EARTH Interactions



# Human Influences on Wildfire in Alaska from 1988 through 2005: An Analysis of the Spatial Patterns of Human Impacts

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**ABSTRACT:** Boreal ecosystems in Alaska are responding to climate change in many ways, including changes in the fire regime. While large-scale wildfires are an essential part of the boreal forest ecosystem, humans are changing fire regimes through ignition and suppression. The authors analyzed the impact humans have on fire ignitions and relative area burned with distance into the forest from human access points such as settlements, highways, and major

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rivers in Alaska from 1988 to 2005. Additionally, a fire prediction model was created to identify drivers for lightning fires in the boreal forest. Human presence increases the number of ignitions near settlements, roads, and rivers and appears to reduce the area burned within 30–40 km of villages and rivers. In contrast to fires near roads and rivers, human presence may somewhat increase the area burned within 30–40 km of highways. The fire prediction model indicated that the probability of fire increases as distance from human settlements increases. In contrast, the model indicated that the probability of fire decreases as distance from roads increases and that the probability of fire in relation to distance from rivers depends on the year of analysis. While the ecological consequences of these human impacts are still unclear, this research shows that human influences on fire regime clearly affect the pattern of fire within 40 km of settlements, which is an area that represents 31% of interior Alaska. Future research should focus on more completely understanding the role of human presence in the suppression of wildfires in interior Alaska.

**KEYWORDS:** Fire; Boreal forest; Prediction model

## 1. Introduction

There is considerable evidence that arctic and boreal ecosystems in Alaska are responding to recent climate changes (Goetz et al. 2005; Hinzman et al. 2005; Jorgensen et al. 2001; Keyser et al. 2000; Serreze et al. 2000) in ways that could feed back to the global climate system (Bonan et al. 1995; Chapin et al. 2000; McGuire and Chapin 2006). An expected increase in naturally occurring wildfires in the boreal forest (Stocks et al. 2000; Westerling et al. 2006; Yarie and Parton 2005) will likely accelerate carbon losses from this ecosystem, which is currently considered a carbon sink (Harden et al. 2000; Kasischke et al. 1995; Zhuang et al. 2006). Humans affect wildfire through ignition and suppression, but it is generally assumed that human-caused fires burn an insignificant amount of land, and the effectiveness of suppression is still debated (Cumming 2005; Johnson et al. 2001; Miyanishi and Johnson 2001; Ward et al. 2001). However, humans are an integral part of this system and their role must be considered for a complete understanding of fire in the boreal forest.

Large-scale wildfires have regularly occurred in the boreal forest of Alaska for the past 7000 yr (Lynch et al. 2003; Lynch et al. 2004). These fires are the result of airmass storms rather than intense synoptic storms (Henry 1978), and annual area burned in Alaska has been linked to the Pacific decadal oscillation and the east Pacific teleconnection indices (Duffy et al. 2005) as well as El Niño (Hess et al. 2001). During these storms, lightning strike density is influenced by boreal forest cover and topography (Dissing and Verbyla 2003). Occurrence of fire seems to be a function of weather rather than fuel load (Johnson et al. 2001), though presence of black spruce plays an important role (Hu et al. 2006; Lynch et al. 2003), affecting both fire frequency and fire size (Rupp et al. 2002).

Interior Alaska is classified as a frontier because of its very low population density (<7 persons per square mile or 2.7 persons per square kilometer), and annual area burned is mostly the result of a few very large fires. The frequency of large fires caused by humans is much lower than those ignited by lightning and account for only 10% of area burned in Alaska despite the observation that humans start >60% of all fires (Kasischke et al. 2006). Fire suppression seems to be most effective on small fires (0.4 ha; DeWilde 2003) and has had “a nontrivial impact on area burned over recent decades” (Cumming 2005). The extent of human impact on natural fires varies among regions in interior Alaska (DeWilde 2003).

Human influence on fire can be measured by the number of human fire starts and the total area burned by both human- and lightning-caused fires. Therefore, we analyzed the geographic relationships (nearest distance) between fire locations, both in terms of ignitions and area burned, and settlements, major highways, and major rivers in interior Alaska to address the following questions: 1) Do the number of human fire ignitions differ from lightning ignitions with distance to settlements, highways, and major rivers? 2) Does relative area burned vary with distance from settlements, highways, and major rivers? Additionally, we developed a model to predict the occurrence of lightning-initiated fires based on these three distance measurements and several additional parameters to determine how strongly fire was affected by proximity to humans.

We focus our analysis on the time period from 1988 through 2005 for two reasons. First, the proportion of human-ignited fires in the area burned in interior Alaska has changed since 1960. During the 1960s and 1970s, human-ignited fires resulted in more than 15% of the area burned in interior Alaska, while since that time human-ignited fires accounted for less than 7% the burned area (Kasischke et al. 2006). This change in the areal importance of human-ignited fires may be associated with the change in fire management in 1984 that implemented fire suppression in Alaska based on a fire management zone system. Second, the spatial quality of fire data in interior Alaska is consistently good since 1988, but deteriorates as we go further back in time (Kasischke et al. 2002). The 1988–2005 record contains all fires greater than 100 acres (0.4 $km^2$), while from 1950 to 1987 the fire data record contains only fires greater than 1000 acres (4 $km^2$). The improved reliability and finer resolution of the spatial data since 1988 were particularly important for the fire prediction model (1 $km^2$ resolution) we developed in this study.

## 2. Methods

To answer the two research questions on the human influence on fire, we performed a spatial analysis of fire locations and fire outlines in reference to geographic features such as settlements, major rivers, and highways in Geographic Information Systems [GIS; workstation ArcInfo 8.3, Environmental Systems Research Institute (ESRI)]. We then converted a large number of datasets that could potentially predict fire occurrence into a 1-km grid cell format and used these datasets to develop a logistic regression model with *R* to predict the probability that a cell may burn because of lightning. Since there is no official delineation for interior Alaska, we overlaid the boreal zone in the combined Omernik–Bailey ecosystem classification of Alaska (http://agdc.usgs.gov/data/projects/fhm/#G) with the fire outlines from the large firescar database and extracted the area of overlap, which essentially removed areas at higher elevations where fires rarely occur (Figure 1). Kasischke et al. (Kasischke et al. 2002) found that nearly 99% of all area burned in interior Alaska from 1956 to 2000 was at an elevation of less than 800 m. This corresponds to the observation that maximum lighting-strike

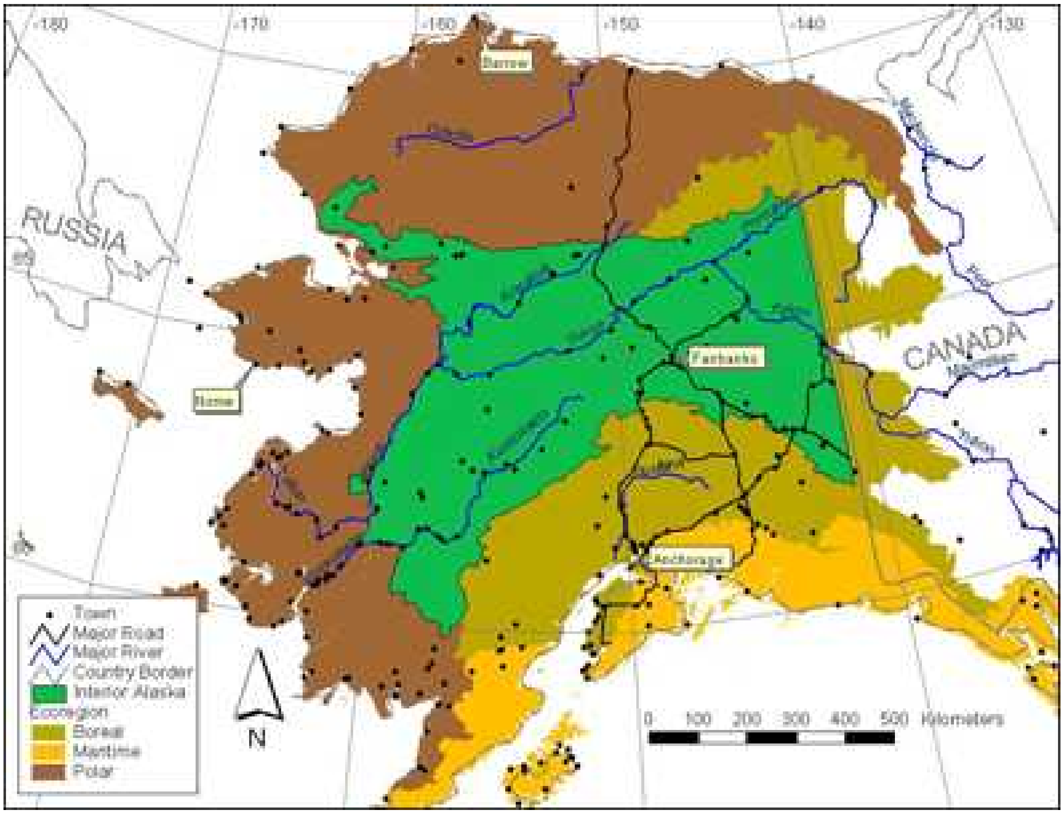


**Figure 1. Delineation of interior Alaska (in green) based on the boreal ecoregion of the Omernik–Bailey's ecosystem classification and the firescar record.**

density occurs at 800 m (Reap 1991). In contrast, Dissing and Verbyla (Dissing and Verbyla 2003) found a positive relationship between elevation and lightning-strike density up to between 1100 and 1200 m and attributed differences with the analyses of Kasischke et al. (Kasischke et al. 2002) and Reap (Reap 1991) to differences in the areas and scale of analyses.

## 2.1. Human influence on fire

Although our study is focused on the time period from 1988 through 2005, we first report background information from 1956–2000 from a fire ignition database of the Alaska Fire Service that lists fire cause and size with a point location (Kasischke et al. 2002; Murphy et al. 2000). The primary dataset for the analyses we conducted in the study are based on the large firescar database for 1988 to 2005 from the Alaska Fire Service, which includes digitized fire perimeters for all fires >100 acres (>0.4 $km^2$) for each year. Thus, all analyses that required exact locations of fire perimeters are based on the large firescar dataset and include years 1988 through 2005 (such as percent area burned in Figure 3). While most of the area burned can be attributed to a few very large fires caused by lightning, human fires tend to be very small. From 1992 to 2001, 78% of human-caused fires in interior Alaska were less than 0.004 $km^2$ (0.4 ha) in size, more than 50% of fires were between 0.4 and 4 $km^2$, and only roughly 2% of all human-caused fires were greater than 0.4 $km^2$ (DeWilde and Chapin 2006).

We created buffers at 1-km intervals around all named settlements (more information is available online at http://www.asgdc.state.ak.us/metadata/vector/cultural/towns.html) and major highways and rivers (Digital Chart of the World, Environmental Systems Research Institute; www.esri.com) in ArcInfo. For the analysis, we used 5-km bins up to a distance of 30 km for ignition points and 50 km for area burned.

## 2.2. Lightning fire prediction model

Since lightning data was only available for 1990–2000, we restricted model development to this 11-yr time frame; which provided almost 5 million cells and seemed sufficient for model development. We performed Pearson's correlations among datasets to identify the most important drivers from a long list of potential parameters. The following predictors were used in the final model: average June temperature and total June and growing season precipitation as monthly data from the Climate Research Unit (CRU; New et al. 1999); total snowpack depth in April and May (simulated based on CRU climate parameters); monthly dry lightning strikes per square kilometer from May through August (Dissing and Verbyla 2003); elevation [U.S. Geological Survey (USGS) Digital Elevation Model] and aspect and slope interpolated from it; distances to settlements, major highways, and major rivers in 1-km increments; and STATSGO soil drainage type (Harden et al. 2003). The U.S. Department of Agriculture (USDA) State Soil Geographic (STATSGO) soil drainage types reflect the speed at which water is removed from the soil after a rainfall event and range from 1 ("excessive," meaning very rapid water loss) to 7 ("very poor," meaning waterlogged soils; more information is available online at http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/index.html). An additional predictor was stand age, which was assumed to be the time since the last fire. For cells that had not burned since 1950 and fire history was therefore not available from the large firescar database, we used a hypothetical fire interval dataset, which is based on the application of a smoothing algorithm to the historic firescar record to expand fire information to the entire region (Calef et al. 2005). Additionally, we used vegetation types separated into black spruce forest, white spruce forest, deciduous forest, and tundra. The four-class vegetation land cover was developed with algorithms designed to reduce a commonly used classification with 23 land-cover classes (Fleming 1997) to the four major types using topography and climate (Calef et al. 2005; Rupp et al. 2007). Tundra is delineated from deciduous forest based on low growing season temperature and geographic location. In contrast, both spruce types occur only in areas with higher growing season temperatures, but, unlike white spruce, black spruce is located primarily at a northern aspect and low slope angles (flat areas). Fire locations were extracted from the firescar database. A fire prediction model for lightning-caused fires was then created with forward stepwise logistic regression on a subsample of 90 000 cells randomly selected across years, plus all cells that burned.

Model prediction accuracies were tested by comparing fire probabilities of randomly selected cells in interior Alaska with cells in actual firescars. Additionally, predicted annual area burned was compared with actual area burned. When we used 0.5 as the prediction threshold for all years with an average prediction accuracy of 73%, the model substantially overestimated the annual area burned in individual years. Instead, we created an optimization function using linear regression to adjust the prediction threshold for each year between 1990 and 2000, which vastly improved prediction. After testing several climate parameters individually and in combination, we chose the following function to calculate the annually varying prediction threshold:

$$y = -0.049 \times (\text{mean July temperature}) + 1.3284$$

The use of the prediction threshold based on this function explained 93.5% of annual area burned in interior Alaska between 1990 and 2000.

## 3. Results

### 3.1. Background information on the Alaska fire regime (1956–2000)

From 1956 through 2000, humans have been responsible for nearly half of the number of fires in interior Alaska (an average of 131 human-caused fires per year compared to 136 lightning fires per year), but there is much less interannual variability in the number of human-initiated fires than in the number of lightning-initiated fires (Figure 2a). Lightning-initiated fires are also characterized by higher interannual variability in total annual area burned, which ranged from 2 to 11 476 $km^2$ (Figure 2b); the total annual area burned by human-initiated fires varied between 0.5 and 5601 $km^2$ (Figure 2b). Likewise, mean annual fire size for lightning fires fluctuated from 0.07 to 95 $km^2$ per fire, with a long-term mean of 15 $km^2$ per fire (Figure 2c). In contrast, mean annual fire size of human-initiated fires has varied from 0.01 to 36 $km^2$ per fire, with a long-term mean of 2 $km^2$ (Figure 2c).

### 3.2. Human influence on fire patterns (1988–2005)

From 1988 through 2005, human fire ignitions greatly exceeded lightning ignitions within 10 km of settlements and highways and decreased with distance (Figure 3). The number of lightning ignitions per square kilometer remains relatively constant and begins to exceed human ignitions at a distance of greater than 20 km from settlements and highways. Along rivers, the number of human fire ignitions is highest within less than 5 km but never exceeds the number of lightning ignitions. More detailed analysis showed that the number of human fire ignitions is highest within 1 km of rivers (not shown).

Our analysis indicated that human-caused fires comprised very little of the total fire area that occurred within 50 km of settlements, highways, and rivers. We therefore only analyzed the total area burned with distance (Figure 3), which essentially identifies the spatial variability of human effects on the area burned by lightning-caused fires. Approximately 2% of the area within 5 km of settlements burned from 1988 through 2005, and the percent of area burned increases with distance until it peaks between 8% and 10% between 35 and 50 km from settlements (Figure 3a), which is also roughly the average distance between settlements

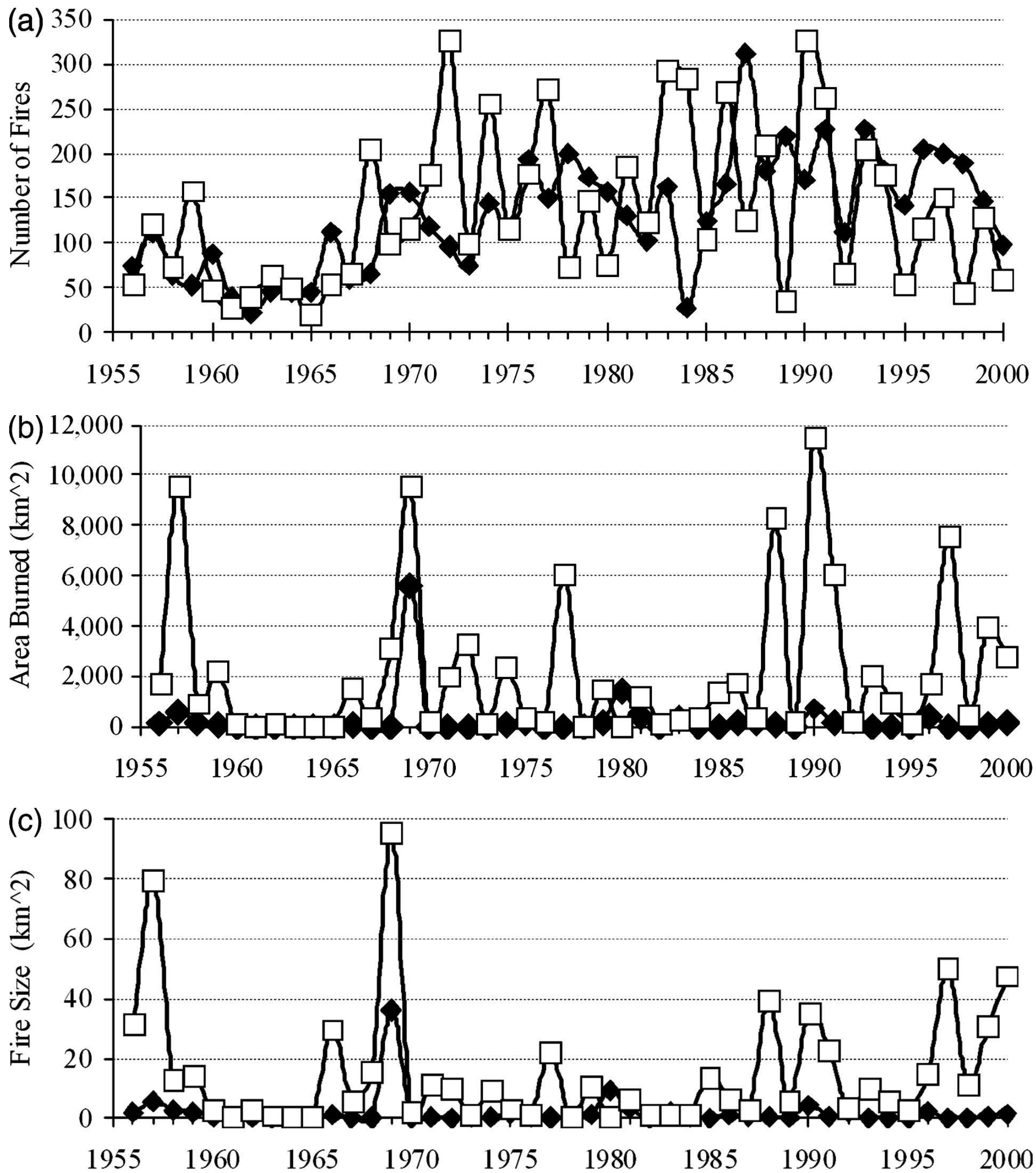


Figure 2. (a) Total number of fires, (b) total annual area burned, and (c) average fire size from 1956 to 2000 in interior Alaska by ignition type; here black diamonds represent human ignition and white squares represent lightning ignition.

in Alaska that we determined using GIS. The peak of 8%–10% area burned might be considered a background level of burning that occurs in regions that are minimally influenced by human fire suppression efforts. This analysis based on distance from settlements suggests that human suppression efforts extend to approximately 40 km from settlements, which represents 31% of the area in interior Alaska.

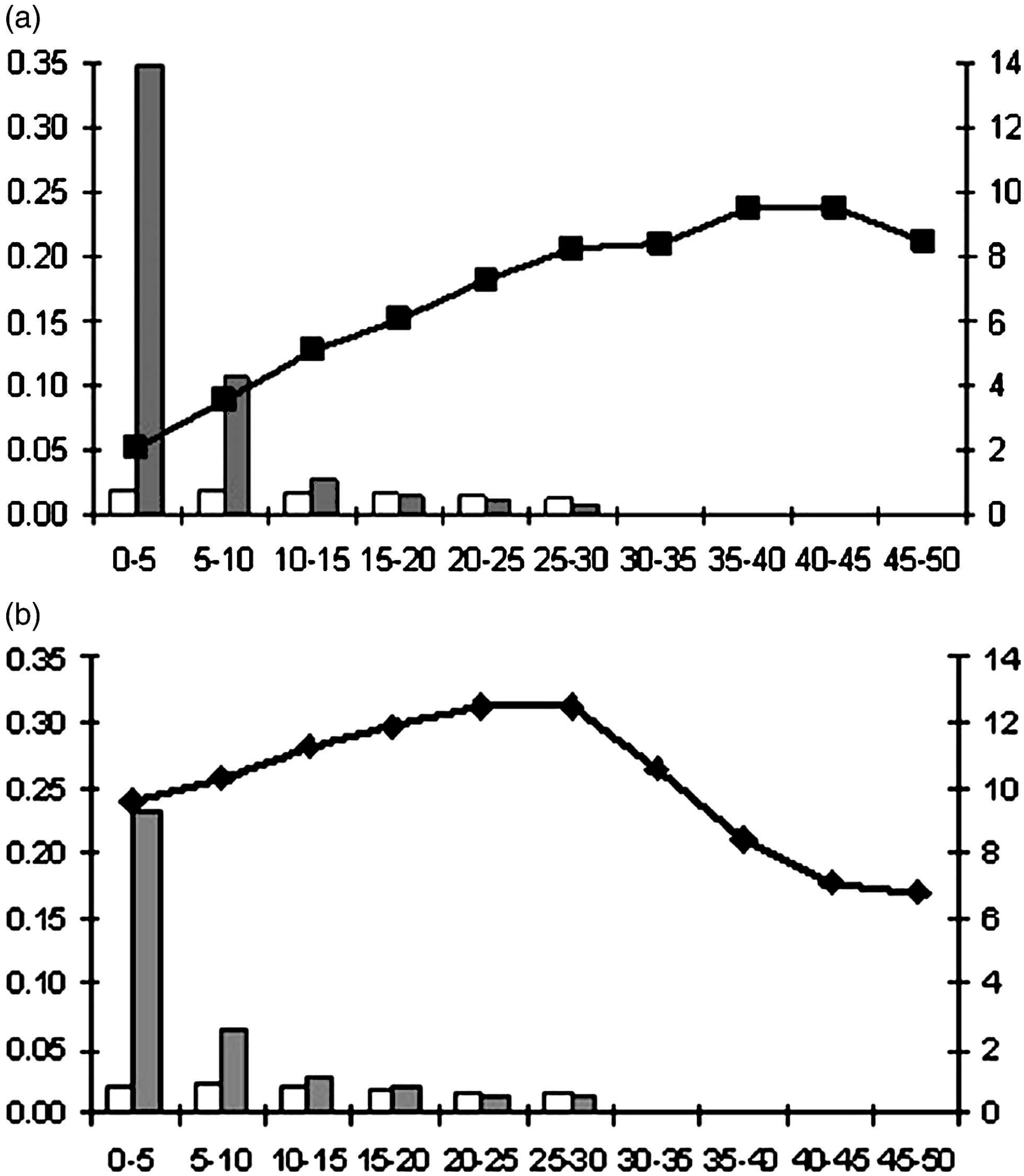


Figure 3. Number of fire ignitions per square kilometer from 1956 to 2000 (bars; left *y* axis) and percent area burned from 1988 to 2005 (symbols and lines; right *y* axis) within 50 km of (a) settlements, (b) highways, and (c) major rivers. Solid bars represent human-caused ignitions, while white bars represent lightning ignitions. Note that the scale on the left *y* axis of (c) differs from (a) and (b) by a factor of 10. The *x* axis represents distance class (km).

In contrast to the pattern for settlements, the area burned is nearly 10% within 5 km of highways and increases to 12% between 20 and 30 km from highways before dropping to around 7% at 45–50 km from highways (Figure 3b). Thus, it appears that human activity may be slightly increasing the area burned within 30

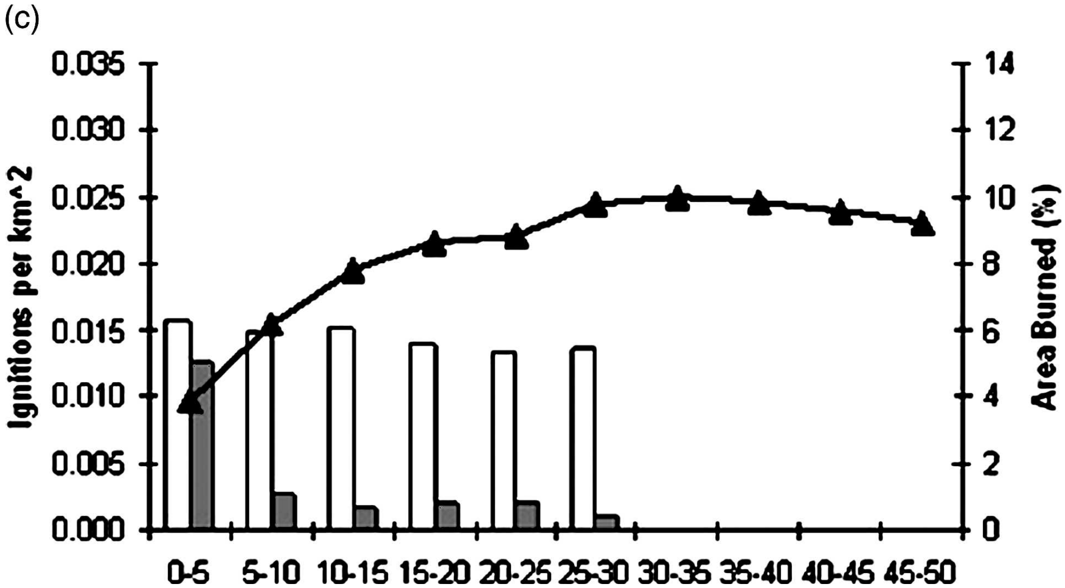


Figure 3. (*Continued*)

km of highways, with the area burned dropping to background levels farther out. Since we are not separating area burned from human versus lightning, this interpretation could indicate a potential increase in lightning-caused fires near roads. This is only possible when considering indirect human influences on fire such as long-term fuel accumulation due to constant suppression. The pattern of area burned with distance from rivers is similar to the pattern for settlements, with area burned from 1988 through 2005 being approximately 4% within 5 km of rivers and increasing gradually to between 8% and 10% (i.e., background levels) at a distance of approximately 30 km.

## 3.3. Lightning fire prediction model

The fire prediction model indicates that lightning-caused wildfires are strongly driven by a warm, dry June (when the majority of large fires take place), distance from settlements, and stand age (Figure 4). Consistent with the analysis in Figure 3b, fire probability decreases with distance from highways in almost all years with the exception of 1997, which has a strong positive correlation (0.55) and 2000 with basically no correlation (−0.02). In contrast to the analysis of Figure 3c, the model indicates that fire probability decreases with distance from rivers. The seemingly negative influence of river distance is composed of 5 yr with negative correlations between fire pixels and river distances, 5 yr with positive correlations, and one year in which correlations are close to neutral. When all 11 yr are combined in the model, river distance becomes a negative predictor for fire probability.

Additional minor drivers indicated that fire probability was increased by poorer drainage, flatter slopes, wetter growing season, shallower April and May snowpacks, and higher elevation. Fire probability was significant correlated with the presence of black spruce. While fire probability was weakly associated with July

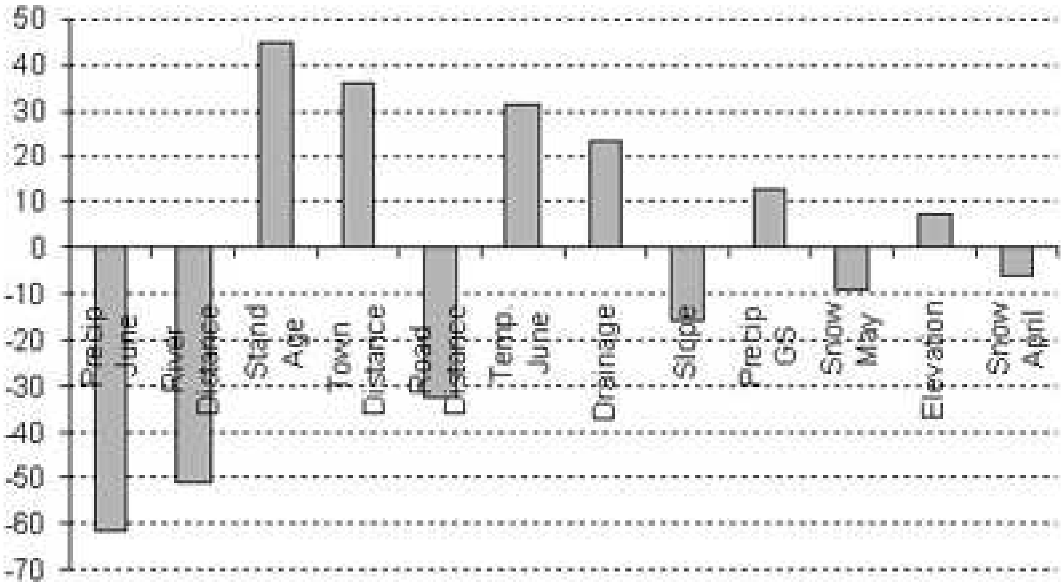


**Figure 4. Lightning fire predictors sorted by absolute *t* value (significant at 0.001) as determined by the logistic regression model.**

lightning density ($0.05 < p < 0.1$), the variables of aspect, deciduous vegetation, and lightning in May, June, and August were not significant. However, we kept these nonsignificant variables in the model because we felt that they were ecologically important.

Simulated fire probabilities of actual firescars are higher than for randomly selected cells (Figure 5); exceptions are the years 1992, 1994–1996, and 1998, which are characterized by extremely low annual area burned (less than 1000 $km^2$). In these extremely low fire years, some other factors that are not included in the model likely prevented fires from getting large. The model overpredicted annual area burned when we used a single threshold value to distinguish burned from unburned grid cells; however, using the optimization of separate thresholds for each year improved the prediction skill of the model (Table 1).

## 4. Discussion

Fire plays an important ecological role in the boreal forest of Alaska: it thaws and clears the ground, releases nutrients, resets succession, and rejuvenates the forest (Van Cleve et al. 1983; Viereck et al. 1983; Yarie and Van Cleve 2006). Additionally, fire plays a beneficial role in the lives of people living in this region: it enhances berry and mushroom harvests (Nelson et al. 2008), maintains moose habitat (Maier et al. 2005), and provides much-needed wages for fire fighters (Trainor 2006). Currently, areas in Alaska adjacent to roads and settlements are zoned for intensive fire suppression, while areas away from roads and settlements still experience a more natural fire regime. This ambiguous relationship between humans and fire (Huntington and Huntington 2005) is undergoing rapid change in

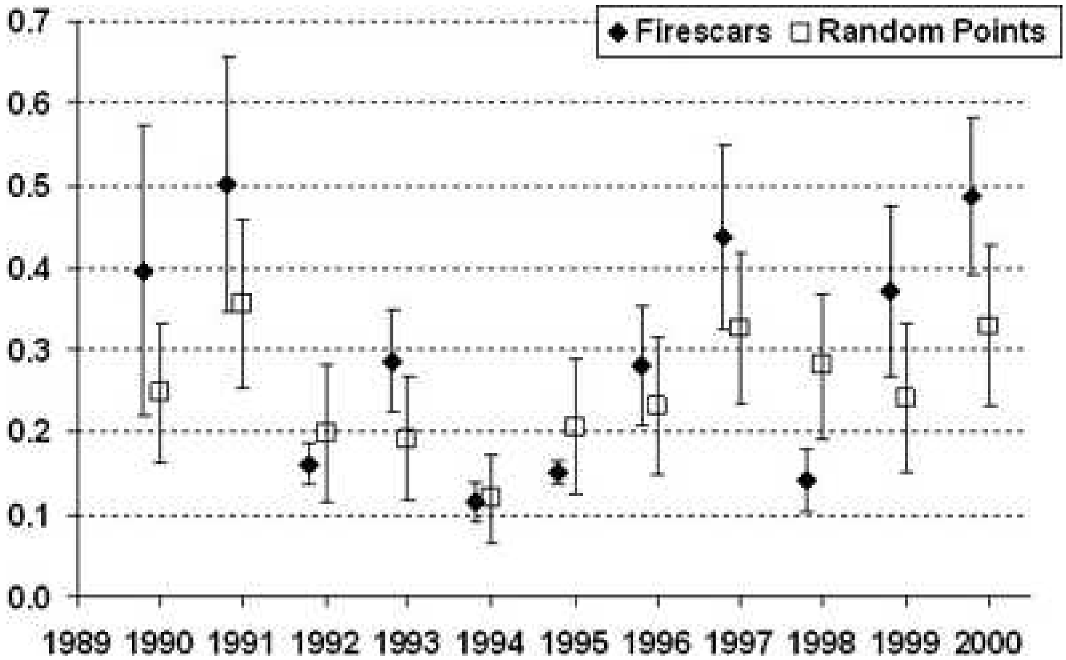


**Figure 5. Mean fire probability values simulated for randomly selected cells and for cells that contain actual firescars across years. In most years, the simulated probability is higher for cells that actually burned than for randomly selected cells; exceptions are very low fire years (1992, 1994, 1995, 1996, and 1998).**

Alaska because of human population pressure, land-use decisions, fire protection policies, and climate change. In this study we sought to better understand how human activity in interior Alaska is currently influencing the spatial pattern of the number of human-initiated fires and the spatial pattern of area burned. We focused

**Table 1. Annual area burned ($km^2$) in interior Alaska by human and lightning causes and area burned prediction with and without threshold optimization. The model without threshold optimization used a prediction value of 0.735 to separate burned from unburned. For years with annual area burned below 1000 $km^2$ (1992, 1994, 1995, 1996, 1998), the model vastly overestimated area burned; the only possible threshold would have been 0.999 and could therefore not be optimized. (N/A: not available.)**

| Year | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lightning fire | 10 791 | 6136 | 245 | 2189 | 984 | 135 | 1671 | 7030 | 512 | 4015 | 2783 |
| Human fires | 742 | 166 | 141 | 3 | 9 | 16 | 437 | 6 | 214 | 94 | 131 |
| All fires | 11 533 | 6302 | 386 | 2192 | 993 | 151 | 2108 | 7036 | 726 | 4109 | 2914 |
| Area burned prediction | | | | | | | | | | | |
| Without optimization | 281 | 17 256 | 1825 | 1926 | 1825 | 1825 | 1825 | 5539 | 1825 | 5343 | 7491 |
| Adjusted threshold | 0.68 | 0.80 | N/A | 0.66 | N/A | N/A | N/A | 0.71 | N/A | 0.77 | 0.79 |
| With optimization | 5818 | 5771 | N/A | 2444 | N/A | N/A | N/A | 8880 | N/A | 3315 | 2984 |

our analysis on the time period from 1988 through 2005 because of changes in fire management that occurred in interior Alaska during the 1980s and because of the improved reliability and finer resolution of the spatial data on fire that has been available since 1988.

From 1988 through 2005, our analysis shows that the presence of humans increases the frequency of fire ignitions near settlements, highways, and rivers, which is consistent with the observations of Kasischke et al. (Kasischke et al. 2006). In comparison to lightning-caused fires, humans increase the number of fires 20-fold within 5 km of settlements and 6-fold between 5 and 10 km of settlements. Similarly, humans increase the number fires 11-fold within 5 km of highways and 3-fold between 5 and 10 km of highways, respectively. The increase in the number of fires caused by humans is more than double the number of natural ignitions up to distance of 20 km from settlements and roads. Human fire ignitions can also be found along major rivers, though in much smaller numbers. Our results are generally consistent with other studies in the pan-boreal region. For example, a study in central Siberia found strong correlations between forest fires and within 130 km of roads, within 200 km of railroads, and within 100 km of human settlements (Kovacs et al. 2004). Continued human population growth and rural development into formerly “natural” boreal forest could further increase this human impact. For example, the current policy of selling remote parcels of land in Alaska will increase human traffic into currently uninhabited forests, thus increasing the potential for human ignitions (probably followed by suppression of area burned).

Despite an equivalent number of fires ignited by humans and lightning, the annual area burned by humans is less than 7% since 1980 (Kasischke et al. 2006). There are three reasons why human fires stay small: human-caused fires are 1) often outside the fire season, 2) in vegetation that does not sustain large fires, and 3) in areas where fires are immediately suppressed (DeWilde and Chapin 2006). DeWilde and Chapin (DeWilde and Chapin 2006) found that 85% of lightning-caused fires in interior Alaska began in June and July when soils were dry, dry lightning storms frequent, and long rains rare; in contrast, the majority of human-caused fires occurred in the shoulder seasons with a peak in May (see also Kasischke and Turetsky 2006 and Kasischke et al. 2006). Human-caused fires burned predominantly in moderately flammable vegetation types such as mixed hardwood and spruce, open tundra, shrub, and grass, which was especially true for the May fires that seemed to mostly appear as ground fires consuming dry grass (DeWilde and Chapin 2006). Finally, human-initiated fires in interior Alaska generally occur in close proximity to major population centers and roads (Kasischke et al. 2006).

In contrast to this increase in ignitions near settlements and highways, humans suppressed total area burned within 40 km of settlements. The land area within 40 km of settlements accounts for 31% of interior Alaska. However, our analysis suggests that human activity may slightly increase area burned within 30 km of highways. Since we are using a combined dataset of human- and lightning-caused fires, it is not clear if this could represent an increase in lightning-caused fires. One possible interpretation is fuel accumulation near highways due to long-term suppression eventually leading to larger areas burned. Similar to our results for distance from settlements, area burned was reduced near rivers. This may partially reflect settlement patterns, since many settlements are located on major rivers and thus fall into high fire protection zones. For example, roughly one-third of the land within 5 km of rivers is also within 20 km of settlements, and an additional one-third of this area is within 20–40 km of settlements and thus within the sphere of influence of settlements. Also, vegetation along rivers consists of deciduous forest that does not burn as easily as black spruce stands because of higher moisture content and different crown structure.

The lightning fire prediction model produced reasonably good predictions of annual area burned and confirmed that large-scale fire probability is driven by high temperatures, low precipitation, and increased stand age, all of which have been identified by other researchers as affecting fire weather and fuel accumulation (Johnson et al. 2001; Krawchuk et al. 2006). The analysis represented by our model differs from other similar analyses in that it included distances from settlements, highways, and rivers among the five most important drivers and thus identified the important role humans are playing in spatial pattern of fire in interior Alaska. The model also identified that fire probability increased with poorer soil drainage, which has also been previously linked to fire probability (Harden et al. 2003). More poorly drained areas in interior Alaska are often dominated by black spruce forest, and thus the analysis may identify the role of ground fuels of black spruce forests and peatlands in the fire regime. Surprisingly, the model did not identify a dominant role of black spruce vegetation in predicting fire probability (Krawchuk et al. 2006). A more detailed analysis showed that 45% of the burned area was located in deciduous forest, which generally does not burn well, and that only 29% of the burned area occurred in black spruce. One possible explanation is that the vegetation dataset is not very accurate based on a compounding effect of noise between mixed pixels in the underlying 1-km pixels remote sensing–based classification (Fleming 1997), which was then further aggregated to make it more useful. Though this simplified vegetation classification seems far from ideal, it is currently the best available classification for Alaska for these types of modeling applications and emphasizes the urgent need for better land-cover datasets in this region.

While effective fire suppression reduces area burned during a fire, it can lead to many unintended changes in the ecosystem. Fire suppression prevents large-scale stand replacement and promotes the dominance of highly flammable black spruce across the landscape. As a result, long-term suppression can lead to more flammable vegetation in the landscape (Chapin et al. 2003) and changes in fire severity can result in alternate successional trajectories (Johnstone and Kasischke 2005). Local populations of black spruce might become extinct if the fire interval is substantially reduced (Le Goff and Sirois 2004; Lloyd et al. 2005) or in the total absence of fire, since black spruce needs fire to reproduce effectively (Lloyd et al. 2005). Additionally, climate change might already be increasing the size and frequency of fires (Bachelet et al. 2005; Kasischke and Turetsky 2006; Westerling et al. 2006) while climate-induced drought stress is negatively affecting growth and regeneration of white spruce trees (Barber et al. 2000; Hogg and Wein 2005; Wilmking et al. 2004).

We found that humans are responsible for a very high number of fire ignitions near settlements, highways, and rivers while simultaneously suppressing a majority of large fires in those areas. Since very few of the human-caused fires turn into large fires, most of the total area burned (and the associated carbon release) in interior Alaska can largely be attributed to lightning-caused wildfires. However, our analysis suggests that humans do affect the area burned by lightning-caused fires.

## 5. Limitations and further research

Alaska is a vast, remote state, and generally there is less GIS and scientific data available in Alaska than for other states in the conterminous United States. This lack of continuous high-resolution data imposes limitations on historic analyses. Two major limitations we encountered were based on the short record of high quality firescar data as well as on the availability of lightning data from the lightning network.

We focused the analyses in this paper on the time period from 1988 through 2005 because of changes in fire management implemented during the 1980s and because of the improved quality of data on fires starting in 1988. Thus, our analysis did not span the full length of the fire record in Alaska, which began in 1950. While data quality is consistently good since 1988, it deteriorates as we go further back in time (Kasischke et al. 2002). From 1950 to 1987, the firescar record contains only fires >1000 acres; in contrast the more recent record contains all fires >100 acres. An analysis of the time period before the changes in fire management that occurred during the 1980s would complement the analysis presented in this paper, but would have to rely on lower-resolution datasets.

Another source of fire data is the ignition database from 1956 to 2000, which contains the ignition point, ignition cause, and total size of a fire. We used this database for some of the analyses we presented in this study, and it provided valuable information for matching the spatially resolved firescars from 1988 to 2000 with an ignition cause. Unfortunately, this dataset has not been updated recently, and therefore the development of the lightning fire prediction model was not able to incorporate information from 2001 through 2005. The advantage of this dataset is that it includes small fires; however, the only way to extract some approximation of area burned is by assuming circular fires and then buffering the ignition point until total fire size is reached. This results in an incorrect firescar shape and location since the point is unlikely to be in the center of the actual firescar, and fires are not circular in shape. For very coarse analyses this might not matter, but we were interested in 1-km distance increments that we later binned into 5-km increments and incorrect location of firescars would have corrupted the resolution of our analysis. Furthermore, the fire prediction model we developed was at a 1-km resolution, and we therefore needed to make use of spatially resolved data in developing that model.

While this study shows that humans are responsible for approximately half of the ignitions in Alaska, the question of whether human ignitions and suppression balance each other out requires a detailed analysis of area burned associated with human-caused ignitions and how humans have affected the area burned by lightning-caused fires. We have conducted such a study to extend the analyses presented in this paper (Calef et al. 2007, manuscript submitted to *Int. J. Wildland Fire*).

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