the lower 48 states, fire suppression has led to vertical fuel buildup in pine and sequoia forests, which has allowed ground fires to propagate into the canopy and destroy the forests (Bonnickson and Stone 1982). If these forests were left in their natural state, frequent ground fires would prevent this vertical fuel buildup. Vertical fuel buildup is unlikely to be important in Alaskan forests, even with fire suppression, because ladder fuels occur naturally, even in young stands, and carry the fire to the canopy. Consequently, most fires kill the trees and result in stand-replacing fires. However, suppression does generate larger horizontal expanses of flammable fuels and thus potential for large fires in the future. Even this problem is minimal in Alaska. In Limited lands, the natural fire regime has produced large expanses of flammable Boreal Spruce. In areas of high human populations this flammable vegetation is usually more fragmented
by clearing, small human-caused fires, roads, and other human activities. Therefore, I would argue that the legacy of fire suppression in Alaska will not create the problems that have occurred in the lower 48 states. Designation of specific areas for suppression undoubtedly reduces the total cost of suppression and increases its effectiveness compared to a blanket suppression policy such as that which characterizes the rest of the United States. Since most of Alaska is unpopulated, managers are capable of a more ecologically informed fire policy, that focuses suppression efforts on those areas with greatest risks to human life and property and greatly reduce the costs of fire suppression.

In these areas designated for high suppression, efforts could be focused on land clearing or prescribed burning to eliminate continuous expansion of flammable fuels at the urban-wildland interface. Since most of Alaska’s vegetation will burn under the right conditions of drought and wind events, a more serious concern is changing weather and its impacts on the future fire regime of Alaska.