

Fire in the range of the Western Arctic Caribou Herd

By Kyle Joly, T. Scott Rupp, Randi R. Jandt, and F. Stuart Chapin, III

Abstract

Wildfire is the dominant ecological driver in boreal forest ecosystems. Although much less is known, it also affects tundra ecosystems. Fires effectively consume fruticose lichens, the primary winter forage for caribou, in both boreal and tundra ecosystems. We summarize 1950-2007 fire regime data for northwestern Alaska and sub-regions. We also identified meteorological factors that help explain the variability in fire extent across this landscape.

We review information and inferences from recent studies on tundra fire regimes for managing caribou winter range.

Climate warming may increase fire size and frequency in this region, which may substantially impact the vegetation, wildlife, and people of this region.

Introduction

Although much attention has been focused on the role of wildfire in boreal forest ecosystems, its role in tundra ecosystems has largely been overlooked (*but see Miller 1985, Racine et al. 1985*). Wildfires effectively consume ground-dwelling lichens that are the primary winter forage for Western Arctic Herd (WAH) caribou. These lichens can take decades to recover to pre-fire levels in northwestern Alaska (*Jandt et al. 2008*). Wildfires potentially limit caribou winter range by destroying preferred forage (*Rupp et al. 2006*). The WAH has undergone a population expansion starting in 1976 until reaching a high of 490,000 caribou in 2003 (*Dau 2005*). The herd has expanded and shifted its primary

winter range to the Nulato Hills and the Seward Peninsula from its historic winter range in the Buckland Valley and Selawik National Wildlife Refuge (*Figure 2*). Both density dependent (i.e., increasing herd size leading to reduced lichen biomass) and density-independent (i.e., increasing area burned by wildfires leading to less mature habitat) may factor into the changes in winter range distribution exhibited by the WAH.

Temperatures, in Alaska, including northwestern Alaska, have been rising and the rate of climate warming is predicted to increase (*Stafford et al. 2000, AC14 2005*). Summer precipitation has decreased at many locations throughout Alaska, and Barrow has seen declines in annual precipitation as well (*Stafford et al. 2000*). Warmer and drier summers are associated with greater area burned in Alaska (*Duffy et al. 2005*). In the tundra ecosystem, wildfires are also predicted to increase (*Higuera et al. 2008*). Regional temperature and precipitation are correlated with large scale climatic regimes, such as the Pacific Decadal Oscillation (PDO) (*Hartmann and Wendler 2005*). Our goals were to 1) elucidate the fire regime in northwestern Alaska and in tundra ecosystems, 2) test whether wildfires are increasing in extent and frequency in the range of the WAH and 3) identify meteorological variables that correlate with annual area burned.

Methods

We summarized the data contained in the Alaska Fire Service's geodatabase, which catalogs the extent, number and location of large fires mapped from 1950-2007 (*Figure 3*; data at <http://agdc.usgs.gov/data/fire/index.html>).

Kasischke et al. (2002) performed similar analyses for Interior Alaska, but we calculated them for northwestern Alaska and various subsets including the WAH core winter range, outer range, and potential future winter range - defined as a 30-mile (50-km) wide buffer around the outer range (*Figure 2A*). We also summarized burn area by conservation unit (ecoregion, tundra ecosystem, boreal forest ecosystem and also the area north of the 68th latitude (*Figures 2 and 3*). Tundra ecosystems were differentiated from forested areas using the 33-yard (30-m) National Land Cover Database - Alaska 2001 coverage (<http://www.epa.gov/mrlc/nlcd-2001.html>).

For all of these areas, we also calculated the percentage of burned area that burned two or more times during the 58-year study period. Similarly, we calculated the fire cycle (i.e., the number of years required to burn over an area) (*Kasischke et al. 2002*) for these areas. We calculated this by dividing 1 by the proportion of area burned and multi-



Figure 1. Grazing caribou.

plied the dividend by the duration of the study period (58 years). We used linear regression to test whether annual area burned and number of wildfires were increasing over time and for correlation among variables. We used average monthly temperature and total monthly precipitation data (Western Region Climate Center, <http://www.wrcc.dri.edu/summary/climsmak.html>) from 1950-2005 to develop climatic models to explain the variance in the amount of area that burned annually. Sets of station averages were compared to find the grouping that provided the most predictive power. We also transformed these data, by exponentiation, and included measures of the strength (average of January and February as per Duffy et al. 2005) of the PDO (University Of Washington, <http://jisao.washington.edu/pdo/PDO.latest>) to develop alternative models. The best models were chosen based on predictive ability and parsimoniousness using Akaike's Information Criterion (AICc).

Results

More than 10.5 million acres (4-3 million hectares) burned in northwestern Alaska between 1950 and 2007, covering approximately 10.9% of the region. Of these burned acres, 7.9% have re-burned during this time period. We determined the fire cycle for the region to be 535 years. The range of the WAH covers this entire region, excluding the western most extremes of the Seward Peninsula. The percent area burned and re-burned, and fire cycle for other portions of the WAH's range, conservation units, and ecoregions are shown in Figure 4. Ecoregion fire cycles were similar to those reported by Kasischke et al. (2002). North of 68° latitude, only 1.1% of the area had burned with no re-burning at all. More than half of the burned area was attributed to the 2007 Anaktuvuk River fire. In the boreal forest ecosystem, 24.1% had burned but only 1.5% of those burned areas had re-burned during the past 58 years. The fire cycle for forested areas was 240 years. Burns only covered 9.2% of the tundra ecosystem, but 7.0% of that

area had re-burned in the past 58 years. The fire cycle for tundra areas was 630 years.

The average of the seven weather stations (Bettles, Big Delta, Fairbanks, McGrath, Nome, Northway and Tanana) that Duffy et al. (2005) used to model area burned in Interior Alaska provided the most explanatory power versus various subsets or the inclusion of the Barrow and Kotzebue station data. Average June and July temperatures have increased over time in northwestern Alaska (Figure 5; $F_{1,55} = 18.67$, $P = 0.001$, $Fr_{55} = 10.99$, $P = 0.002$), though average August temperature and precipitation from June through August did not show a significant relationship. The average August temperature for Barrow, Kotzebue and Nome was 46.7°F (8.2°C) $\pm 2.6^{\circ}\text{F}$ (1.4°C).

There was no significant relationship with time and area burned (i.e., there was no evidence that burned area is increasing over time; $F_{1,57} = 0.61$, $P = 0.439$).

However, when we omitted years with more than 200,000 acres (81,000 hectares) burned, the amount of burned area did

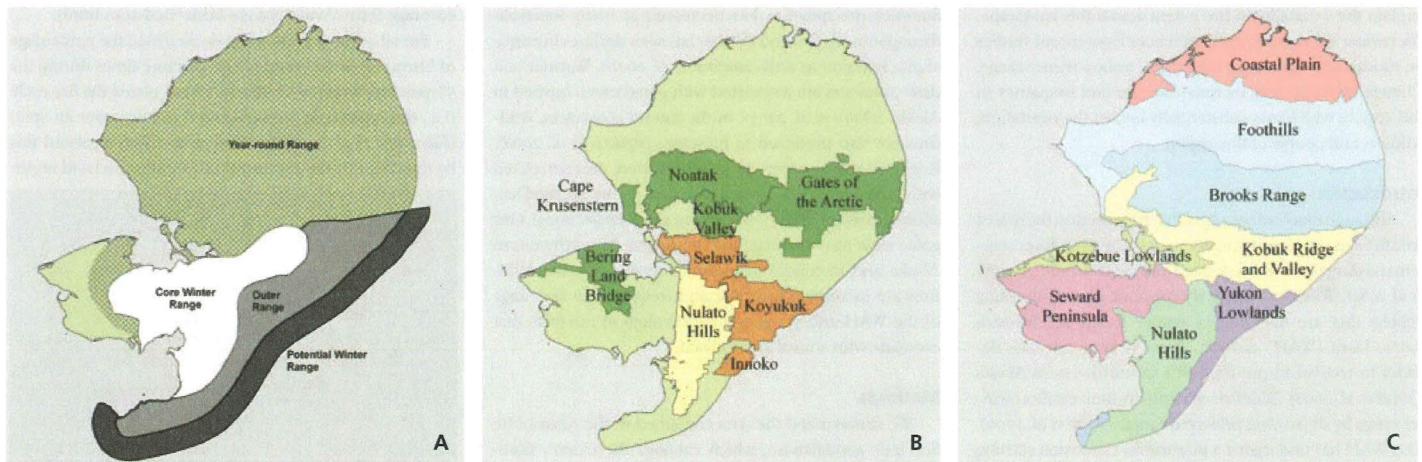


Figure 2. Study Area. A) Range of the Western Arctic Herd caribou. B) Conservation system units of northwestern Alaska: dark green, brown, and pale yellow are managed by NPS, USFWS, and BLM respectively. C) Ecoregions of northwestern Alaska.

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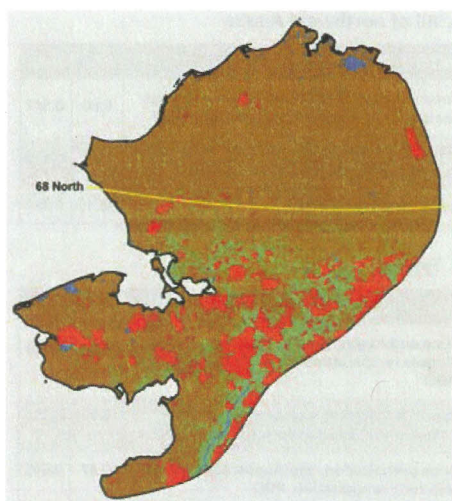


Figure 3. Wildfires on the landscape of northwestern Alaska, 1950-2007. Red polygons are burned areas, brown areas are dominated by tundra (non-forested) habitats, green is boreal forest ecosystems and blue depicts water.

increase over time ($F_{1,42} = 9.95$, $P = 0.003$). There were 15 years where the annual burn area was greater than 200,000 acres (81,000 hectares) and they were clustered into 4 groups - each group contained three to five years of high burn area, spanned four to nine years and were temporally separated by an average of 16.3 years ($sd = 0.72$). All but 1 (i.e., 14 of 15) of these high fire years were associated with average August temperatures exceeding 53°F (11.7°C). The exception occurred in 1969, which had the lowest June precipitation on record - well less than half the normal for the month. Although burned area was more than double in years with average August temperatures $> 53^{\circ}\text{F}$ (11.7°C), 226,000 versus 96,000 acres (91,000 versus 39,000 hectares), the difference was not statistically significant ($P > 0.1$).

The number of wildfires in northwestern Alaska and in the tundra ecosystem significantly increased from 1950 to

Region	% Area Burned	% Area Re-burned	Fire Cycle (years)
Caribou			
Core winter range	19.6	8.7	296
Outer range	34.9	6.8	166
Potential winter range	42.8	13.2	136
Conservation Units			
Cape Krusenstern (NPS)	0.1	0.0	53349
Gates of the Arctic (NPS)	2.7	5.0	2173
Noatak (NPS)	4.7	5.2	1237
Bering Land Bridge (NPS)	4.9	0.0	1188
Kobuk Valley (NPS)	6.9	3.5	844
Nulato Hills (BLM)	19.9	1.3	292
Selawik (FWS)	28.0	15.7	207
Koyukuk (FWS)	45.1	11.0	129
Innoko (FWS)	57.6	12.7	101
Ecoregions			
Coastal Plain	0.0	0.0	n/a
Brooks Range	1.0	3.3	5917
Foothills	1.7	0.0	3467
Kotzebue Lowlands	6.8	2.9	859
Seward Peninsula	13.9	15.1	418
Nulato Hills	20.5	2.0	283
Kobuk Ridge and Valley	30.0	8.6	193
Yukon Lowlands	42.2	10.0	137

Figure 4. Percent area burned and re-burned from 1950-2007 and fire cycle for various regions within northwest Alaska.

2007 ($F_{1,57} = 11.50$, $P = 0.001$, $F_{1,57} = 11.40$, $P = 0.001$, respectively). These trends disappeared when the analysis was limited to 1988-2007 ($F_{1,18} = 0.73$, $P = 0.404$, $F_{1,18} = 0.72$, $P = 0.406$, respectively). Dry weather in August was significantly associated with high August temperatures ($F_{1,55} = 7.42$, $P = 0.009$). A 6-factor (June-September precipitation and July-August temperature) model explained the most variation, approximately 31%, in annual burn area in northwestern Alaska. Explanatory power was increased when non-linear factors were added; a 5-factor model (June and August precipitation, exponential of June precipitation, ex-

ponential of August temperature and PDO) explained 55% of the variance in annual burned area. This model plus the exponential of June temperature explained 67% of the variance of average annual burned area within tundra ecosystems. The single factor of the exponential of August temperature explained 28% of the variance in burned area for northwestern Alaska and 47% for tundra fires in this region. For more on models, see Figure 6.

Discussion and Conclusions

We found that wildfire is a common occurrence in

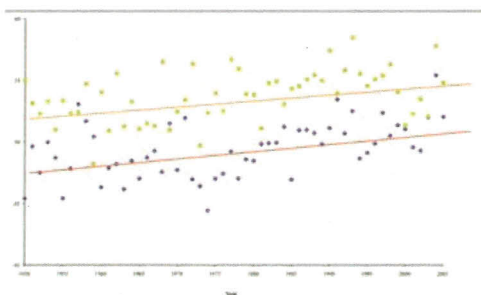


Figure 5. Significant increases in average June (blue diamonds) and July (green circles) temperatures from 1950-2005 in northwestern Alaska. Corresponding regression lines are depicted in red (lower line) and orange (upper line). Temperatures represent an average for the Barrow, Bettles, Kotzebue, McGrath, Nome and Tanana weather stations.

northwestern Alaska, in the range of the WAH and in tundra ecosystems. Burn acreage tended to decrease with latitude and longitude as, historically, fires have been rare events north of the Brooks Range and in maritime climates. Nearly 20% of the WAH core winter range has burned during the past 58 years. With current high population densities and declining lichen cover, the herd may seek out additional winter ranges Joly *et al.* 2007b). We found that the WAH's outer range has burned even more extensively than its core winter range. Potential future winter range, further to the east, was one of the most extensively burned areas in the region and also appeared to have one of the highest incidences of re-burning - likely because it is in the warmer and drier continental Interior climate zone. We believe this level of burning may prove to be an impediment for the herd to expand its winter range possibilities as extensive, mature lichen mats are unlikely to be found in these areas.

The extent of burned area within Selawik National Wildlife Refuge (28%) came as a surprise, as well as the fact that this area had the highest percentage of re-burned area of any sub-region within northwestern Alaska. These facts may help explain why the herd has largely abandoned

its historic winter range in the refuge, though density-dependant factors are likely to have also played an important role. The Seward Peninsula ecoregion had the second highest re-burn percentage, but is still utilized by the herd Joly *et al.* 2007a). One possible reason for the continued use of this region as winter range is that it contains > 4 times more area that has not burned in the past 58 years than the Selawik. Re-burn estimates need to be cautiously interpreted, however, as fire perimeters in the AFS database do not account for unburned inclusions and in earlier years were often based on rough maps produced by firefighting crews.

As we expected, wildfire affected a greater percentage (~25%) of forested areas than tundra areas (< 10%) in northwestern Alaska during the past 58 years. We found that burned tundra was 4-5 times more likely to re-burn than burned forest during our 58-year study period. This finding is intuitive because grasses and sedges that dominate tundra ecosystems recover very quickly (Jandt *et al.* 2008), and produce an important surface fuel (dead leaf litter) to carry new fires. Conversely, surface fuel loads (dominated by feather mosses) in the boreal forest can take decades to return (Kasischke and Stocks 2000, Camp *et al.* 2007). The fire cycle for tundra areas was more than 2.5 times longer than for forested areas. We did not find any examples of forested areas being re-burned more than once, while we found 11 cases in the tundra where a patch had re-burned more than once and one location on the central Seward Peninsula was mapped as burned in 1971, 1990, 1997 and 2002.

Using the large fire database, we were unable to detect a trend of increased annual burn area over time. This may be because climate warming is not yet strong enough to impact northwestern Alaska's fire regime or is intertwined with other factors that may suppress wildfires. However, when we omitted large fire seasons, we found a strong increasing trend (Figure 7). This may be explained in at least two ways. First, changes in the accuracy of fire maps and in fire suppression capability and management over the period of record may affect apparent burn acreage trends. Alterna-

A. All of northwest Alaska

Model Variables	Δ	Adj.
June and August precipitation, exp August temperature, exp June precipitation, PDO	0.00	0.547
June precipitation, exp August temperature, exp June precipitation, PDO	0.40	0.532
exp August temperature	20.12	0.284

B. Tundra

Model Variables	Δ	Adj.
June and August precipitation, exp June and August temperature, exp June precipitation, PDO	0.00	0.667
June precipitation, exp June and August temperature, exp June precipitation, PDO	0.16	0.656
June precipitation, exp August temperature, exp June precipitation, PDO	0.47	0.645
exp August temperature	19.10	0.467

Figure 6. Models for explaining the annual amount of area burned for (A) all of northwestern Alaska and (B) just for tundra (non-forested) ecosystems in northwestern Alaska, 1950-2005. The term "exp" means the exponential of that variable was used. The term "PDO" is the average of the January and February values of the strength of the Pacific Decadal Oscillation.

tively, climate warming may indeed be increasing annual area burned, but some other factor may induce pulses of large fire seasons that mask this overall trend when included in the regression analysis. The number of wild and tundra fires in northwestern Alaska appear to have significantly increased during the past 58 years. This, however, may also be an artifact of the fact that fires less than 1,000 acres (405 hectares) were not regularly mapped prior to 1988. We did not find evidence that the number of wild and tundra fires have increased since 1988 - a time period when all of these factors should be equivalent in the database. Increases in both the area burned and number of fires in the boreal forest

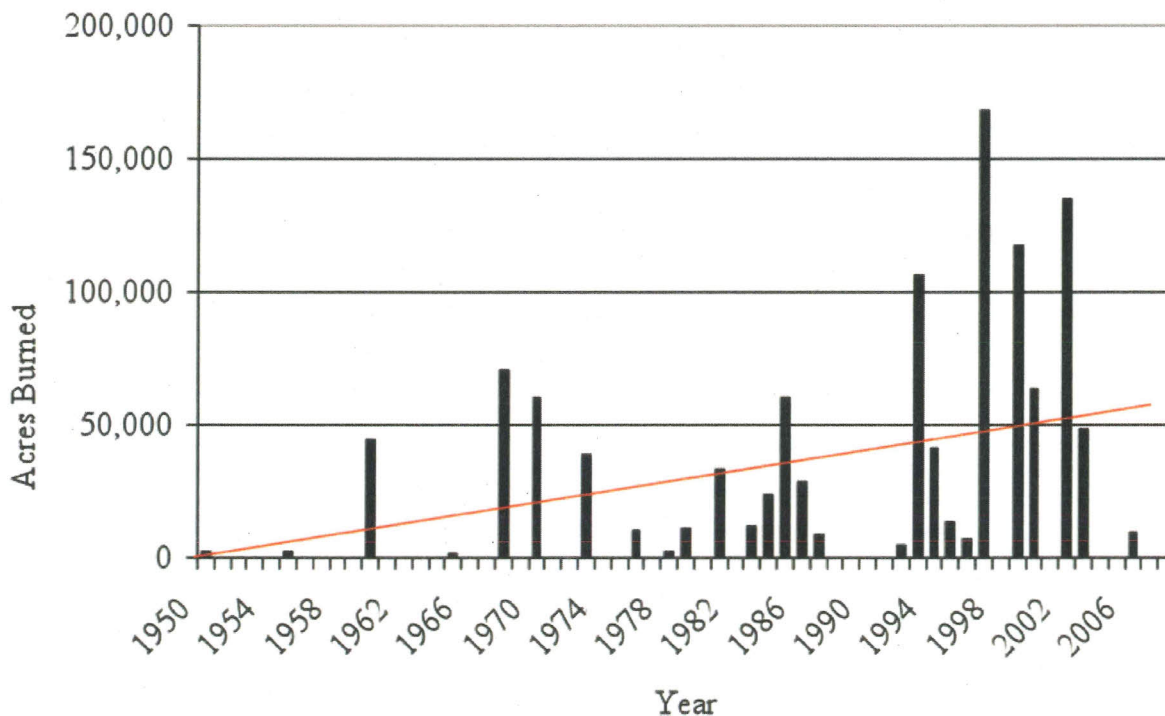


Figure 7. Amount of burned area in northwestern Alaska, 1950-2007, excluding years with very high acreages (> 200,000, n = 15). Red line is the regression line showing a significant increasing trend in burned area. This trend may be real or an artifact of the large fire database due to varying fire suppression and mapping efforts over the years.

have been identified (Kasischke and Turetsky 2006).

Our addition of non-linear and Pacific Decadal Oscillation factors greatly improved our model's ability to predict annual burned area. The model was even stronger at predicting the amount of burned tundra. The effects of climate change, potentially warmer and drier summer weather, may have non-linear effects on the fire regime of northwestern Alaska. For northwestern Alaska and tundra, the exponential of August temperature had the greatest explanatory power. For Interior boreal forests, June temperature was the single most important factor explaining variance in burned

area (Duffy et al. 2005). Part of this difference may be explained by phenology differences between the ecosystems - in other words, summer simply comes later to northwestern Alaska than it does to the Interior, therefore temperatures later in the year are more important in determining annual burn area. Additionally, August is on average the coolest of the summer months but has the greatest variability. Warm temperatures in August were correlated with dry weather and thus it is not surprising that they are associated with increased annual burned area in northwestern Alaska (Miller 1985).

Management Implications

The management of wildfires is a contentious issue, not least of all because of its implications for caribou winter range. Our findings are based on the large fire database maintained by the Alaska Fire Service and thus should be viewed carefully. We believe our preliminary findings provide a starting point for understanding the importance of wildfire in northwestern Alaska and tundra ecosystems in general. While fires are less common in tundra ecosystems than in boreal forests, tundra ecosystems are capable of burning much more frequently. Understanding the fire regime of this region and its impacts on the WAH will be

critical information utilized in the development of a fire management plan for the winter range of the herd.

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