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Bryan Kim　　　　　　　　Date

Climate factors associated with human exposure rate to fox rabies in Alaska,

USA, 1995-2008

By

Bryan Kim

Master of Public Health

Global Epidemiology

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Kevin Ward
Faculty Thesis Advisor

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D.V.M. Konkuk University, 2009

Faculty Thesis Advisor: Kevin Ward, PhD

An abstract of
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Abstract

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By Bryan Kim

Rabies is regarded as endemic among the arctic fox (*Vulpes lagopus*) and the red fox (*Vulpes vulpes*) in northern and western Alaska and this study describes how climate factors are likely to be associated with cyclic rabies incidence and human exposure rate to fox rabies based on the ecology of fox species. Based upon study results, there is a pronounced seasonal trend of reported rabid foxes in Alaska, with a peak in winter. Reported rabid foxes in northern Alaska appear to have a stronger seasonal effect than rabid foxes in southern Alaska. Rabid arctic foxes seem to be affected by climate change to a greater degree than red foxes. In the case of arctic foxes, climate factors from 2 months prior to the reported cases had the most significant effect. The effect of climatic change may also be associated with the sea ice stability which is the key factor for the marine food sources of arctic foxes and the variation of sea ice extent may affect arctic fox population dynamics. In the case of red foxes, seasonality was not found to be significant across the overall study area.

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Introduction

Climate factors are a necessary component of investigation when studying the epidemiology of infectious disease and infectious disease patterns (1). This relationship applies to zoonotic infectious disease as well. Zoonotic diseases are infectious diseases that can be transmitted from wild and domestic animals to humans. Many zoonotic diseases in the Arctic area, such as rabies, brucellosis, and tularemia, are assumed to be associated with climate variation but the exact relationship is not fully understood (2). Rabies is a well known zoonotic infectious disease and rabies virus belongs to the family *Rhabdoviridae* and the genus *Lyssavirus* (3). Rabies is often called 'Polar madness' in the Arctic area (4) and is believed to be endemic among the fox population with a three to four year epizootic cycle (5). The epizootiology and perpetuation of rabies virus in Alaska, however, remains largely unknown.

The arctic fox (*Vulpes lagopus*) and the red fox (*Vulpes vulpes*) are the two major fox species in Alaska The arctic fox is known as the smallest species among the family *Canidae* with a weight of 2.5 to 4kg (6). They are well adjusted to the cold weather with heat saving body structures and can even lower their metabolic rate when necessary (7). The Arctic fox usually lives in the tundra and has been shown to switch habitat types between the inland and coastal tundra based on food availability (6). The home range of the arctic fox includes the arctic tundra of Eurasia and North America, and most arctic islands such as Greenland, Iceland, and Canada (8).

The other main fox species in Alaska is the red fox, which has the widest home range among carnivores. They are known to have expanded their distribution into the northern region in the early 20th century (9). The red fox is considered the relatively larger and stronger competitor of the arctic fox (9). It has been suggested that arctic foxes will avoid breeding near red foxes because of competition and usually locate their dens in higher altitudes to avoid contact with their superior competitors (10, 11). While resource availability is considered the main factor for the northern advance of the red fox, the arctic fox distribution is driven by interspecific competition with many arctic foxes becoming expelled from their dens by red foxes (11). This competition is more likely to increase in winter due to reduced food sources. There are even reports of the red fox preying on the arctic fox (12). It is widely understood that rabies transmission can be surged due to exacerbated competition and physical contact through fighting or predation (12).

The western Arctic went through a temperature increase during the twentieth century (13) and is believed to be more susceptible to climate change as global warming has a greater influence at high latitudes (14). The average temperature of the Arctic has increased by 4°C over this century to an average of 7°C. This is much higher than other areas of the world (15). Climate change, however, is not just confined to temperature. It also involves other factors such as precipitation (16), snow cover (17, 18), and sea ice concentration (19). Accelerated climate change may alter the spread and proliferation of zoonoses by affecting host population densities, home ranges, and seasonal disease dynamics (20), as well as the timing and persistence of outbreaks (2). Furthermore, interactions with other species may also influence the populations indirectly (21). In this thesis, we examine if there are any apparent seasonal, regional, temporal or climate effects upon the occurrence of rabies in Alaska foxes, and model the potential outcome upon resultant human exposures to rabid foxes.

Materials and Methods

Study area

Alaska is the largest state of the United States at almost 571,951 square miles. It is the twice the size of Texas. Oil, tourism, and fisheries are the primary sources of the local economy. More than 80 percent of the state's budget is from oil revenue and there are about 1.6 million visitors every year (22). The overall population of Alaska is 626,932 based on 2000 U.S. Census data. Unlike most other states in the U.S. which are divided into counties, Alaska is instead divided into 16 boroughs. The study area for this analysis consists of five boroughs where the majority of rabies cases were reported (Figure 1): North Slope (population: 7,385), North West Arctic (population: 7,208), Nome (population: 9,196), Bethel (population: 16,006), and Bristol Bay (population: 1,258). These five boroughs comprise only 6.5 percent of the state's total population but together reported 286 (96.6%) of the state's 296 reported rabid animals from 1995 to 2008.

Rabies surveillance data

In 1938, animal rabies became a notifiable disease throughout the United States (23). New cases are reported to the local health or agricultural department after laboratory verification and the Centers for Disease Control and Prevention (CDC) then collects these data on a weekly basis (23). The Alaska State Virology Laboratory (ASVL) in Fairbanks serves as the central processing center for rabies verification in Alaska and has done so for the last 50 years. According to the Alaska Rabies Prevention and Control Manual, animals are tested for rabies if they meet any one of the following criteria (24).

" 1. Animals that have bitten humans to determine whether rabies post-exposure prophylaxis is indicated.

2. Wildlife that have bitten pets to determine the appropriate follow-up for the pet, i.e., euthanasia or variable periods of quarantine/confinement.

3. Animals exhibiting rabies compatible behavior as part of surveillance for detecting rabies activity in certain parts of the state."

The number of cases meeting each of the above individual criteria is uncertain as this level of detail is not reported to the Alaska State Section of Epidemiology (SOE) (24). It is also important to note that only health care providers are legally required to report suspected exposures or rabies case. As the exact species of fox was not collected prior to 1995, our analyses include surveillance data from 1995 to 2008.

Climate data

The coastline of Alaska spans approximately 6,640 miles and as such a large portion of Alaska is affected by ocean water and sea ice. Climate data were obtained from the Alaska Climate Research Center located at the Geophysical Institute, University of Alaska Fairbanks (25). There are 21 first order stations in Alaska which are maintained by the National Weather Service (NWS). Five climate factors were extracted on monthly basis from 1995 to 2008 from the 5 stations located in the boroughs involved in this study. Factors included average temperature (degrees Celsius), precipitation (inches), snowfall (inches), snow depth (inches), and temperature range (degrees Celsius, maximum temperature - minimum temperature). Annual averages or totals, as appropriate for each factor, are provided in Figures 2-6.

Statistical Analysis

Poisson regression (26) was used to examine the patterns of human exposure to fox rabies with respect to climate factors. The unit of analysis was a borough-month, calculated as the number of boroughs (5) times the number of months (168), for a sample size of 840. Model parameters included average temperature, precipitation (rain), snowfall, snow depth, temperature range, borough, season, year and life cycle of the arctic fox. Borough was included to test for spatial variation among borough, year to examine temporal associations, and season to explore the effects of seasonal variation. Season was defined using a 3 month time interval as follows: Winter (Dec to Feb), Spring (Mar to May), Summer (Jun to Aug), and Fall (Sep to Nov). We also created dummy variables for the life cycle of a fox including fox breeding season (Feb to May) and dispersal season (Sep to Nov) to see the influence of life cycle on rabies exposure rate. Alpha was set at 0.05 and p-values were obtained using a Wald chi-square test. The population size of each borough, based on 2000 U.S. Census data, was used as an offset for the Poisson model since our goal was to measure the human exposure rate to rabid foxes. 2000 Census data were used as they were measured in the middle of study period and were the most accurate and standardized estimate available of the population. Modeling was performed using SAS 9.2. and model fit was evaluated using the deviance and Pearson chi-square of each model (27). The measure of effect for multivariate analysis was the exposure rate ratio. Potential overdispersion was adjusted by SCALE=PEARSON.

The incubation period of rabies is diverse, but is usually estimated between 3 to 8 weeks in Alaska according to the rabies control manual (24). To more fully understand the effect of climate at the time of rabies transmission, we needed to include time lag climate data of at least 2 months based on the incubation period of infected animals. Therefore, to fully account for the effect of climate around the time of transmission, all 5 climate factors were evaluated with a time lag up to 3 months. To account for correlated data, we screened the time lag variables by dropping the most statistically insignificant one until we had only one time variable per climate factor. Variable interactions were assessed in the model by creating all possible 2-way interaction terms among the climate factors. Collinearity of the data was evaluated using variance inflation factors (VIF) and condition indices (CI) (28, 29). We also created separate models by fox species to better understand the factors affecting human exposure rates to each species.

Results

The number of reported rabid animals fluctuated over the study period (Figure 7). A total of 716 animals were tested for rabies in the 5 boroughs and 286 were identified positive. Foxes (113 arctic, 140 red, one unspecified fox) accounted for the majority (88.6%) of the 286 positive reports while 28 dogs, two otters, one wolf, and one coyote were also reported rabid. The reported number of rabid arctic and red fox were correlated over the study period (r = 0.47, P<0.01, Figure 8). Table 1 presents total case counts and average climate data over the study period by borough and season. Arctic fox cases were primarily reported from the North Slope borough while red fox cases were more evenly distributed across the five boroughs. Climate data varied considerably as the 5 boroughs differ in terms of latitudinal location. Average temperature, precipitation, and temperature range generally increased at lower latitudes while average snow depth generally increased at higher latitudes. Nome had the greatest snowfall and snow depth in winter while Bristol Bay, located in the most southern region among the 5 boroughs, had the least. Correlation analyses were conducted to estimate the univariate association between each time-lagged climate factor and the number of reported rabid foxes (Table 2). The results showed that average temperature, precipitation, and temperature range were inversely correlated with reported cases. Snow depth and snow fall, on the other hand, were positively correlated with case counts but were only statistically significant for selected time lags.

In the arctic fox model (Table 3), two month time lag data was modeled for all climate variables. The exposure rate was negatively associated with precipitation (ERR = 0.21, P<0.01) and positively associated with snowfall (ERR = 1.09, P<0.01) Snow depth, lifecycle, and calendar year were nonsignificant predictors and were dropped from model. Independent of the associations with the 2 month time lagged climate variables, there was a pronounced seasonal effect for the exposure rate to rabid arctic foxes with rates greater in winter, fall and spring, relative to summer. There was also a significant geographic effect with the North Slope having a 13 fold increased exposure rate to arctic fox rabies (ERR = 12.89, P<0.01) relative to the referent borough of Bethel. An interaction between average temperature and temperature range was observed in this model. If the temperature range was lower than around 7.85 (modeling average value of other predictors), the exposure rate to rabid arctic foxes was inversely related with the average temperature. In contrast, if the temperature range was higher than about 7.85, the exposure rate increased as the average temperature increased (Table 4). Thus, the effect of average temperature changed as the temperature range changed. It is noteworthy, however, that the average temperature range of North Slope, where the majority of the rabid arctic fox cases were reported, was consistently lower than 7.85.

The red fox model is presented in Table 5. The average temperature of the preceding month and precipitation 3 months prior were both negatively associated with the exposure rate to rabies. No relationship with other climate factors was identified. Unlike the model for arctic foxes, seasonality was not found to be significant in the red fox model after controlling for other factors. As opposed to arctic foxes, where the ERR was greatest in the most northern borough, the exposure rate to red foxes was greatest in Bristol Bay, the most southern of the 5 boroughs (Table 5). The offset of the model was the population of each borough and the relatively small population of Bristol Bay may have affected model results.

Discussion

Our findings from this study indicate that the human exposure rate to fox rabies was related with time lagged climate variation, specifically for average temperature, precipitation, and snow fall. Seasonal and geographical differences were also identified although there were distinct differences between fox species. This was true for the climate effects as well. Based on our study results (Tab 3,5), the exposure rate to the rabid arctic fox seems more likely to be affected by climate change than the exposure rate to the rabid red fox.

As we seek to better understand the specific mechanisms through which the factors identified as significant in this study may indirectly affect the exposure to fox rabies, we look to the existing literature for possible pathways. As noted in our study, there was a seasonal effect of human exposure to arctic fox rabies in Alaska with a peak in reported rabid foxes in winter and a significant effect in spring. It has been shown that seasonality may be associated with mating season when foxes actively protect their territories against invaders (3). Arctic foxes usually breed between February and May, with parturition taking place from April to July, following a gestation period of 51 to 54 days (30). This behavioral change may lead to increased contact rates between fox species and result in increased human exposure to fox rabies. Contact rates could then be reduced in summer and fall as foxes stay close to their den to take care of the litter. In winter, Arctic foxes switch to migratory behavior to seek food (31) and contact rates are again likely to increase. In our analysis, we created dummy variables to see the influence of life cycle on human exposure rate but the results were not statistically significant once other factors were controlled. This ecological cycle alone, thus, may not be sufficient to explain the variation observed in the human exposure rate as it does not entirely account for population density and other factors. It has been observed that young foxes typically leave their dens in the fall and this dispersal may increase the population density of foxes throughout the winter (32). Several authors have concluded that rabies primarily affects young animals (33-35) and that a lack of experience regarding territory and harsh environment might be one of the reasons for this observation. Unfortunately the specific ages of reported foxes were unavailable in this study so we could not explore this association. Another factor that could influence population density is precipitation. Our data did indicate that precipitation was negatively associated with the exposure rate to fox rabies in Alaska (Tab 3, 5). There is a possibility that the precipitation around the time of transmission is related with fox population dynamics. As precipitation increase, foxes may move relatively short distances because of heal loss, resulting in reduced contact rates.

To further understand the effects of seasonal variation, we need to look at the ecology of arctic foxes and the relationship of climate change to habitat site. Arctic foxes normally utilize two different habitat types: inland and coastal tundra (6). Lemmings and small rodents are the main food source within inland habitats but lemming populations have been shown to exhibit large fluctuation with a 3 to 5 year cycle (36). Research has demonstrated that arctic fox population dynamics are closely related with lemming dynamics (37). Unfortunately recent lemming population cycles and the effects of climate change on these cycles in Alaska were not available. Nonetheless, it is important to at least consider the effects of understand lemming population cycles as one recent study suggested that climate warming may extend the length of the cycle and abate the maximum densities (38). For example, the typical 4-year lemming cycle has been absent in eastern Greenland since 2000 (38). Another statistical modeling study of Norwegian lemming dynamics (39) also supported that climate warming has led to a recession of the lemming cycle. If the lemming cycle in Alaska is also similarly affected by climate change, it is possible that arctic foxes might switch to primarily coastal habitats which appear to be supported by our data.

In the coastal tundra, the marine food sources of the arctic fox mainly consist of seal carcasses left by polar bears (*Ursus maritimus*) on the pack ice (40) and the pups of ringed seals (41). There is evidence that seal productivity is related with arctic fox densities (42). Geese and waders are also part of the marine food source and their reproductive success has been shown to decrease when inland lemming numbers decline (43, 44). These species have restricted distributions and specialized feeding habits based on sea ice extent (45) which suggest that changes in the sea ice may alter ecological dynamics of these species as well as the arctic fox. Seals and polar bears are especially vulnerable to the loss of sea ice (46, 47) and food sources for these species may become less available as sea ice levels decrease (6, 48). Decreased access to food on the sea ice would have a negative influence on arctic fox survival especially when inland food sources are scarce (37).

One primary climate factor that could affect the sea ice extent is temperature. As the average temperature increases, sea ice may become unstabilized which could negatively impact sea ice dependent species as well as access to marine food sources for the arctic foxes. Some authors have already observed that the arctic sea ice and temperature are inversely associated (13).

Based on our findings and the above studies, we hypothesize that our findings could affect rabies exposure through the model presented in Fig 9. Decreased sea ice extent as a result of increased temperatures might hinder or limit the movement of arctic foxes and limit access to marine food sources. This could potentially cause increased isolation of some populations, thus decreasing the opportunity for contact and transmission of rabies. There is a possibility that the limited space available to isolated foxes could contribute to rabies transmission within these isolated fox populations, but these cases are unlikely to be associated with human exposure due to the inaccessibility of these habitats to humans. In contrast, when the temperature decreases and the sea ice become stable, marine food resources for the arctic fox also might stabilize and become more accessible. We would expect the population density to increase or at least be maintained due to stable marine food resources. Arctic fox might then be able to move long distances along the sea ice without geographical restriction, leading to increased contact rates among fox species and increased human exposure rate. Long range movement with a tendency to assemble at limited food sources in winter is regarded as another way for increased transmission of rabies virus (49). We were unable to measure the hypothetical relationship directly in this study.

In Figure 10, the reported number of fox rabies by month is similar to the pattern of the average arctic sea ice extent from 2002 to 2008($r=0.80$, $P<0.01$, data from Japan Aerospace Exploration Agency Earth Observation Research Center (JAXA/EORC)). This pattern is also similar to the annual course of ice concentration for the average of the 36 year time span (1972-2007) for the Southern Beaufort Sea which located in the northern region of the North Slope of Alaska (50). This ecologic correlation lends support to our hypothetical association between the sea ice extent and fox population dynamics in Alaska. This needs to be further explored given the ecologic nature of this data.

In terms of geography, rabies reporting boroughs were primarily located in the coastal area. Although detailed location of fox dens were not available, rabid arctic foxes were mainly reported from three northern boroughs of Alaska. (i.e. North Slope, Northwest Arctic and Nome, Figure 11) Meanwhile, rabid red foxes were primarily reported along the entire northern and eastern coasts of Alaska. One of the main reasons for this distribution might be the food availability. It is well known that food sources inland are unstable compared to marine food sources (6) and unstable and irregular lemming cycle due to climate change might have aggravated the inland food availability and forced fox species to move towards the coastal region.

There are a number of limitations we need to take into account in this study. In the statistical analysis, we used Poisson regression. One of the underlying assumptions with Poisson regression is that the probability of an event during a certain time interval is independent of the occurrence of other events during that interval. Rabies is transmitted by contact and it is hard to conclude that the number of rabies per every unit (borough month) is completely independent of the number of rabies in other units. We assumed that this influence could be minimized because of the large geographical area of each borough. Phylogenetic studies of arctic rabies virus in Alaska during 2005 to 2007 (51) supported that the rabies virus of certain boroughs are geographically independent of adjacent boroughs. Major limitations to model development also include the relatively large size of the unit areas selected based upon political boundaries, imprecise geographical locality data and the lack of enhanced surveillance. Due to the relatively small population in Alaska and large number of travelers, reporting bias might have affected the results of this study. This study also did not consider the seasonal variation of human activity which might have affected the number of reported animals. In addition to this, interaction between the two fox species needs to be taken into consideration to better understand rabies transmission in Alaska even if it is extremely hard to measure.

Based on previous studies and this study's results, it is evident that rabies epidemiology in Alaska is affected by climate change. Prediction of epizootic cycles via enhanced surveillance is essential for preventing potential human rabies infection. Further research efforts should be devoted to the estimate of lemming population cycle and fox population density for better understanding of fox rabies epidemiology in Alaska.

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Table 1. Total number of reported arctic & red fox cases and average seasonal climate data of the 5 study boroughs in Alaska, 1995-2008

Borough	Season	Arctic fox cases	Red fox cases	Average Temperature (degrees Celsius)	Average Precipitation (inches)	Average Snowfall (inches)	Average Snowdepth (inches)	Average Temperature Range (Max-Min)
North Slope	winter	58	19	-23.9	0.1	3.3	10.1	6.7
	spring	20	8	-15.4	0.1	2.9	9.5	6.5
	summer	2	1	3.8	0.8	0.5	0.0	5.9
	fall	8	3	-6.9	0.5	7.5	4.4	4.9
Northwest Arctic	winter	4	12	-18	0.7	12.7	18.6	7.6
	spring	6	13	-8.7	0.5	4.0	17.3	7.7
	summer	0	6	10.4	1.4	0.0	0.0	5.4
	fall	0	0	-3.1	1.0	5.6	2.0	4.9
Nome	winter	4	9	-13.7	1.0	16.3	19.6	8.3
	spring	4	8	-5.0	0.8	6.4	14.7	7.6
	summer	1	7	9.7	2.1	0.1	0.0	6.7
	fall	0	3	-0.9	1.7	5.4	1.4	6.5
Bethel	winter	1	9	-12.6	0.8	10.6	8.2	7.0
	spring	5	25	-1.9	0.9	6.7	3.9	8.8
	summer	0	4	12.5	2.6	0.0	0.0	8.5
	fall	0	3	-0.3	2.1	6.3	1.4	6.8
Bristol Bay	winter	0	3	-8.0	0.9	8.4	2.7	8.9
	spring	0	5	1.1	0.9	3.8	0.5	10.4
	summer	0	2	12.4	2.4	0.0	0.0	9.8
	fall	0	0	1.8	2.4	2.7	0.3	8.7
	Total	**113**	**140**					

Table 2. Correlations between fox rabies and climate factors of 5 study boroughs in Alaska 1995-2008

Climate factors	time lag (months)	r	p value
Average temperature	0	-0.26	<0.01
	1	-0.30	<0.01
	2	-0.26	<0.01
	3	-0.13	<0.01
Precipitation	0	-0.15	<0.01
	1	-0.17	<0.01
	2	-0.17	<0.01
	3	-0.15	<0.01
Snowfall	0	0.03	0.37
	1	0.05	0.11
	2	0.10	<0.01
	3	0.05	0.30
Snow depth	0	0.13	<0.01
	1	0.13	<0.01
	2	0.09	<0.01
	3	-0.02	0.72
Temperature range	0	-0.04	0.24
	1	-0.09	0.01
	2	-0.12	<0.01
	3	-0.09	0.05

Table 3. Factors associated with arctic fox rabies, Alaska, 1995-2008

Variable	p-value	ERR*	95% CI**
Climate factors (2 months prior)			
Average temperature	**0.0002**	0.84	0.77, 0.92
Precipitation	**0.0005**	0.21	0.09, 0.51
Temperature range	0.1225	1.22	0.95, 1.58
Snow fall	**0.0004**	1.09	1.04, 1.14
Interaction***	**0.0023**	1.02	1.01, 1.04
Season			
spring	**0.0088**	5.61	1.55, 20.42
summer	Ref	Ref	Ref
fall	**0.0011**	10.50	2.57, 42.94
winter	**<.0001**	12.68	3.83, 41.97
Borough			
North Slope(PABR)	**<.0001**	12.89	4.88, 34.10
Northwest Arctic(PAOT)	0.0805	2.53	0.89, 7.20
Nome(PAOM)	0.0603	2.65	0.96, 7.34
Bethel(PABE)	Ref	Ref	Ref
Bristol Bay(PAKN)	No Arctic fox case observed		

*ERR represents exposure rate ratio
**CI represents confidence interval
*** Interaction between 2 month time lag average temperature and 2 month time lag temperature range

Table 4. Interpretation of interaction term in the arctic fox model

Average temperature (degrees Celsius)	Precipitation (inches)	Temperature range (Max temp-Min temp)	Snowfall (inches)	Interaction between average temperature & temperature range	Exposure rate ratio
10	0.5	9	5	90	5.38
5	0.5	9	5	45	4.75
0	0.5	9	5	0	4.19
-5	0.5	9	5	-45	3.70
-10	0.5	9	5	-90	3.26
10	0.5	7.85	5	78.5	3.32
5	0.5	7.85	5	39.25	3.33
0	0.5	7.85	5	0	3.33
-5	0.5	7.85	5	-39.25	3.34
-10	0.5	7.85	5	-78.5	3.34
10	0.5	5	5	50	1.00
5	0.5	5	5	25	1.37
0	0.5	5	5	0	1.88
-5	0.5	5	5	-25	2.58
-10	0.5	5	5	-50	3.54

Table 5. Factors associated with red fox rabies, Alaska, 1995-2008

Variable	p-value	ERR*	95% CI**
Climate factors			
Average temperature 1 month prior	**<.0001**	0.94	0.92, 0.96
Precipitation 3 months prior	**0.0009**	0.64	0.49, 0.83
Borough			
North Slope(PABR)	**0.0468**	0.53	0.28, 0.99
Northwest Arctic(PAOT)	0.9669	0.99	0.56, 1.73
Nome(PAOM)	0.9911	0.99	0.57, 1.75
Bethel(PABE)	Ref	Ref	Ref
Bristol Bay(PAKN)	**0.0031**	3.58	1.59, 8.31

*ERR represents exposure rate ratio
**CI represents confidence interval

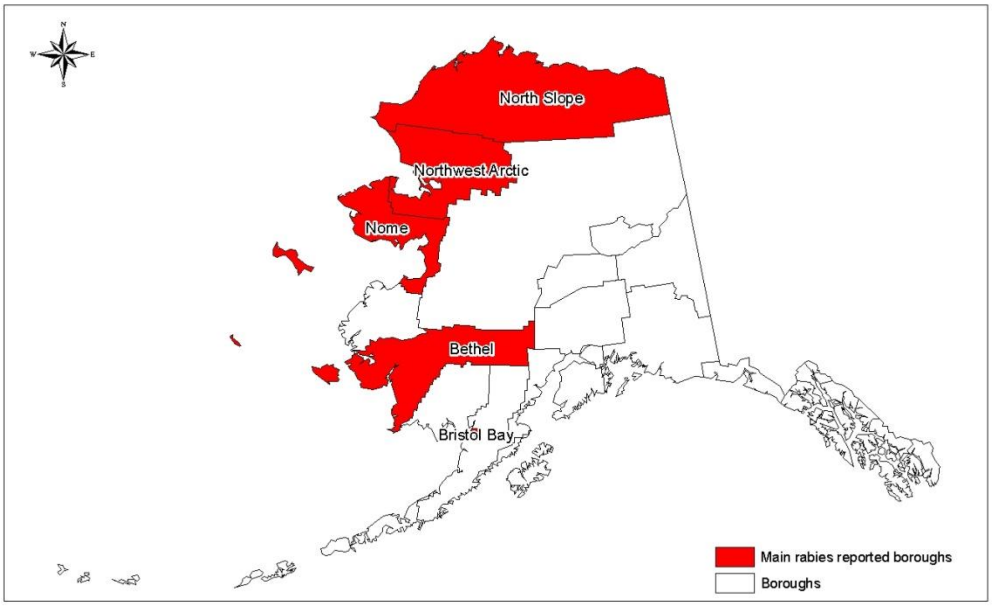


Figure 1. Five primary boroughs with majority of reported rabies cases in Alaska 1995-2008
(North Slope (PABR), Northwest Arctic(PAOT), Nome(PAOM), Bethel(PABE), Bristol Bay(PAKN))

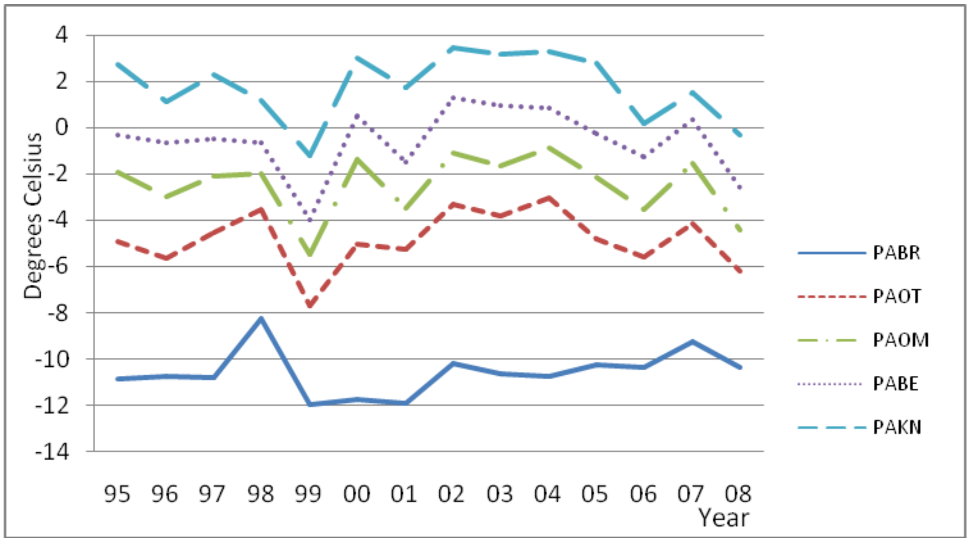


Figure 2. Average temperature of five study boroughs in Alaska

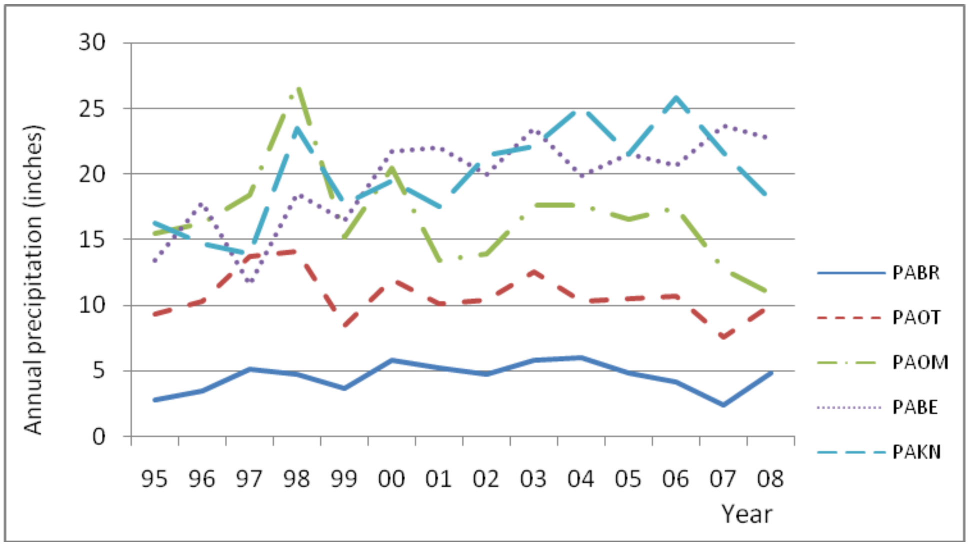


Figure 3. Annual precipitation of five study boroughs in Alaska

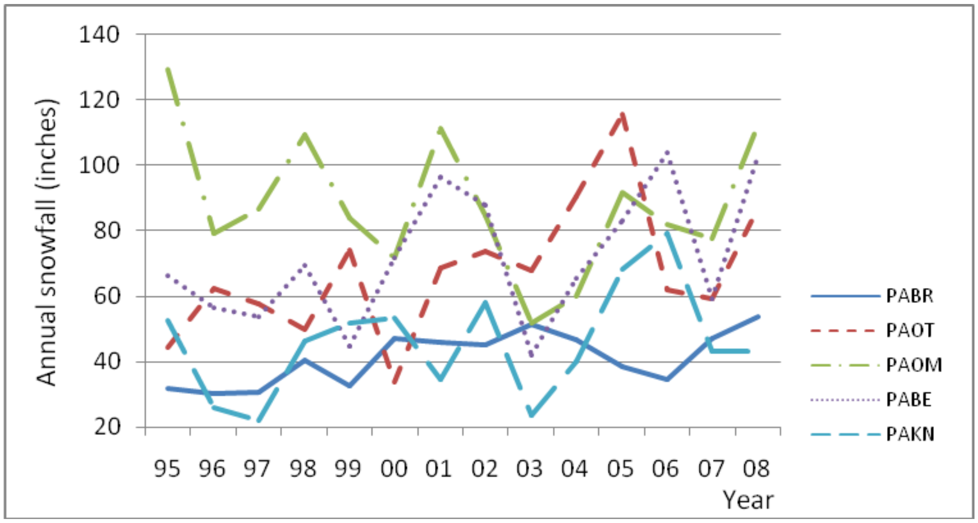


Figure 4. Annual snowfall of five study boroughs in Alaska

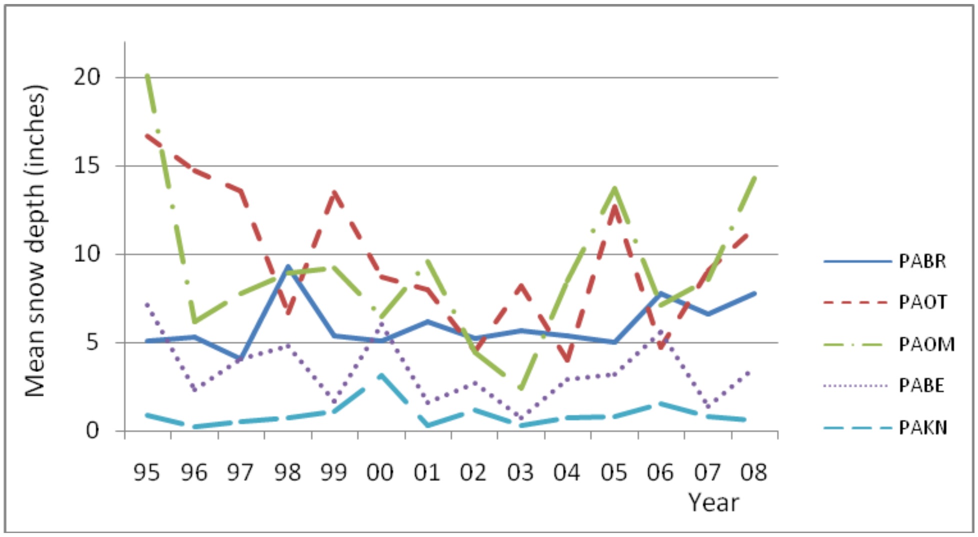


Figure 5. Average snow depth of five study boroughs in Alaska

Figure 6. Average temperature range (maximum-minimum) of five study boroughs in Alaska

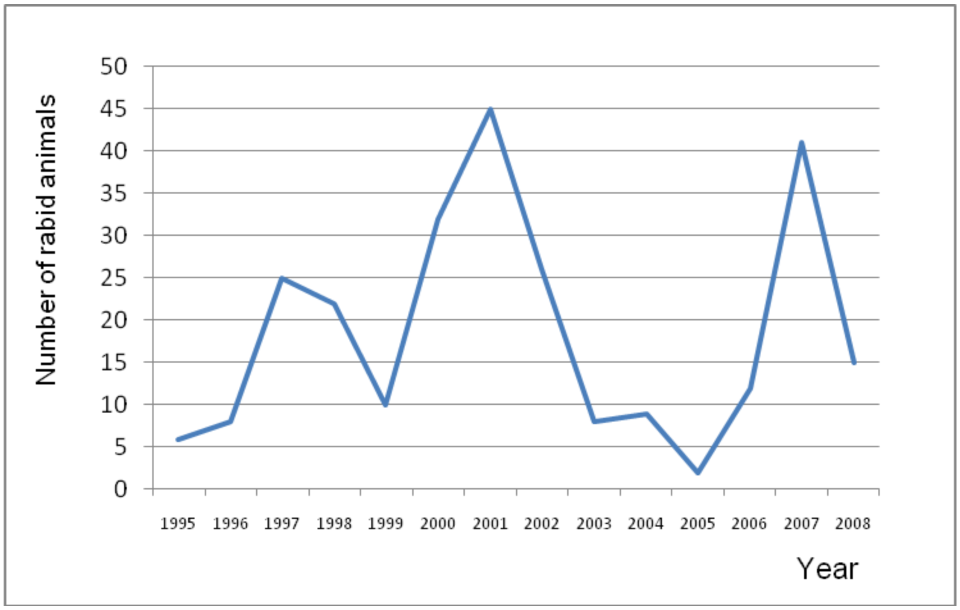


Figure 7. Number of reported rabid animals in Alaska from 1995 to 2008

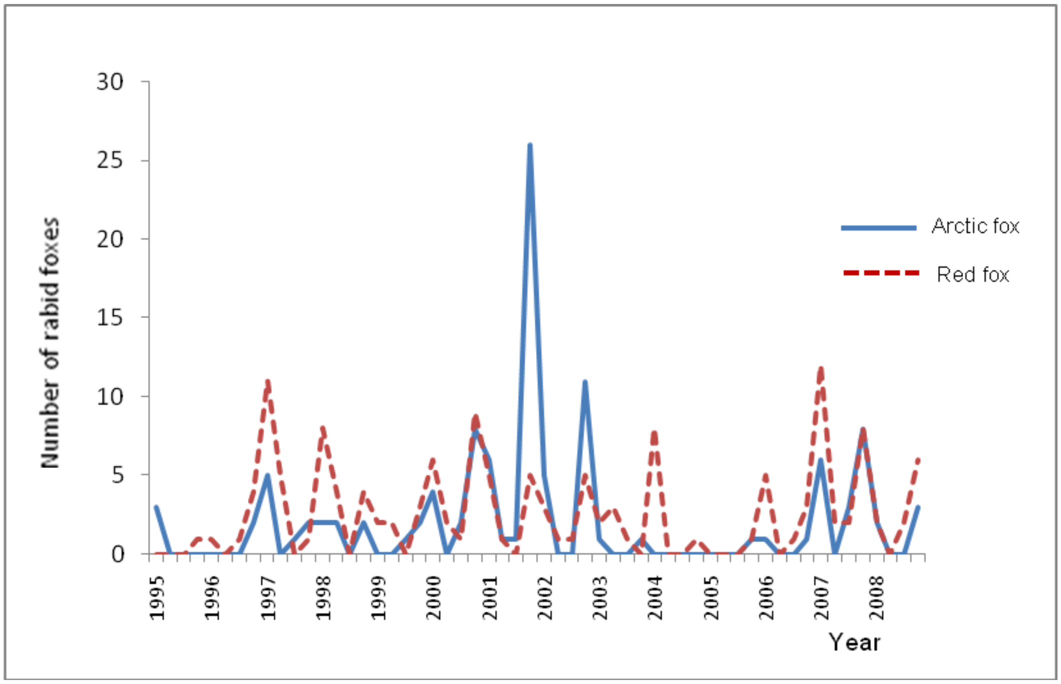
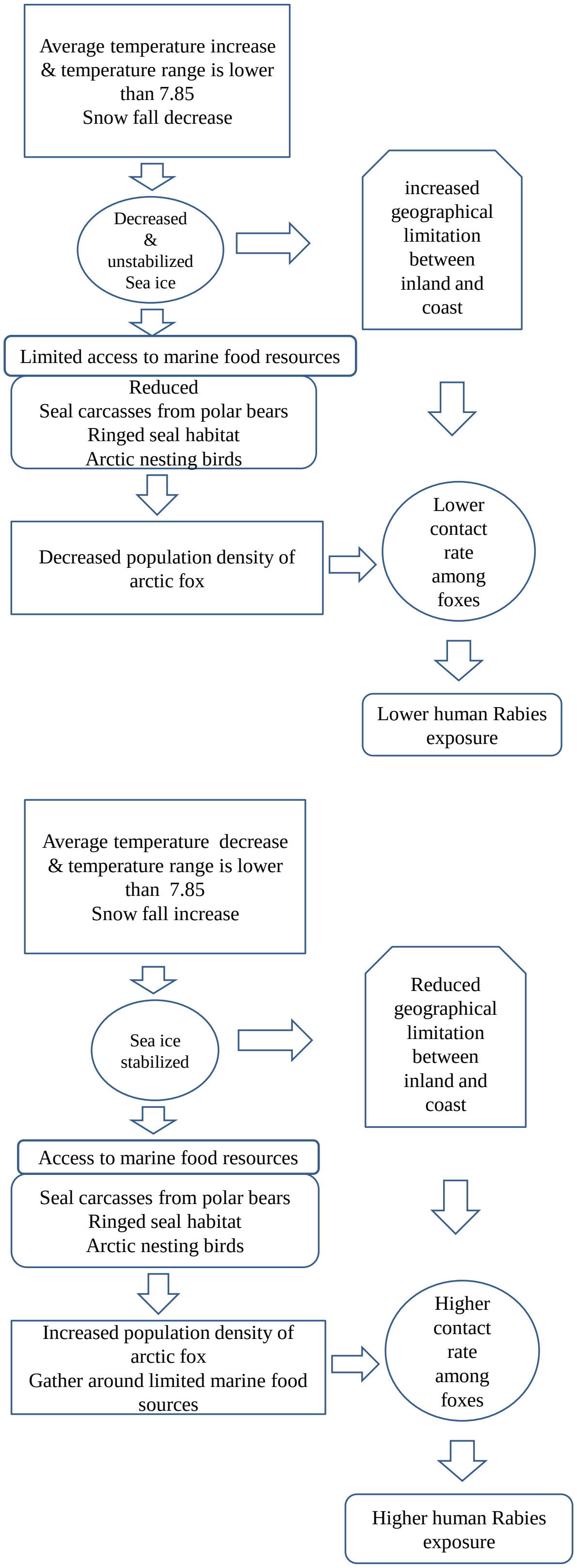


Figure 8. Reported rabies in arctic and red foxes from 5 study boroughs in Alaska,1995-2008

Figure 9. Hypothetical model of climate change on human exposure to arctic fox rabies in Alaska



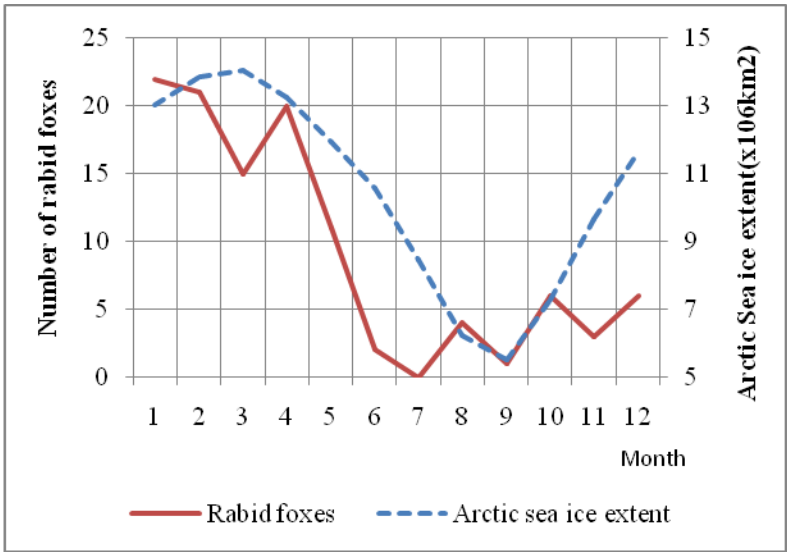


Figure 10. Number of rabid foxes and average arctic sea ice extent for the time period from 2002 – 2008

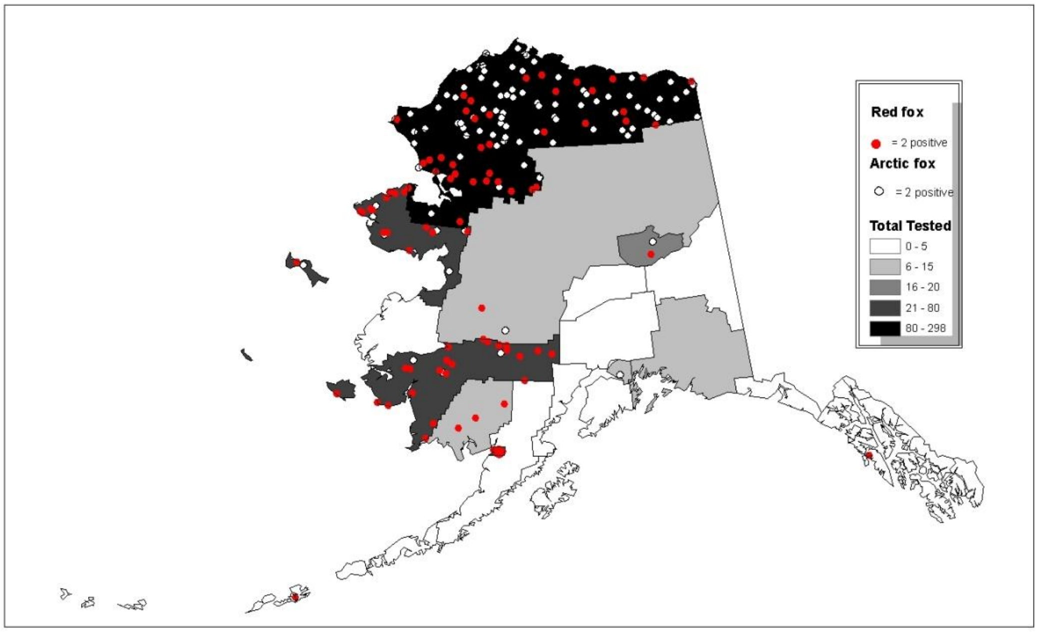


Figure 11. Distribution of Fox rabies, Alaska, 1995-2008(Dots were randomly distributed within boroughs based on densities)