# CUMULATIVE ECOLOGICAL EFFECTS OF SNOWMOBILES

A Proposal

by

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## INTRODUCTION

The continued intrusion of motorized activity and human development into areas formally dominated by natural processes has resulted in the degradation of ecosystems around the world (Hannah et al. 1994). These dramatic changes to the landscape have caused a need to know where human disturbance is located and how those locations are specifically being affected. Snowmobiling is a popular winter activity in North America. It can have its benefits for promoting the use and appreciation of wilderness areas and as an important tool for trappers, hunters, and others (Simpson 1987). However, snowmobile activity also causes a variety of effects to wildlife and the environment during winter when resources are limited and environmental conditions are severe. It is therefore important to improve our understanding of how snowmobiles cumulatively affect the environment in order to make informed decisions to ensure that systems do not become degraded.

A snowmobile is a motorized land vehicle intended for travel over snow. They possess two skis at the front for directional control and a continuous, tank-like, Kevlar-composite track at the rear that provides traction and propulsion. Their design is much like motorcycles and all-terrain vehicles (ATVs) in that they have no enclosure other than a windshield and its engine. Snowmobiles are powered by two-stroke gasoline/petrol internal combustion engines or four-stroke engines (http://en.wikipedia.org/wiki/ Snowmobile).

The movement of the piston in an engine is what is referred to as a stroke. A two-stroke engine has a single piston stroke in each direction whereas a four-stroke engine has one compression stroke and one exhaust stroke followed by returning strokes. The benefits of a two-stroke engine are that they give the machine a significant power-boost, weigh less, and cost less to manufacture. However, compared to four-stroke engines, two-strokes produce far more air and noise pollution. Therefore, four-stroke engines are becoming more common due to new regulations on snowmobile emission standards (http://deepscience.com/articles/engines.html; 40 CFR Part 1051).

The first snowmobile was developed in the early 1900's by Robert and Charles Mathison who sought an easier way to access traplines in Alaska's remote wilderness (Titus 2009). By the 1960's, snowmobiling became a means to provide over-snow transportation to utility companies, forest rangers, doctors, and others who had to get around despite extreme weather conditions (Heath 1968). However, by the late 1960s, demand for snowmobiles as a means for outdoor recreation increased (Butler 1970). Between 1962 and 1963, approximately 10,000 snowmobiles were produced and sold.

By 1970, that number had significantly increased to over 400,000 snowmobiles (Butler 1970). Today, there are nearly 2.5 million snowmobiles registered in North America (ISMA 2009) with over 11.9 million people that snowmobile annually in the United States alone (USDA Forest Service 2004).

Snowmobiling has enabled an increasing number of people to access formerly remote areas in winter. The combination of high-speed, rapid maneuverability and loud noise makes snowmobiling a conspicuous and alarming stimulus in the landscape (Mahoney et al. 2001). Consequently, the dramatic increase in snowmobiles has increased the conflicts between snowmobile enthusiasts, wildlife, and the environment.

Snowmobile impacts are well documented. Studies have shown that snowmobiling compacts snow (Wanek 1971, Neumann and Merriam 1972), damages vegetation (Wanek 1971, Neumann and Merriam 1972, Wanek and Potter 1974, Wanek and Schumacher 1975, Ryerson et al. 1977, Keddy et al. 1979), alters wildlife behavior (Javinen and Schmid 1971, Dorrance et al. 1975, Richens and Lavigne 1978, Simpson 1987, Tyler 1991, Colescott and Gillingham 1998, Mahoney et al. 2001, Bunnel et al. 2006, Kolbe et al. 2007, Seip et al. 2007), increases physiological stress (Tomeo 2000, Creel et al. 2002), and creates noise (Wanek 1971, Dorrance et al. 1975, NPCA 2000, NPS 2000, Burson 2008). These impacts have severe consequences on the integrity of ecosystems. However, few studies have been conducted to determine these ecological effects spatially and cumulatively.

**Snowmobile Effects on Snow**

Wanek (1971) and Neumann and Merriam (1972) found that temperature gradients and thermal insulation of snow beneath the surface are drastically reduced by the compaction of snow caused by snowmobiles. The specific gravity of snow doubles below the surface, and triples at the surface by the passage of snowmobiles compared to areas without snowmobile passages, ultimately increasing thermal conductivity below and at the surface by four and nine times, respectively (Neumann and Merriam 1972). These temperature reductions have significant impacts on small mammals living in the subnivean environment (Jarvenin and Schmid 1971) and can reduce the soil bacteria population by 100-fold (Wanek 1971).

Changes in snow structure caused by compaction also reduce its water holding capacity by 70% near the surface, and 40% below the surface (Neumann and Merriam 1972). In general, snowmobile trails melt more slowly than areas without snowmobile compaction; as can be seen widely in early spring on snowmobile trails. These effects would significantly reduce the ability of snow to slow runoff and to moderate the effects of thawing during snow melt, as well as affect vegetative growth and composition (Neumann and Merriam 1972).

**Snowmobile Effects on Vegetation**

Snowmobiles have direct and indirect effects on vegetation. Direct effects of snowmobiles to vegetation occur when snowmobile skis and tread come in contact with individual plants (typically woody species) protruding above the snow surface. This results in physical damage of plant tissue inhibiting growth or causing mortality (Wanek 1971, Neumann and Merriam 1972, Wanek and Schumacher 1975). Indirect effects of

snowmobiles are caused by their tendency to compact the snow surface, otherwise changing the condition of the snow environment that plants have adapted to.

Under undisturbed conditions, snow creates an insulated environment for plants under the surface. This subnivean environment is typically warmer than the above-snow temperatures depending on the density of snow (Marchand 1982). However, when snow depths are equal to or greater than 50 cm, the subnivean temperatures become stable regardless of snow density (Marchand 1987). The subnivean environment essentially provides a protection zone for plants against the harsh winter elements above the snow, even providing temperatures substantial enough for cell division (Kimball and Salisbury 1974). When this subnivean environment is disturbed by snowmobiles it consequently stresses the underlying vegetation.

Changes in temperature gradients and thermal conductivity of snow caused by snowmobiles create a colder environment for plants during winter months thus increasing plant's susceptibility to winter mortality (Wanek 1971, Neumann and Merriam 1972, Grellera et al. 1974, Ryerson et al. 1977). Additionally, snowmobile compacted trails have been found to melt slower than areas without snowmobile snow compaction resulting in a shorter growing season otherwise decreasing plant's reproductive period (Neumann and Merriam 1972, Keddy et al. 1979, Roland 2000).

In areas that have both protruding vegetation above the snow surface and underlying vegetation in the subnivean environment, the direct and indirect effects of snowmobiles are cumulative thus making a more substantial impact on environmental conditions. These cumulative impacts can lower plant density and composition (Neumann and Merriam 1972), reduce productivity and growth (Wanek and Potter 1974, Wanek and Schumacher 1975), and delay seed germination and flowering (Keddy et al. 1979).

**Snowmobile Effects on Wildlife Mortality, Energy, and Behavior**

Ecologically competent and peer reviewed literature on the subject of snowmobile impacts on wildlife is sparse but, relatively speaking, the most studied. Several studies have been conducted in the United States, Canada, and Svalbard, but with conflicting results. Boyle and Samson (1985) cited that 12 of 166 articles with original data on recreational impacts to wildlife actually addressed snowmobile use effects on wildlife. Of these articles, seven were stated as having a negative impact, one had a positive impact, and three stated an undetermined or no impact.

*Snowmobile Effects on Small Mammals*

Jarvinen and Schmid (1971) conducted a study to determine the survival of small mammals living in subnivean environments following snow compaction caused by snowmobile traffic. Their study was conducted on a 50 by 60-m grid where half the grid was sectioned as a treatment area where snowmobiles traversed, while the remaining half was sectioned for control. A total of 143 small mammals were captured across the entire grid prior to treatment. Post-treatment revealed 103 captures on the control plot and zero captures on the treatment plot. Of the 21 individuals captured on pre-treatment plots, none of them were recaptured after treatment. The authors concluded that snow compaction caused by snowmobile traffic increased the winter mortality of small mammals due to the elimination of the subnivean environment.

*Snowmobile Effects on White-tailed Deer*

Richens and Lavigne (1978) studied use of snowmobile trails by white-tailed deer (*Odocoileus virginianus*) during the winters of 1972 to 1975 in Somerset County, Maine. They found that snowmobile trail use was correlated with deer densities and winter severity. Most deer followed snowmobile trails for short distances especially those trails near major bedding sites. Deer traveled and fed along 9.1 km of snowmobile trails in open areas. In this study, deer were not disturbed from their preferred bedding and feeding sites due to snowmobile activity.

Conversely, Dorrance et al. (1975) found that white-tailed deer in Minnesota increased their home range size, movements, and distance from the nearest trail with increasing snowmobile activity in an area where snowmobiles had previously been prohibited. Numbers of deer along snowmobile trails also decreased with increasing snowmobile activity in areas that have been open to snowmobiling. Deer immediately adjacent to trails were displaced by light snowmobile traffic.

*Snowmobile Effects on Caribou*

Tyler (1991) studied the short-term, immediate responses of Svalbard reindeer (*Rangifer tarandus platyrhynchus*) to snowmobile provocation. He found that group minimum reaction distance was 640 m, disturbance distance was 410 m, and actual distance at initial flight was 80 m. Reindeer in this region experienced an increase in daily energy expenditure and a loss in grazing time. Reindeer tended to display bunching behavior when provoked by snowmobile, a typical anti-predator behavior that was unexpected in this protected and predator-free population. Tyler concluded that the cost of energy and foraging loss caused by direct snowmobile provocation may have cumulative negative impacts (Tyler 1991).

Similarly, Mahoney et al. (2001) tested the response of caribou (*R. t. terranovae*) to direct snowmobile provocation in Gros Morne National Park, Newfoundland, after the methods designed by Tyler (1991). They found that distance at minimum reaction was 205 m, disturbance distance was 172 m, and distance at initial flight was 100 m. Although they suggested that caribou in this region were, to some extent, habituating to snowmobile activity, their results indicate that approaching snowmobiles displaced caribou from resting activities and initiated avoidance reactions that interrupted feeding bouts and increased locomotion rates.

Both Tyler (1991) and Mahoney et al. (2001) support the findings of Powell (2004) who found that maternal caribou groups in Coast Mountains, Yukon had a greater tendency to flee approaching snowmobiles than adult male groups. Powell also found that snowmobiling frequently interrupted feeding bouts by increasing vigilance and movement. Caribou who ran from snowmobiles required nearly triple the amount of time needed to resume normal behavior than when they did not run. In some instances, maternal groups abandoned their winter range.

Simpson (1987) found that fewer mountain caribou (*R. t. caribou*) in Revelstoke, British Columbia used areas of high snowmobile activity and caribou tended to move away from areas of intensive use where snowmobiling averaged 22 hours per day. Caribou avoided high snowmobile use areas related to the presence of human scent and large groups of rapidly moving snowmobiles. Simpson concluded that the current levels

of snowmobile activity were incompatible with the continued occupancy of mountain caribou.

Similar to the findings of Simpson (1987), Seip et al. (2007) observed from surveys of mountain caribou in central British Columbia that few to no caribou were found in an area intensely used by snowmobiles despite the presence of habitat that seemed to be similar to neighboring mountains supporting hundreds of caribou. Seip et al. used a Resource Selection Function (RSF) based on telemetry data to quantify the relative value of habitats across different mountain ranges surveyed for caribou. In most years, caribou were completely absent from the snowmobile use areas. However, the RSF predicted high-quality habitat in this area and estimated that 53 to 96 caribou could be supported by the available habitat. Therefore, the low level of caribou use in the snowmobile survey block could not be attributed to poorer habitat quality. They concluded that intensive snowmobiling displaced caribou from an area of high-quality habitat because snowmobile use was concentrated on these habitat types. Seip et al. also suggested that snowmobilers appeared to be selecting for the same features preferred by mountain caribou.

*Snowmobile Effects on Moose*

Colescott and Gillingham (1998) studied the effects of snowmobile traffic on wintering moose (*Alces alces*) in Greys River Valley, Wyoming between January and February of 1994. Moose bedding within 300 m and feeding within 150 m of active snowmobile trails altered their behavior in response to snowmobile disturbance. The response was more pronounced when moose were within 150 m of active snowmobile trails. Moose appeared to move away from snowmobile trails as the day progressed. Although snowmobile activity did not cause moose to permanently leave their preferred habitat, it did influence moose behavior within 300 m of snowmobile traffic and temporarily displaced moose to less favorable habitats.

*Snowmobile Effects on Coyotes*

Bunnel et al. (2006) tested the hypothesis that snowmobile-packed trails would facilitate coyote (*Canis latrans*) incursions into deep snow areas causing a negative impact to lynx (*Lynx canadensis*) populations through interference of exploitation competition. They used aerial track and ground counts to compare coyote activity in deep snow areas to areas with and without snowmobile trails in northeastern Utah and the intermountain west to test their hypothesis. They found that snowmobile-packed trails were good predictors of coyote activity in deep snow with over 90% of coyote tracks found within 350 m of a snowmobile trail. Their results suggest that, during periods of deep snow, coyotes require persistent trails to exploit an area.

Kolbe et al. (2007) also investigated how coyotes interacted with compacted snowmobile trails by conducting track surveys and by tracking radio-collared adult coyotes in areas of western Montana where lynx and snowmobile use were both present. Coyotes remained in lynx habitat having deep snow throughout the winter but used snowmobile trails only 7.69% of the time. In general, coyotes did use shallower and more supportive snow surfaces when traveling, but snowmobile trails were not selected for more than randomly expected. Overall, Kolbe et al. concluded that snowmobile trails did not influence coyote movements and foraging success in their study area.

These studies provide evidence that snowmobile activity affects wildlife in many different ways. In some instances wildlife are completely or partially displaced from preferred habitats. In other ways, snowmobile activity in the formation of compacted trails can facilitate wildlife activity. In any case, snowmobiling affects wildlife movements and energy expenditure that can stress wildlife during winter when resources are limited.

**Snowmobile Effects on Specific Aspects of Wildlife Physiology**

Stress is defined as a significant disturbance of homeostasis caused by marked or unpredictable environmental change (Wingfield and Raminofsky 1999, Nelson 2000). In mammals, the perception of a stimulus as threatening activates the hypothalamo–pituitary–adrenal axis which stimulates the secretion of adrenocorticotropic hormone from the anterior pituitary. Adrenocorticotropic hormone then stimulates the secretion of adrenal cortex steroids such as glucocorticoids (GC) that regulate glucose metabolism (Harder 2005). The secretion of GC alters an animal's behavior and physiology consistent with an emergency response (i.e., fight or flight; Wingfield et al. 1998).

Prolonged exposure to a frequent stimulus can result in an animal becoming habituated or experiencing chronic stress (Cyr and Romero 2009). When an arousal is chronic, the brain mobilizes cardiac, vascular, and renal mechanisms to raise blood pressure. At least in humans, this high pressure causes damage, which typically leads to end stage diseases such as coronary heart disease, stroke, and kidney disease, all of which can be fatal to an individual (Sterling and Eyer 1981). It is likely that these same outcomes can also be attributed to other large mammals.

A stimulus that is infrequent is typically perceived as threatening causing an animal or group to experience acute stress levels. Acute stress levels can cause animals to be temporarily or permanently displaced from an area (Cyr and Romero 2009). Complete displacement from preferred wintering habitats likely forces animals into inferior habitats where the risk of energy expenditure, grazing time, and mortality is greater (Seip et al. 2007).

Circulating levels of GC such as cortisol and corticosterone provide a direct measure of the endocrine response to acute stress. These hormones are secreted into the blood and continuously metabolized in the liver and eventually excreted in urine and feces. The concentrations of GC accumulate between the hours between defecation and therefore, in fecal samples, GC is represented as an average concentration of stress hormone within the animal (Harder 2005). These concentrations of stress hormones can be correlated with environmental stimuli providing information of how disturbance is physiologically affecting wildlife.

Creel et al. (2002) tested for associations between snowmobile activity and GC levels in elk (*Cervus elaphus*) and wolves (*Canis lupus*) from fecal pellets in the Greater Yellowstone Area of Wyoming. Wolves showed higher levels of GC in areas and at times of heavy snowmobile use. The day-to-day variation in elk fecal GC levels paralleled the variation in the number of snowmobiles after controlling for the effects of weather and age. Data showed that both species had a strong correlation between stress-hormone levels with snowmobile usage on both daily and annual time scales.

Likewise, Tomeo (2000) studied the response of fecal GC levels in moose to the presence of snowmobiles in Central Alaska. She found that moose in areas with

snowmobile activity had higher fecal GC levels than moose in areas where snowmobiles were not present. These hormones can affect an animal's reproductive and territorial behavior, immune function, foraging efficiency, glucose metabolism, and locomotion, all of which help an individual to cope in an unpredictable situation (Lynn et al. 2010).

The changes in wildlife behavior and physiology have been correlated with the presence of snowmobiles in the landscape. In addition to the visual presence and movements of snowmobiles across the landscape, snowmobiles also create non-visual disturbances in the form of noise. Cumulatively, these affects can be detrimental to wildlife populations which alter ecosystem processes that naturally occur in the absence of snowmobiling.

**Soundscape Ecology and the Effects of Anthropogenic Noise on Wildlife**

The emerging field of soundscape ecology focuses its attention on the temporal and spatial arrangement of sound within the landscape. A soundscape is the sounds occurring over an area which is made up of a collection of biological, geophysical and anthropogenic sounds that emanate from the landscape (Pijanowski et al. in press). The collection of sounds produced by biological organisms is termed biophony (Krause 1998). Sounds originating from the geophysical environment (e.g., wind, rain, thunder, etc.) are termed geophony whereas sounds produced by humans are termed anthrophony (Pijanowski et al. in press).

According to Pijanowski et al. (in press), a soundscape possesses four measurable properties. These include acoustic composition, temporal patterns, spatial variability, and acoustic interactions. Acoustic composition is the frequency (measured in hertz) and amplitude (measured in decibels) of all sounds occurring at the same location. Temporal patterns are the biological events that occur in the landscape over a given time period. The heterogeneity of the biophysical environment makes up the spatial variability of sounds and the relationships between biophony, geophony, and anthrophony are essentially acoustic interactions.

The amplitude of sound, or decibels (dB), are logarithmic units indicating the ratio of a physical quantity (usually power or intensity) relative to a specified reference level. Decibels are usually expressed in relation to human's ability to hear sounds. Therefore, the lowest detectible sound of a human ear is 0 dB while the loudest sound at which point hearing loss occurs is 120 dB. Since decibels are based on a logarithmic scale, an increase of 10 means that a sound is 10 times more intense or twice as loud to human ears. Normal conversation sound levels are approximately 60 dB whereas the sound of a shotgun blast is approximately 150 dB. Hertz (Hz) on the other hand is the unit used to measure frequency of sound. Sound travels as a wave caused by an oscillation of pressure which is perceived by humans as pitch. Humans typically hear frequencies from 20 Hz to 20,000 Hz (or 20 kHz).

The amplitude of sound levels has important implications to wildlife and the environments they occupy. Anthropogenic sound levels caused by motor vehicles and equipment can mask the sounds usually attributed to natural environments (Bowles 1995). This effect may inhibit the ability of animals to effectively utilize "spectral niches" (Wrightson 1999) or identify meaningful sounds important for their survival. It is difficult, however, to interpret sound levels alone as anthropogenic or natural because

decibels do not define a sound source, they simply provide information of how loud a certain area is.

Anthropogenic sound levels can be very similar to those of biological sounds. For instance, road traffic and a river can both emit similar decibel levels. Essentially, both sound levels have the ability to mask sounds in the environment but each are perceived differently by wildlife and Wilderness visitors and are distributed throughout the landscape in very different ways. A river, for example, is a linear feature emitting decibel levels at a constant rate much like a snowmobile. Unlike the river though, snowmobiles can move haphazardly across the landscape resulting in broader patterns of sound distribution.

Identifying sound levels of the soundscape is an important step in understanding how sound levels are distributed throughout the landscape. The other component of most interest is the source of those sound levels. Are they anthropogenic or natural? The frequency of a sound can give more insight into what the source is. Anthropogenic sound sources such as motor vehicles and stationary machines (e.g., oil compressors) typically occur at low frequencies less than 4 kHz (4,000 Hz). Geophysical sounds such as wind, rain, and running water occur between frequencies of 100 Hz to 8 kHz, while biological sound sources like that of bird calls typically occur at high frequencies greater than 4 kHz (Pijanowski et al. in press).

Snowmobiles have the capability of drastically altering the soundscape. Areas devoid of snowmobiles are usually composed of biophonic and geophonic sounds. However, when snowmobiling is introduced to those areas they transform the landscape into areas affected by anthrophony. Snowmobiles can therefore change the spatial variability and acoustic composition of the landscape otherwise altering landscape patterns. Snowmobiles and other sound sources (e.g., aircraft, watercraft, etc.) have distinct sound properties that can affect the natural environment. These sounds are generally perceived as undesirable, or noise. Therefore, mechanical sounds can have negative effects on wildlife and recreationists seeking to experience solitude in the natural environment without the influence of man-made noise.

A few studies have reported that snowmobiles can be heard from a half a mile to nearly 20 miles away (Burson 2008, NPCA 2000, NPS 2000). Wanek (1971) found that all snowmobiles measured while traveling 10 to 30 mph had noise emissions of 100 dB with some even approaching 120 dB, a level determined by authorities to permanently damage the ear over a period of time. Wanek (1971) also found that groups of snowmobiles did not appreciably add to the noise emission of a single snowmobile and vegetation was not found to muffle the noise across the landscape. However, newer models of snowmobiles have been developed to reduce noise emissions (Miers et al. 2000). Recent snowmobile sound levels have been lowered to an average sound level reading between 70 and 80 dB (at 15.2 m, 20 mph; Daily 2001), equivalent to the sound of traffic noise within a car. Regardless, snowmobile noise propagates throughout the landscape that can affect wildlife.

*Snowmobile Noise Effects on Wildlife*

The manner in which snowmobiles move across the landscape and the noise they emit may have compounding effects on wildlife stress and distribution. Simpson (1987) suggested that animals surrounded by fast-moving stimuli may panic as they are unable

to locate multiple threats. Moen et al. (1982) mentioned that snowmobilers roaming through the landscape may unintentionally "chase" animals in response to noise.

Wanek (1971) looked at snowmobile noise emissions and the response of white-tailed deer. Deer appeared to lose their wariness of snowmobiles after frequent exposure. However, when deer were exposed to snowmobiles infrequently they reacted "violently" which may be detrimental to their survival due to more rapid expenditure of energy and increased stress levels. Dorrance et al. (1975) also studied the effects of snowmobile noise on white-tailed deer. He found that deer in heavy snowmobile use areas were habituated to snowmobile noise while deer in areas without snowmobiles increased their home-range size when exposed to snowmobile activity.

Similarly, Eckstein et al. (1979) studied the effects of snowmobiles on the movements of white-tailed deer in the Chequamegon National Forest, Wisconsin. They found that snowmobile traffic had little effect on overall winter movements and did not alter deer home ranges in this region. The authors presumed that deer probably became accustomed to the noise of machinery due to logging in the area which decreased their reaction to snowmobiles.

*Aircraft Noise Effects on Terrestrial Mammals*

A landscape affected by snowmobile noise is also affected by other noise sources such as low-flying aircraft (e.g., airplanes and helicopters). Calef et al. (1976) studied the effects of fixed-wing aircraft and helicopter noise on caribou populations in Alaska and northern Yukon. All groups exhibited a high percentage of individuals reacting in panic or strong escape to aircraft at altitudes less than 60 m. At 150 m, 30 to 65% of all groups continued to exhibit strong responses. They concluded that helicopters were more effective at creating a strong response due to their ability to follow animals at low altitudes. Similarly, Harrington and Veitch (1991) found that caribou in Labrador usually responded to jet overflights with a startle reflex that intensified with direct overpasses.

These reactions in winter can cause depletion of energy reserves critical to an animal's survival. For example, bighorn sheep (*Ovis canadensis nelson*) response to helicopter overflights in the Grand Canyon were found to be more sensitive to noise during winter. Sheep during this time period experienced a 43% reduction in foraging efficiency (Stockwell et al. 1991).

Krausman et al. (1986) tried to determine whether low-flying aircraft (30 to 300 m in altitude) shifted mule deer (*Odocoileus hemionus crooki*) use of habitats in Arizona. They found that 97% of the time deer rarely responded to overflying aircraft by changing their habitat. They suggested that deer were likely habituated to noise levels because of their close orientation to the highway system.

*Anthropogenic Noise Effects on Marine Mammals*

Although few studies have been conducted on terrestrial mammal responses to anthropogenic noise, several studies have shown that marine mammals respond negatively to anthropogenic noise sources as well. Lesage and Barrette (1999) found that beluga whales (*Delphinapterus leucas*) in the St. Lawrence River Estuary of Canada changed their calling behavior in response to rapid motorboat and slow-moving ferry noise. Both vessels induced changes in calling rates and an upward shift in calling frequency. Beluga whales and bottle-nose dolphins (*Tursiops truncatus*) have both

exhibited significant increases in stress levels after high-levels of exposure to a seismic water gun and simulated sonar tones (Romano et al. 2004).

Miller et al. (2000) discovered that male humpback whales (*Megaptera novaeangliae*) altered their singing behavior when they were exposed to low-frequency active sonar. Since the song of these whales is associated with reproduction, widespread alteration of their singing behavior might affect demographic parameters. Foote et al. (2004) investigated the vocal behavior in the presence and absence of whale-watcher boat traffic of three social pods of killer whales (*Orcinus orca*) living in the near-shore waters of Washington state. They found longer call durations in the presence of boats for all three pods.

Edrén et al. (2004) found that sound pulses from pile-driving caused by wind turbine construction resulted in a 10 to 60% reduction in the number of harbor seals (*Phoca vitulina*) on sand banks that were approximately 10 km away compared to periods with no pile-driving. Similarly, Tougaard et al. (2005) found that there was a reduction in harbor porpoise (*Phocoena phocoena*) 'clicks' during periods of pile-driving but after pile-driving ceased, porpoises returned to normal clicking activity. Richardson et al. (1999) found that most migrating bowhead whales (*Balaena mysticetus*) avoided airguns at a range of about 20 km.

It is evident that anthropogenic noise affects both terrestrial and marine mammals. The tendency of mammals to avoid anthropogenic noise provides profound implications as to how the cumulative effects of anthrophony in the soundscape can influence mammal stress levels and community distributions.

**Summary**

Considering that snowmobiles create linear features across the landscape, they end up creating unique patterns of noise, wildlife movements, and fragmentation that influence natural processes. Much of the work done to determine the impacts snowmobiles have to wildlife and the environment have concluded there to be negative effects (Wanek 1971, Dorrance et al. 1975, Colescott and Gillingham 1998, Seip et al. 2007). Although these studies have important implications to resource managers, the manner in which snowmobiles are regulated tends to have varying effects on wildlife and their habitats. Additionally, most studies have only focused on a single aspect of snowmobile effects (e.g., species-specific behavioral responses, vegetative responses, etc.) without getting a larger picture of the collective effects of snowmobiles. Together, these studies provide important information of how snowmobiles can change the landscape. Unfortunately, very few studies have taken a spatially explicit approach to make proper landscape-scale conclusions. Determining how current regulations on snowmobiles are affecting ecological systems is an important subject to address scientifically. It essentially requires quantitative and sophisticated techniques to determine how areas subjected to snowmobile activity compares to areas without snowmobiles. This approach can also allow the incorporation of science-based adaptive management through the establishment of monitoring methods.

**Objectives**

The objectives of this study are to answer the following questions:

1) What areas have the highest amount of snowmobile activity and when are those areas used?
2) Do areas with high snowmobile activity stress wildlife and how?
3) Do areas of high snowmobile activity influence the distribution of wildlife communities and how?
4) What areas have the highest and lowest amounts of anthropogenic noise and when do they occur?
5) Do areas with high amounts of anthropogenic noise stress wildlife?
6) How is vegetation affected by varying intensities of snowmobile traverses at varying snow depths?

METHODS AND MATERIALS

**Study Area**

*Kenai National Wildlife Refuge*

This study will be conducted in the Kenai National Wildlife Refuge (KENWR). The 805,000 ha of the KENWR is located on the Kenai Peninsula in south-central Alaska, USA (Fig 1). The KENWR's lowland forests are dominated by white spruce (*Picea glauca*) and black spruce (*P. mariana*) with a mixture of aspen (*Populus tremuloides*), birch (*Betula neoalaskana*), and an extensive network of peatlands. Lichen, mountain hemlock (*Tsuga mertensiana*), and sub-alpine shrub (*Alnus* spp.) dominate areas above treeline in the Kenai Mountains and Caribou Hills. Temperatures rarely exceed 26º C in the summer or drop below -18º C in the winter. Year-round precipitation on the Kenai Peninsula can range from 43 cm in the lowlands to 502 cm in the Kenai Mountains.

The KENWR was first established on 16 December 1941 as the Kenai National Moose Range by Executive Order 8979. On 2 December 1980, the boundaries were modified, purposes expanded, and name changed to the Kenai National Wildlife Refuge under the 1980 Alaska National Interest Lands Conservation Act (ANILCA; Public Law 96-487 Stat. 2371). Under the provisions of ANILCA, the purposes for the KENWR are to "*(i) to conserve fish and wildlife populations and habitats in their natural diversity including, but not limited to moose, bear, mountain goats, Dall sheep, wolves and other furbearers, salmonids and other fish, waterfowl and other migratory and nonmigratory birds; (ii) to fulfill the international treaty obligations of the United States with respect to fish and wildlife and their habitats; (iii) to ensure to the maximum extent practicable and in a manner consistent with the purposes set forth in paragraph (i), water quality and necessary water quantity with the refuge; (iv) to provide in a manner consistent with subparagraphs (i) and (ii), opportunities for scientific research, interpretation, environmental education, and land management training; and (v) to provide, in a manner compatible with these purposes, opportunities for fish and wildlife oriented recreation.*"

The KENWR is also under the mandate of The Wilderness Act of 1964 (Public Law 88-577) which was enacted to assure that an increasing population resulting in expanding settlement and growing mechanization did not occupy or modify all areas of land in the United States. The Wilderness Act's purposes are to secure an enduring

resource of wilderness, to protect and preserve the wilderness character of areas within the National Wilderness Preservation System, and to administer this wilderness system for the use and enjoyment of the American people in a way that will leave them unimpaired for future use and enjoyment as wilderness (Wilderness Act 1964). Currently, KENWR has over 5,000 $km^2$ of congressionally designated Wilderness.

The KENWR currently allows snowmobiling access to approximately 505,800 ha (63%) of the Refuge (Fig 2). To reduce the impacts snowmobiling has on wildlife and the environment, the KENWR established basic regulations to restrict the size of machines to less than 101.6 cm wide, the time of use to take place from December to April (provided there is adequate snowfall), the type of use (e.g., no racing or road use), and the exclusion of alpine areas (with the exception of the Caribou Hills).

**1. Measuring and modeling snow depth**

*Measuring Snow Depth*

Snow depth is an important environmental variable that can influence the distribution of wildlife throughout the landscape and is used by the KENWR Refuge Manager to determine when snowmobiles are allowed into the Refuge. Until recently, snow depth was measured anecdotally from law enforcement officers in the field to indicate adequate snow depth to allow snowmobiles into the Refuge. However, snow data for KENWR has also been available from a single snowpack telemetry (SNOTEL) station established by the Natural Resources Conservation Service (NRCS). Basic SNOTEL stations have a pressure sensing snow pillow, storage precipitation gage, and air temperature sensor that collect data every 15 minutes and are available online (http://www.wcc.nrcs.usda.gov/snow/).

Although SNOTEL is an excellent source of snow depth information, it is not a spatial representation of the entire KENWR. In order to obtain a better spatial distribution of snow depth throughout KENWR to be used as a monitoring tool and an environmental variable for additional spatial data, I deployed 30 aerial snow depth markers (i.e., snow benchmarks) throughout KENWR during the summer of 2009 (Fig 4).

Aerial snow depth markers are 12 ft tall poles with reflective black and orange horizontal plates placed 12 inches apart (Fig 5). Snow depth is recorded by flying over the snow benchmark and documenting the lowest visible horizontal bar above the snow (Fig 6). These data can then be incorporated with or compared to SNOTEL snow depth data.

To spatially distribute these snow benchmarks, I created a spatial sample design of KENWR in ArcGIS 9.3 (available from *http://www.esri.com/software/*). This process consisted of overlaying shapefiles of KENWR, the SNOTEL site, and Digital Orthophoto Quadrangles (DOQs) of KENWR. I created a grid of 15 $km^2$ cells in Hawth's tools using the extent of the KENWR boundary. I clipped the grid to KENWR boundary and deleted cells that 1) contained the SNOTEL station, 2) had greater than half their area outside the KENWR border, and 3) consisted of a large body of water or glacier in more than half the cell (Fig 4). I then selected deployment sites within each cell using the DOQs. Sites were selected so they were open enough for visual recording from aircraft, had a safe landing area for deployment, and were isolated for the prevention of vandalism and collisions with snowmobile traffic.

During the winter of 2009 and 2010, snow benchmarks were surveyed once a month for five months (December, January, February, March, and April). The data collected for each month were input into a Microsoft Excel spreadsheet including the marker number, geospatial coordinates (in Universal Transverse Mercator [UTMs], WGS 1984), and snow depth for each month. December and January were combined because pilots surveyed snow markers on dates spanning both months instead of a single day of the month. All other surveys were conducted over a one day time frame. The average snow depth for December and January was 99 cm (SD = 69 cm, n = 29), for February it was 42 cm (SD = 34 cm, n = 30), for March it was 60 cm (SD = 56 cm, n = 30), and for April average snow depth was 38 cm (SD = 67 cm, n = 30).

For the duration of this study, snow markers will be surveyed each month for five months (December to April) for two consecutive years. These data will provide temporal data to be compared. A Shapiro-Wilk test for normality will be used to test whether snow depth data are normally distributed. To test whether each month is significantly different ($\alpha = 0.05$) from one another, a Kruskal-Wallis non-parametric test will be used for non-normally distributed data or an ANOVA for normally distributed data.

*Modeling Snow Depth*

Landscape ecology has become increasingly reliant on modeling as an efficient and reliable means to explore large-scale patterns that emerge from the complex dynamics of smaller scales (Caspersen et al. 1999). A 'model' in this sense is a simplified representation of ecological relationships in the landscape based on spatially explicit data taken from the field and processed in a geographical information system (GIS). Often, it is difficult for landscape ecologists to conduct landscape-scale experiments that are statistically satisfying, or the landscape is logistically impractical to

sample on such a large scale. In these cases, spatially explicit models allow scientists to simulate ecological relationships using data that is easily obtainable (e.g., digital elevation models, aerial photography; Turner et al. 1995). Spatially explicit models are important tools for investigating scale-related questions in landscape ecology, especially the response of organisms to habitat change occurring at a variety of spatial and temporal scales (Dunning and Stewart 1995).

As a modeling exercise, snow depth data collected from the 2009-2010 snowmobile season was interpolated between aerial snow markers for each month using krigging in the geoR package in R (available at http://www.r-project.org/; Appendix 4). According to the models, snow depth was generally deepest in the high country of the eastern, southwestern, and southern portion of the Refuge (Fig 8). This exercise provides an example of how models can be used to determine patterns in the landscape.

For this study, snow depth data and its associated coordinates will be model-predicted for each month to determine the spatial and temporal variation of snow depth across the entire Refuge. Snow marker coordinates and associated snow depth data for each month will be input into ArcMap and overlaid onto layers consisting of a map of KENWR, slope, elevation, and aspect. All data will then be overlaid onto a sample grid of the study area, combining all variable values into one attribute table. These data will then be input into TreeNet software (available from http://salford-systems.com/, Craig and Huettmann 2009) to make predictions of how snow depth is distributed throughout the KENWR. Predictions will then be input into ArcMap to compare spatially using a yet to be determined spatial statistics method.

**2. Identifying areas of snowmobile activity**

But this power analysis does not take into account zero-inflated data. To deal with these data, I will use a zero-inflated regression model using the pscl package in R. Zero-inflated models are two-component mixture models that combine a point mass at zero with a count distribution (e.g., Poisson; Zeileis et al. 2008) allowing data sets to be weighted based on the abundance of zeros and recorded snowmobile trails.

Using MatLab's Image Processing Toolbox, color JPEG images will be converted into black and white, binary images based on a threshold that trails produce given the shadows they create on the ground. The number of pixels occupied by snowmobile trails will then be used to spatially index the amount of area covered by snowmobile trails for each image. An alternative method is to visually count snowmobile trails from JPEGs and create a density index from the actual numbers of snowmobile trails present. Following this step, each image will be georeferenced with their respective GPS location.

This information will provide latitude and longitude coordinates for each image. These coordinates and their associated snowmobile trail densities will then be input into ArcMap and overlaid onto layers consisting of a map of KENWR, slope, elevation, snow depth, distance to roads, distance to water, distance to seismic lines, and distance to developed areas (e.g., housing developments). All data will then be overlaid onto a sample grid of the study area, combining all variable values into one attribute table. These data will then be input into TreeNet software (available from http://salford-systems.com/, Craig and Huettmann 2009) to make predictions of where snowmobile trails are most likely to be present and in what density across the entire KENWR according to the environmental variables for each month surveys were flown. Predictions will then be input into ArcMap creating a model of where the highest and lowest densities of snowmobile trails are present (Fig. 10) and what months have the highest densities. These data will provide a high-quality snapshot of snowmobile trail densities for the KENWR over the course of two winters over monthly time spans.

**3. Modeling the soundscape**

Federal lands that have congressionally designated Wilderness are required by law to preserve the natural condition of the wilderness and provide visitors with outstanding opportunities for solitude (Wilderness Act 1964). In areas that are dominated by human activities (e.g., towns, roads, airports, etc.), the distribution of anthropogenic noise is expected. Conversely, in designated Wilderness that is set aside for wildlife and visitors as a refuge from human activities, it is expected that these areas are completely dominated by natural sounds. In essence, the composition of the soundscape and the distribution of anthrophony and biophony are expected to be associated with and representative of the land use patterns of the area they are produced. The presence of motorized vehicles that are allowed to access designated Wilderness under the mandates of ANILCA may disrupt the natural condition of the wilderness and visitors' experience as a result of anthropogenic noise intrusion.

With the innovations of acoustic technology, soundscape variables can now be measured using sound level meters and automated digital recorders. Sound level meters (SLMs) are used to measure sound pressure levels (dB) whereas automated acoustic digital recorders record ambient sound frequencies (Hz). Both devices store acoustic information detected by microphones with a decibel range of 20 to 140 dB or frequency range of 20 Hz to 20 kHz, equivalent to the threshold of human hearing.

For this study, two types of SLMs (Larson Davis 831 and Larson Davis 820; Fig 11; Larson Davis, Provo, Utah, USA) will be used to record environmental decibel levels. Both the LD831 and LD820 are precision integrating sound level meters that meet American National Standard Institute (ANSI) and International Electrotechnical Commission (IES) standards. They have long-term data logging capabilities for storing interval, time, daily, and event histories. They have linear, slow, fast, impulse, and peak detectors and A, C, and Z frequency weighting. Unlike the LD820, the LD831 also has the capabilities of digitally recording sounds that exceed a predetermine decibel level.

For digitally recording ambient sound frequencies I will use Wildlife Acoustics Sound Meter SM-2 Digital Field Recorders (SM-2; Fig 12; Wildlife Acoustics Inc., Concord, Massachusetts, USA). The SM-2 has programmable sampling rates, gain, filters, and triggers with sophisticated scheduling for customization. It includes two SMX-II weather resistant acoustic microphones and can record up to 240 hrs spread throughout weeks or months.

Digital sound recorders store the timing and intensity of sounds that allows signal processors to reconstruct the frequency distribution of signal intensity over time (Pjanowski et al. in press). The SM-2 samples frequencies at 44.1 kHz with a 16-bit depth (compact disc quality) and stores those data as uncompressed Wave files (.wav). These data are then displayed in a spectrogram (Fig 12). A spectrogram contains three dimensions of sound: 1) time (x-axis), 2) frequency (y-axis), and 3) energy or amplitude (normally displayed as a color coded plot along the z-axis).

A spectrogram is read much like sheet music, where notes are linearly arranged over time with higher frequencies (or pitches) located at the top of the musical staff and lower frequencies located closer to the bottom (Pijanowski et al in press). The acoustic frequencies of each recording can be decomposed into spectral bands of 1 kHz widths with threshold amplitude set at -50 dBFS (decibels relative to Full Scale or the maximum peak level). This allows the spectral bands at specific frequencies to be identified. A library of sounds is then used in an automated system to identify spectral bands as biophonic or anthrophonic sources. Measuring both the amplitude and frequency of the soundscape can provide information to determine 1) how loud the landscape is, 2) what the sources of those sound levels are, and 3) how anthrophony and biophony are distributed.

To answer the question *"how loud is the landscape?"* in quantitative terms, thirteen SLMs will be deployed throughout the KENWR. Ten LD820s will be placed at permanent sound stations at stratified, random sites throughout the Refuge to obtain a spatial distribution of sound levels across the landscape between December and April. Three LD831s will be rotated every 25 days throughout the Refuge in order to sample a wider range of sound levels during monthly time frames. Sound level meters will be set to record A-weighted frequency decibels (dBA; the frequency equivalent to human hearing), sound equivalent level ($L_{eq}$), maximum sound level ($L_{max}$), and minimum sound level ($L_{min}$). Sound levels that exceed decibel levels of $\geq$ 70 dBA for a period of $\geq$ 3 seconds will be digitally recorded.

Areas with similar attributes tend to have similar sound sources, sound levels, and propagation and attenuation properties. Therefore, sample areas will be stratified based on their similarities of vegetative cover, land cover, topography, elevation, and climate, all of which will be assessed using data layers in ArcMap from KENWR's geodatabase.

The specific sites to establish sound stations will be prioritized based on Refuge management zones (i.e., snowmobile use areas), proximity to natural and human-caused sounds, and equipment considerations.

The geographic coordinates of each SLM and their associated sound levels will be input into ArcMap and overlaid onto layers consisting of a map of KENWR, slope, elevation, vegetation cover, distance to roads, distance to water, distance to seismic lines, distance to airports, and distance to developed areas (e.g. housing developments). All data will then be overlaid onto a sample grid of the study area, combining all variable values into one attribute table. These data will then be input into TreeNet software to make predictions of how decibel levels are distributed throughout KENWR. Predictions will then be input into ArcMap creating a model of where the highest and lowest sound levels are present. However, more complicated and sophisticated logarithmic calculations will need to be applied to account for attenuation across topography and vegetation types. This methodology has yet to be determined but I am currently in contact with sound technicians who can assist with this.

To answer the question, "*what is the source of sounds produced in the landscape?*" thirteen SM-2s will be integrated with the SLMs and be deployed together at the same sound station. Ambient sounds will be recorded for 15 minutes at the top of every hour. The acoustic frequencies of each recording will be decomposed into spectral bands of 1 kHz widths with threshold amplitude set at -50 dBFS. Spectral bands at specific frequencies will then be identified. A library of sounds will then be used in conjunction with an automated system to identify spectral bands as biophonic or anthrophonic sources. The ratio of biophonic to anthrophonic sounds (biophony/anthrophony) will be calculated for each sound station. A ratio > 1 is expected to indicate areas dominated by biophonic sounds whereas a ratio < 1 would indicate an area is dominated by anthropogenic noise.

To answer the question, "*how are biophony and anthrophony distributed throughout the landscape?*" the geographic coordinates of each sound station, along with their ratio of anthrophony and biophony will be input into ArcMap and overlaid onto layers consisting of a map of KENWR, slope, elevation, vegetation cover, distance to roads, distance to water, distance to seismic lines, distance to airports, and distance to developed areas (e.g. housing developments). All data will then be overlaid onto a sample grid of the study area, combining all variable values into one attribute table. These data will then be input into TreeNet software to make predictions of where the highest ratios of each, biophonic and anthrophonic, sounds are distributed throughout KENWR. Predictions will then be input into ArcMap creating a map of where those areas are located over monthly time frames.

I plan to overlay the soundscape model of decibels and anthrophony/biophony with the models of snowmobile trail density in ArcMap. This will allow me to obtain the prediction values at each grid point. These values will then be compared and correlated using a non-parametric Spearman rank correlation. It is expected that areas dominated by anthropogenic noise (i.e., grid points with values < 1) will be positively correlated with areas of high snowmobile trail densities.

**4. Modeling Moose stress response to snowmobile activity and noise**

Moose are an important keystone species of boreal ecosystems and a substantial subsistence species for hunters on the Kenai Peninsula of Alaska. However, these animals may be subjected to increased stress levels inhibiting their survival as a result of snowmobile activity and noise. By looking at the physiological responses of moose GC levels to snowmobile activity it is possible to obtain a better interpretation of how moose are responding to these disturbances.

The level of GC can be used as a measure of the intensity of environmental stress (Franzmann et al. 1975). Therefore, determining the GC levels of an animal can give insight into how a stimulus is affecting an animal's physiological condition which ultimately affects an animal's ability to adapt behaviorally. Fecal analysis of GC secretions is an effective and non-invasive alternative to the invasive measures of stress such as blood analysis, heart rate monitoring, respiratory rate, and body temperature (Tomeo 2000). Feces are also more practical and collectable than urine (Brown et al. 1997). Creel (1997) found that fecal GC analysis also provides a better measure of stress levels in an individual over a longer period of time. Fecal GC levels typically indicate the level of hormone 12 to 24 hours prior to defecation (Millspaugh 1999). Fecal hormone analysis is often the most practical, non-invasive method for establishing normative endocrine data and is the preferred method for examining baseline hormone measurements in the wild (Creel 1997).

To obtain GC secretions, fecal samples will be collected opportunistically from three populations of moose: 1) captive moose in a confined enclosure, 2) wild moose in the Caribou Hills region and, 3) wild moose in areas closed to snowmobiles. These three populations are chosen based on the assumption that captive moose are habituated to human disturbance and will serve as a baseline hormone measurement for habituation. Also, wild moose in the Caribou Hills are expected to have higher fecal GC levels than moose in areas closed to snowmobiles based on the findings of Tomeo (2000). However, these moose have been subjected to snowmobile disturbance since the late 1960s and may exhibit a habituated response. By sampling between these populations, a better understanding of how fecal GC levels compare with one another may give an indication as to whether moose in the Caribou Hills are responding to snowmobiles with higher stress hormone levels or are habituated to this disturbance.

According to a power analysis based on the findings of Tomeo (2000), only 60 fecal samples need to be collected per population to achieve an 80% probability of detecting a difference. Therefore, at least 60 fecal samples will be collected from each population over the course of the snowmobiling season on one weekday and one weekend day for two consecutive years.

Samples will be collected in areas open to snowmobiles during the months of February, March, and April when moose are most vulnerable to disturbance (K. Hundertmark, pers comm.) Samples will be collected by traveling along established trails via snowmobile until moose tracks are sighted. Moose tracks will then be followed on snowshoes until a pile of pellets is found on the surface of the snow. In areas closed to snowmobiles, walking or ski trails will be followed on snowshoes or skis and the same procedures of tracking down moose pellets will be followed. Fresh fecal samples will be collected from captive moose within their enclosures. Fecal GC samples are known to remain stable for at least two weeks (S. Creel pers comm., Montana State University).

Therefore, collections from each population will take place within two week time periods.

Once a fecal pile is found, a GPS coordinate will be taken for that location. The entire pile of moose pellets will be collected and mixed (Millspaugh and Washburn 2003). Fecal samples will be kept frozen in the field and stored at no warmer than -20º C until extraction. Feces will be weighed then dried in a rotary evaporator without heat and reweighed to estimate water content. Next, 0.2 g of dried feces will be boiled in ethanol for 20 minutes, and then configured at 1,500 rpm in a centrifuge for 10 minutes. To obtain GC extracts, supernatants will be decanted, dried under air, rinsed with 2-3 ml of ethanol, re-dried, and reconstituted in 1 ml of absolute methanol. Fecal extracts will be stored at no warmer than -20º C and 25 to 50 µl of fecal extracts will be taken for assay. Glucocorticoids will be measured with a previously validated antibody, $^{125}$I-corticosterone assay from ICN Bio-medicals (Millspaugh 1999). There is little cross reaction with this antibody and other steroids (Creel et al. 2002). Assay results will be expressed as ng GC/g dry feces. Corrections for the water content of the feces and the sex and reproductive status of female moose will be made prior to comparison (Creel et al. 2002).

Sex of moose will be determined by amplifying DNA via Polymerase Chain Reaction (PCR) on the X- and Y-linked alleles using the K1 (5′-GCCCAGCAGCCCTTC CAG-3′ ) and K2 (5′TGGCCAA GCTTCCAGAGGCA-3′) primers (Brinkman and Hundertmark 2009). Reproductive status will be made by evaluating the mean levels of progesterone (Monfort et al. 1993). These levels can be generally segregated into two groups, those above and those below 1,000 ng/g equivalent wet weight (Wasser et al. 1991), indicating pregnancy and nonpregnancy, respectively.

Fecal GC levels will then be statistically compared between populations using a Chi-square goodness-of-fit test. Each assay with their corresponding GPS coordinate will be input into ArcMap and overlaid onto layers consisting of a map of KENWR, slope, elevation, snow depth, distance to roads, distance to water, distance to seismic lines, distance to airports, and distance to developed areas (e.g. housing developments). All data will then be overlaid onto a sample grid of the study area, combining all variable values into one attribute table. These data will then be input into TreeNet software to make predictions of where GC levels are most likely to occur throughout the entire KENWR. Predictions will then be input into ArcMap creating a map of where the highest and lowest GC levels are present. These data will provide a distribution map (i.e., a stressscape) of moose GC levels for the KENWR over the course of two winters. I expect to overlay the stressscape model of moose GC levels with the models of snowmobile trail density, anthropogenic noise, and snow depth in ArcMap and obtain the prediction values of each grid point. These values will then be compared and correlated using a non-parametric Spearman rank correlation. It is expected that higher moose GC levels (i.e., higher cell values) will be positively correlated with areas of high snowmobile trail densities, anthropogenic noise, and deep snow.

**5. Modeling the Large Mammal Community**

Large mammals in North America such as ungulates and canids have been found to use and avoid snowmobile trails during winter (Dorrance et al. 1975, Richens and Lavigne 1978, Colescott and Gillingham 1998, Bunnell et al. 2006, Kolbe et al. 2007). Therefore, snowmobile trails may affect predator-prey relationships and cause animals to be displaced from preferred habitats. Determining the presence of large mammals in relationship to snowmobile trails will give insight as to where these impacts may occur.

The presence of large mammal tracks will be inventoried throughout the snowmobile season for two consecutive years. Tracks will be searched for by 1) following snowmobile trails and documenting any animal tracks following, crossing, or adjacent to snowmobile trails (Halfpenny et al. 1997), and 2) taking aerial photographs from a helicopter.

Snowmobile trail searches will occur once a week opportunistically on established snowmobile trails in selected areas of high snowmobile use such as the Caribou Hills. Aerial surveys will take place once a month for five months at 255 monitoring plots established by the Long-term Ecological Monitoring Program (LTEMP; Morton et al. 2009) throughout the KENWR (Fig 13). Aerial photographs will be taken for each point using a Nikon™ D700 camera. The D700 is a professional grade full-frame digital single-lens reflex camera with a 36 by 23.9 mm, 12.1 megapixel sensor. It has a built-in Multi-CAM 3500FX autofocus sensor module featuring 51 AF points with 3D focus tracking. The D700 also possesses an electronic rangefinder function, Automatic correction of lateral chromatic aberration for JPEGs, ISO sensitivity from 200 to 6400, and a GPS interface for direct geotagging.

The GPS coordinate for each mammal species' track identified will be documented. I expect to determine whether the distribution of large mammals can be predicted by the distribution of snowmobile trails, snow depth, and vegetative cover by using a logistic regression analysis. Additional predictions of how large mammals are distributed in relation to these variables will be made using machine learning. The coordinates and respective species will be input into ArcMap and overlaid onto layers consisting of a map of KENWR, slope, elevation, snow depth, distance to roads, distance to water, distance to seismic lines, distance to airports, distance to developed areas (e.g. housing developments), and distance to vegetative cover types. All data will then be overlaid onto a sample grid of the study area in ArcMap, combining all variable values into one attribute table. The data of each species will then be imported into TreeNet software to make predictions of where different mammal species are most likely to occur throughout the entire KENWR, creating a model for each species.

I expect to overlay the model of each species distribution with the model of snowmobile trail density and snow depth in ArcMap and obtain the prediction values at each grid point. These values will then be compared and correlated using a non-parametric Spearman rank correlation. It is expected that the distribution of ungulates such as moose and caribou will be negatively correlated with areas of high snowmobile trail densities and anthropogenic noise. Conversely, the distribution of canids such as wolf and coyotes will be positively correlated with snowmobile trails but negatively correlated with snow depth.

**6. Vegetation response to direct and indirect effects of snowmobiles**

*Direct effects of snowmobiles on woody vegetation*

Woody vegetation can protrude above the snowpack where they are susceptible to direct, physical damage by traversing snowmobiles. Furthermore, snowmobiles are known to compact the snow surface where underlying woody plants may also be physically damaged. An experiment will be conducted during the winter and summer of 2010 and 2011 to determine how woody vegetation responds to direct contact with traversing snowmobiles.

This experiment consists of five transects, one control and four treatment (Fig 14). Transects are 2-m wide and 50-m long. In August of 2010, the beginning and end of each transect, as well as the 2-m intervals, were marked with PVC pipe (5-cm diameter) so that snowmobile traverses and vegetation sampling can take place at the same location every treatment and sampling period.

The height of woody plants obviously determines their susceptibility to being in physical contact with passing snowmobiles. Therefore, the summer prior to winter of 2010, woody plant height was measured using a meter stick at 2-m intervals along a line-point intercept placed at a 90-degree angle from the edge of control and treatment transects. The species height (≥ 30 cm) of each woody plant was measured, identified to species, recorded on a data sheet (Appendix 1), and marked with a plastic zip tie (Fig.15). These plants will later be identified in winter and the presence of direct snowmobile damage will be recorded in terms of tissue damage or breakage of the limbs. The most common species recorded in 2010 were *Betula nana* and *Myrica gale*. The heights for both species were entered into an Excel spreadsheet and averaged for each transect (Table 1). It is expected that these heights will decrease as a result of snowmobile impacts.

During winter, transects will be treated with two or five snowmobile traverses (Keddy et al. 1979). The control transect represents no snowmobile traffic while the remaining transects present treatment groups. Each treatment group is determined by snow depth. When snow depth measures 30 cm two snowmobile passes will be traversed over one transect and five snowmobile passes will be traversed over an additional transect. The significance of this snow depth is based on the fact the Refuge is not open to snowmobiling until snow cover reaches an approximate depth of 12 inches (30.5 cm; A. Loranger, KENWR Refuge Manager, pers. comm). This information provides a minimum snow depth for what may be expected to protect woody vegetation from direct snowmobile impacts.

For a maximum snow depth, the second treatment group is ≥ 50 cm, a depth found to protect the subnivean environment (Marchand 1987). The second treatment will follow the same regiment as the first treatment with two snowmobile traverses for one transect and five snowmobile traverses for an additional transect. All treatment transects will be treated at least once a month for the duration of the snowmobiling season (December to April) to simulate a frequent use of each treatment transect. Snow depth will be measured prior to snowmobile traverses for control and treatment plots at 10-m intervals along each transect using a meter stick. The following summer, the height of each plant identified the previous year will be remeasured and compared.

*Indirect effects of snow compaction on the subnivean environment*

Snow compaction by snowmobiles is known to have significant impacts on the subnivean environment (Wanek 1971, Nuemann and Merriam 1972, Grellera et al. 1974, Keddy et al. 1979). However, no study has determined how snowmobile snow compaction affects subnivean vegetation. In order to address this subject, an experiment will be conducted over the summers and winters of 2010 and 2011 using the same study site used to study the direct effects of snowmobiles on woody vegetation.

One-hundred twenty-five, 40.6 by 50.8 cm plots (25 control, 100 treatment) were established among the five aforementioned transects in August 2010. The 100 treatment plots were divided among the four treatment transects (n = 25/transect). Treatment groups will be the same as those of the aforementioned study on wood vegetation. The aforementioned snow depths are also known to influence the subnivean environment (Wanek 1971, Nuemann and Merriam 1972, Marchand 1987) and cause changes in underlying vegetation (Keddy et al. 1979).

In August 2010, subnivean vegetation (< 30 cm) was measured using a "pin-board." The pin-board is a square table with 5 by 6 pin holes (n = 30) drilled 4 $cm^2$ apart in the top of the table (Fig 16). The table is placed in the center of each transect at 2-m intervals. The legs of the table are adjusted so that the top of the table is level with the ground surface. Two of the four table legs are inserted into PVC pipe that were pushed into the ground so that the table can be placed in the exact same location the following year. A pin (e.g., welding rod) is then inserted through each pin hole and allowed to drop freely to the ground surface. Each pin is segmented into four, 10 cm intervals for measuring the relative height of plants (0 cm, 0-10 cm, 10-20 cm, and > 20 cm) that touch each pin. Every plant that touches the pin is then identified to species, recorded as living or dead and whether it possesses an inflorescence onto data sheets (Appendix 2). These pretreatment data are intended to provide a comparison between control and post-treatment data in order to find significant differences ($\alpha = 0.05$) between all 125 plots.

During winter, snow depth will be measured prior to and following snowmobile traverses for control and treatment plots at 10-m intervals along each transect using a meter stick. Snow density will be measured prior to and following snowmobile traverses at control and treatment transects at 10-m intervals. Ambient temperatures will recorded using a thermometer and subnivean temperatures will be recorded using iButtons placed at ground level at 10-m intervals along control and treatment transects prior to snow fall. Additionally, the date on which snowmelt is completed (i.e., no presence of snow) will be recorded for each plot.

*Data Analysis of 2010 Vegetation Sampling*

Pretreatment data were stored into a Microsoft Excel spreadsheet. The frequency of each species for each transect were quantified (Table 1). *Andromeda polifolia*, *Betula nana*, litter, sedges, and *Vaccinium oxycoccos* were the most frequent species occurring among all transects.

All vegetation data were analyzed using R (see Appendix 3A, B, and C for codes) to determine whether data were normally distributed by using a Shapiro-Wilk test for normality. This test enabled the analysis of tied data. Data were found to be non-normally distributed. To test whether each species were significantly different ($\alpha = 0.05$) between transects a Kruskal-Wallis non-parametric test was used. All but four measured

variables were not significantly different among transects. The four measured variables that were significantly different included *Betula nana* ($p = 0.04$), litter ($p = 0.01$), *Vaccinium oxycoccus* ($p = 0.00$), and water ($p = 0.01$). *Betula nana* was different among transects one and five. Litter was different among transects two and four and two and five. *Vaccinium oxycoccus* was different among transects two and five and three and five and water was different among transects three and four (Table 2). The frequency of living species and dead species was also calculated (Table 3) as well as the frequency of species with inflorescences (Table 4) and frequency of each species at the four designated height classes among all five transects. Post-treatment analysis will also be analyzed using these methods.

**Data Management**

Both hardcopy data and digital data will be kept with the Resource Management Office at KENWR. ArcMap shapefiles will all be projected in WGS 1984 and include FGDC NBII metadata. Copies of all files will be kept by my self for analysis, and be made available later for public use according to federal and university standards. The results of each objective will be written into chapters as a dissertation and published in partial fulfillment for the requirements of a Doctorate of Philosophy in Biological Science.

TENTATIVE TIMELINE 2009-2014

Summer 2009
Acquainted with KENWR study area
Deployed 30 aerial snow markers
Literature research
Purchased equipment

Fall 2009
Classes at UAF
Literature research
MatLab exercise to ID snowmobile trails

Spring 2010
Classes at UAF
Proposal Drafted
Committee Meeting
Proposal Revised

Summer 2010
Sound level meter training
Collected vegetation data

Fall 2010
Wilderness Act training
R training
ANILCA training
Analyzed vegetation data

Fall 2010(cont)
Hired field technician
Acquired equipment
Revised proposal
Committee meeting

Winter 2010-2011
Data collection

Spring 2011
Data entry and analysis

Summer 2011
Data entry and analysis
Collect vegetation data
Write preliminary results

Fall 2011
Data analysis
Write preliminary results
Preparations for winter

Winter 2011-2012
Data collection

Spring 2012
Data entry and analysis
Present preliminary findings
Write preliminary results

Summer 2012
Data entry and analysis
Collect vegetation data
Submit preliminary results for multiple publications

Fall 2012
Classes at UAF
PhD candidacy exams
Teaching assistantship
Analyze data (modeling)
Committee meeting
Write dissertation

Spring 2013
Classes at UAF
Teaching assistantship
Analyze data (modeling)
Present results
Write dissertation

Fall 2013
Teaching assistantship
Analyze data (modeling)
Write dissertation

Spring 2014
Teaching assistantship
Submit dissertation
Defend dissertation

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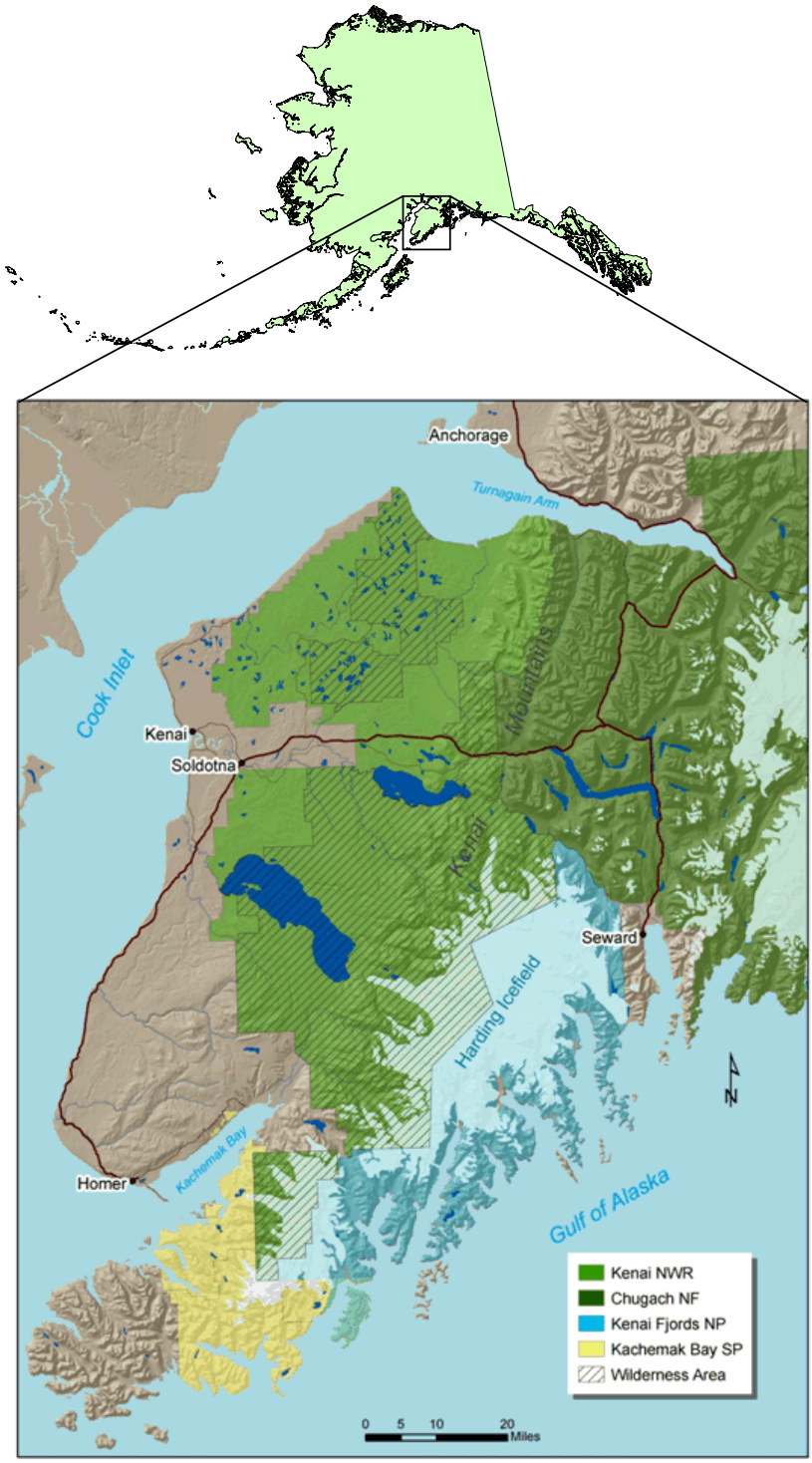



Figure 1. – The proposed study area (Kenai National Wildlife Refuge) in association with surrounding administrative units and congressionally designated Wilderness.

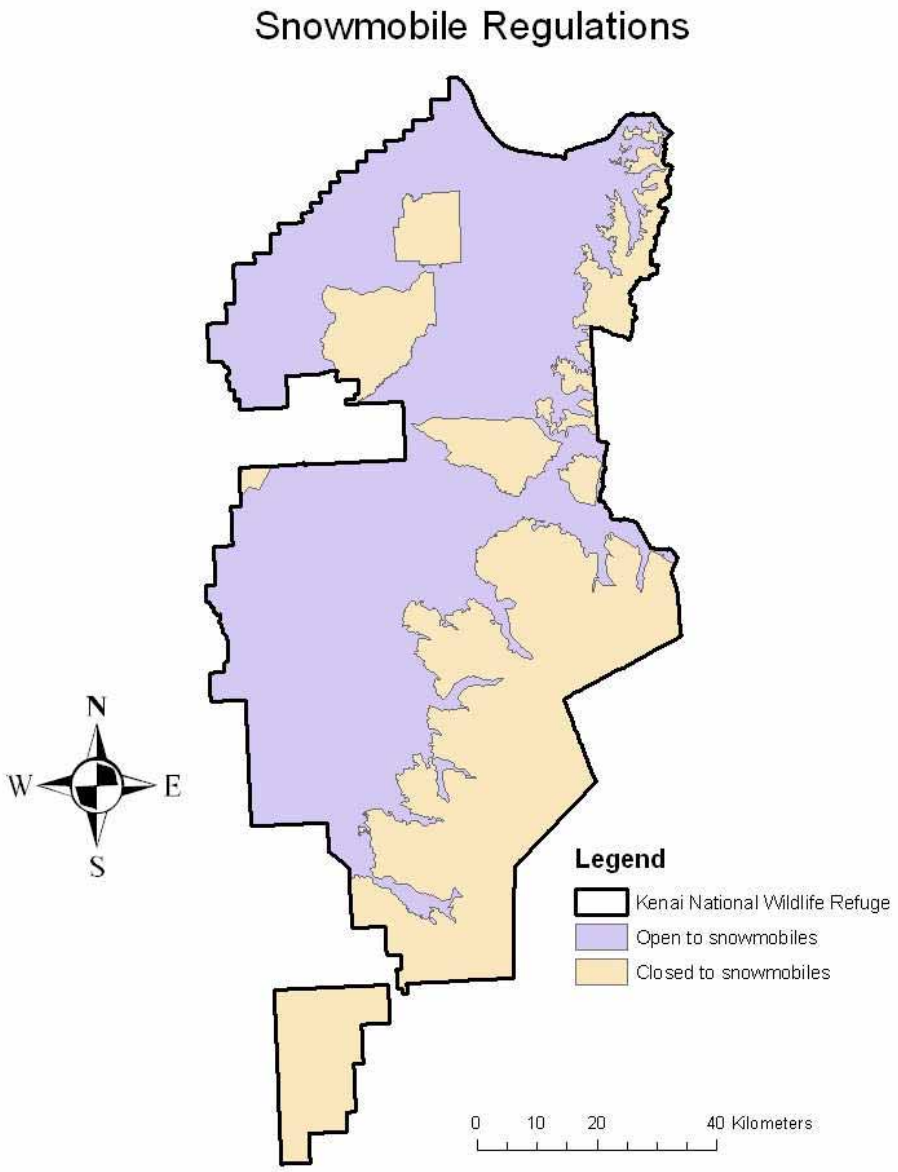



Figure 2. – Areas open and closed to snowmobiles in the Kenai National Wildlife Refuge.

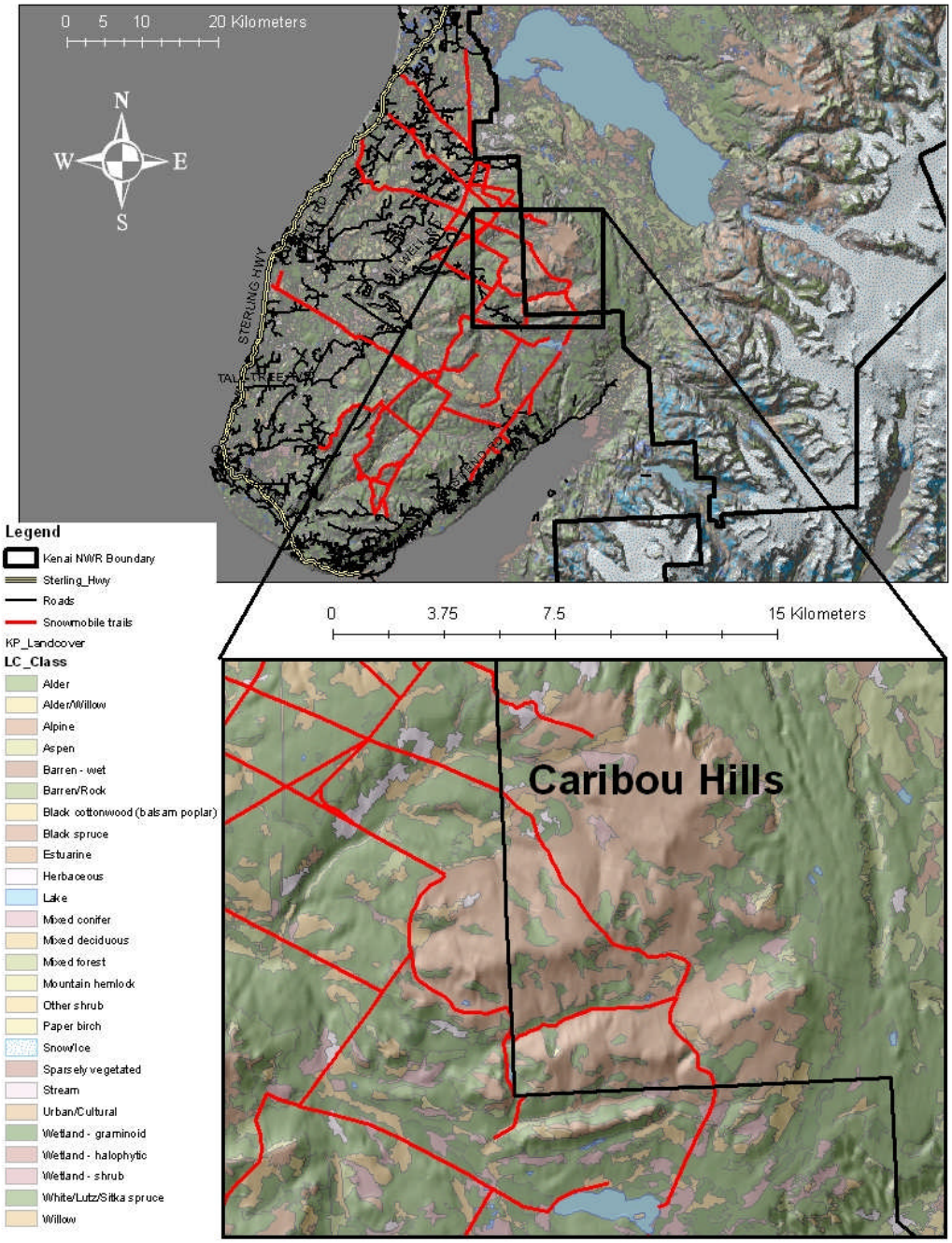



Figure 3. – The orientation of the Caribou Hills and established snowmobile trails in relation to the southwestern Kenai Peninsula road system.

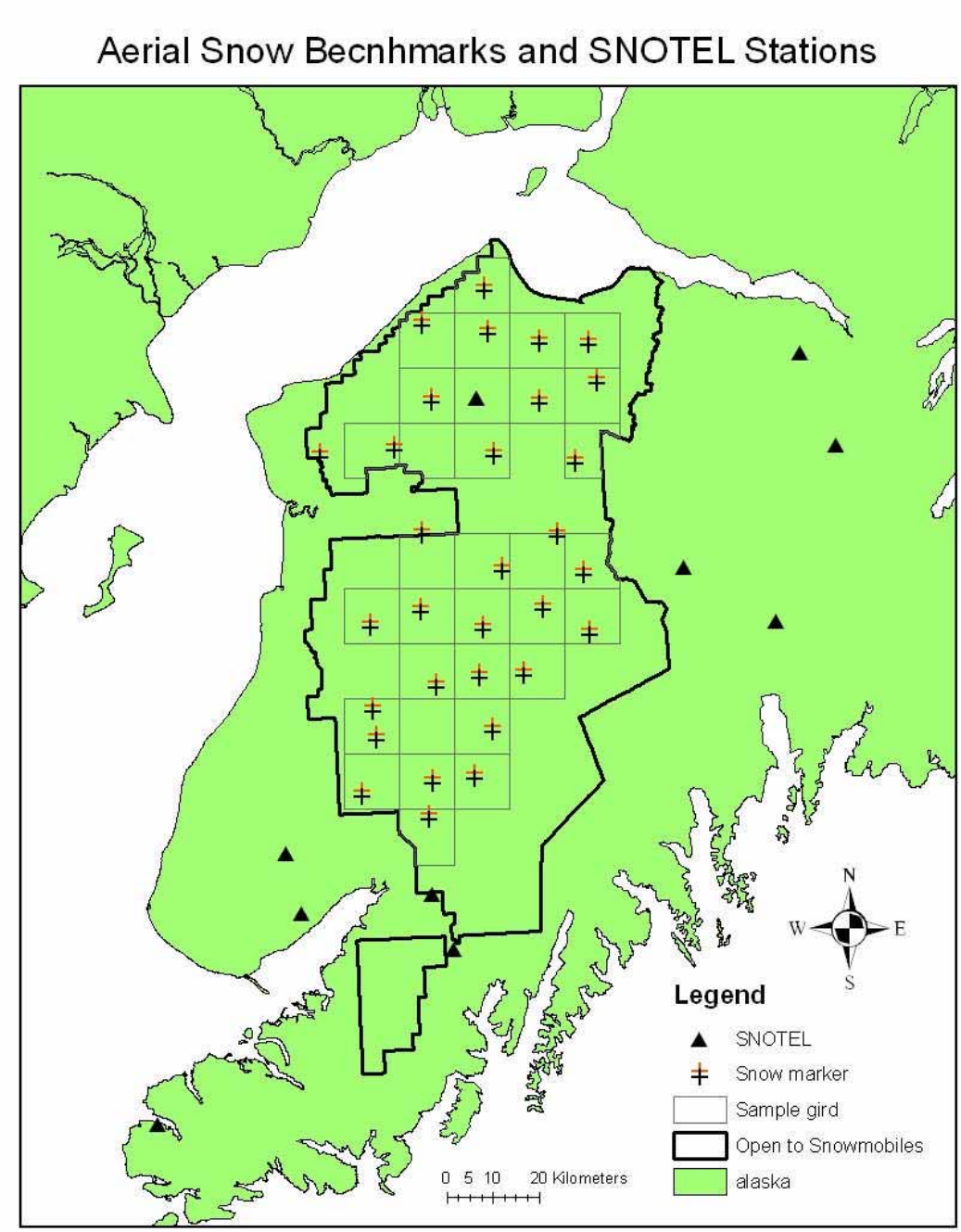
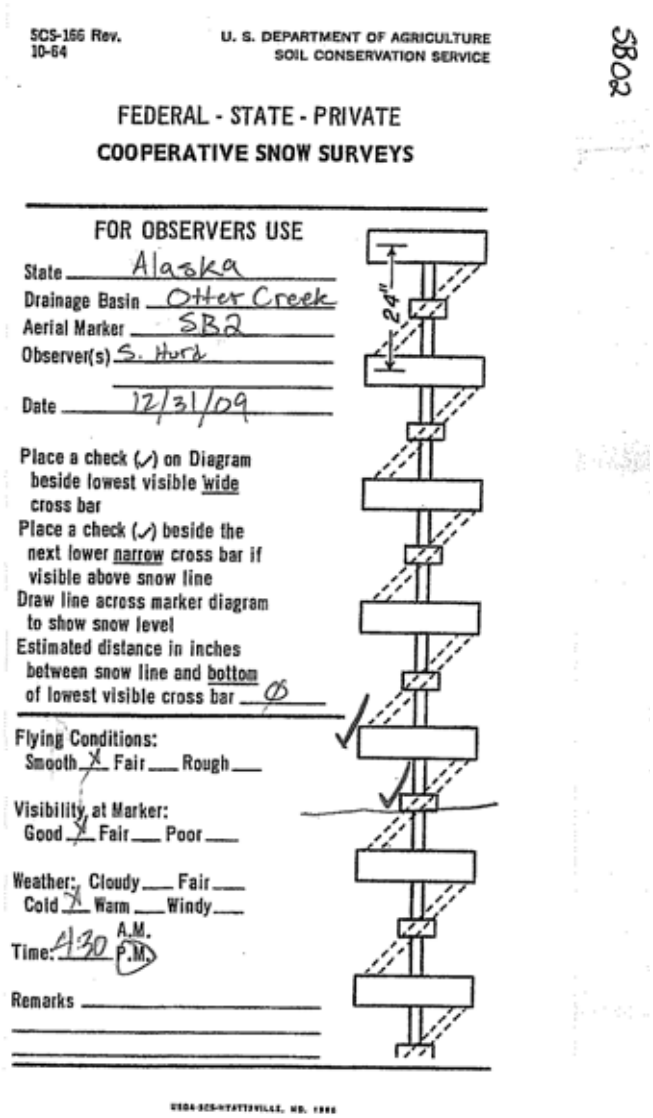



Figure 4. – Distribution of 30 aerial snow markers and SNOTEL stations in relation to a sampling grid throughout KENWR.

Figure 5. – Aerial snow marker.



SCS-156 Rev. 10-64

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

SB02

FEDERAL - STATE - PRIVATE
COOPERATIVE SNOW SURVEYS

FOR OBSERVERS USE

State Alaska
Drainage Basin Otter Creek
Aerial Marker SB2
Observer(s) S. Hurd
Date 12/31/09

Place a check (✓) on Diagram beside lowest visible wide cross bar
Place a check (✓) beside the next lower narrow cross bar if visible above snow line
Draw line across marker diagram to show snow level
Estimated distance in inches between snow line and bottom of lowest visible cross bar Ø

Flying Conditions:
Smooth X Fair ___ Rough ___

Visibility at Marker:
Good X Fair ___ Poor ___

Weather: Cloudy ___ Fair ___
Cold X Warm ___ Windy ___

Time: 4:30 A.M. P.M.

Remarks



Figure 6. – Example of a data sheet used for measuring snow depth from aerial snow markers.

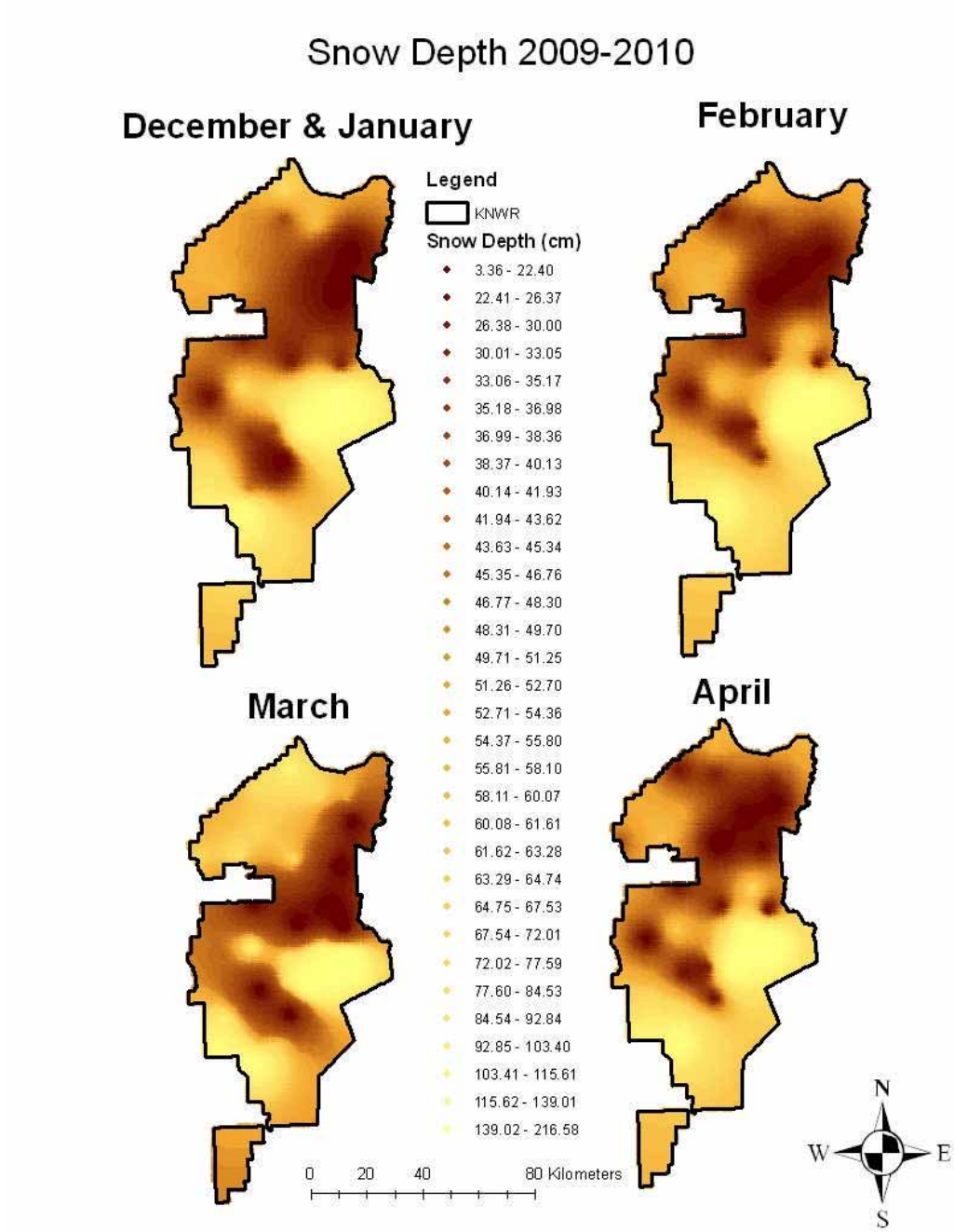



Figure 7. – Modeled distribution of snow depth taken from 30 aerial snow markers surveyed between December 2009 and April 2010.

Figure 8. – A TRAFx traffic monitor buried in snow beneath a snowmobile trail.

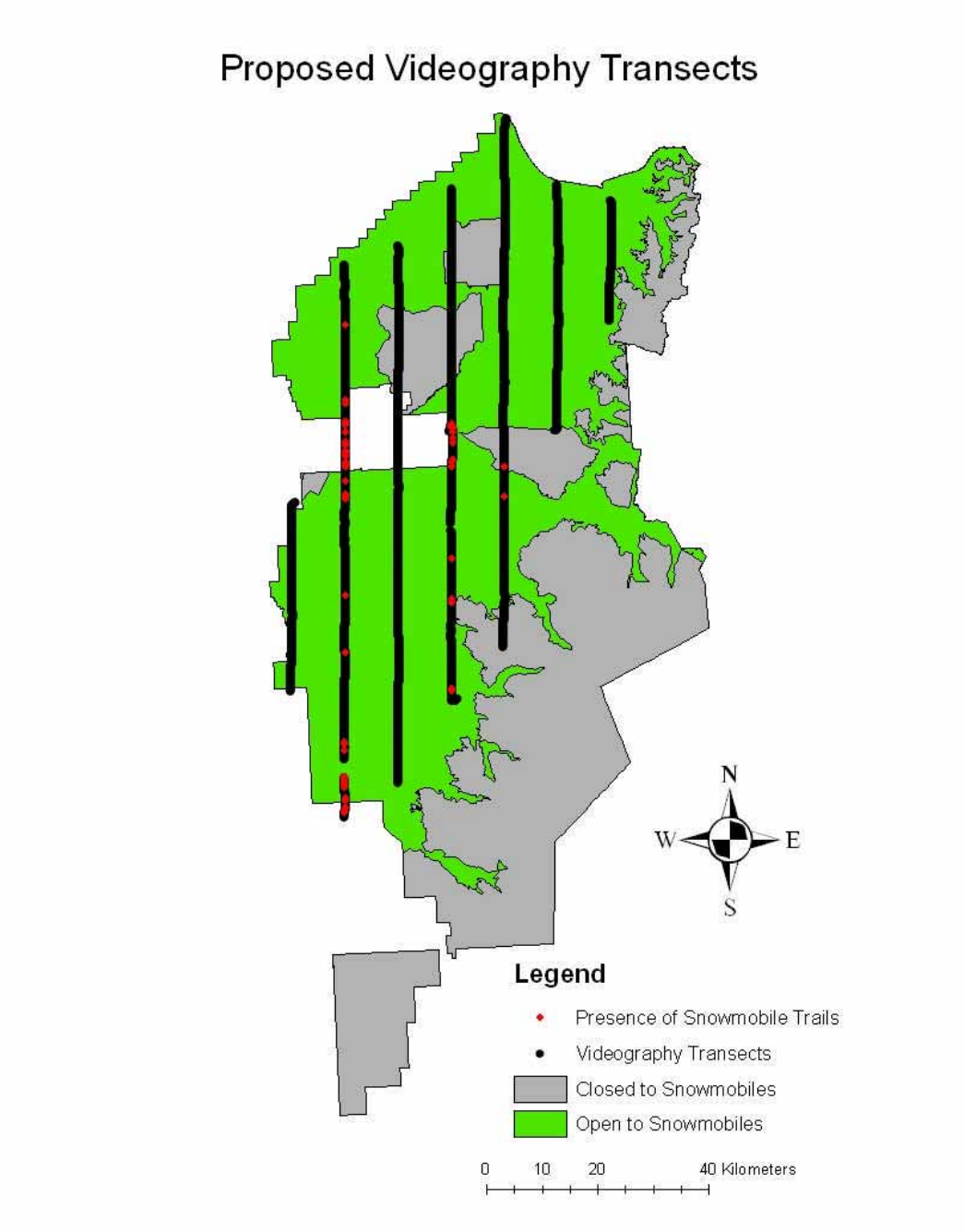



Figure 9. – Map of proposed videography transects for surveying snowmobile trails throughout the Kenai NWR and the presence of snowmobile trails from a 2006 study.

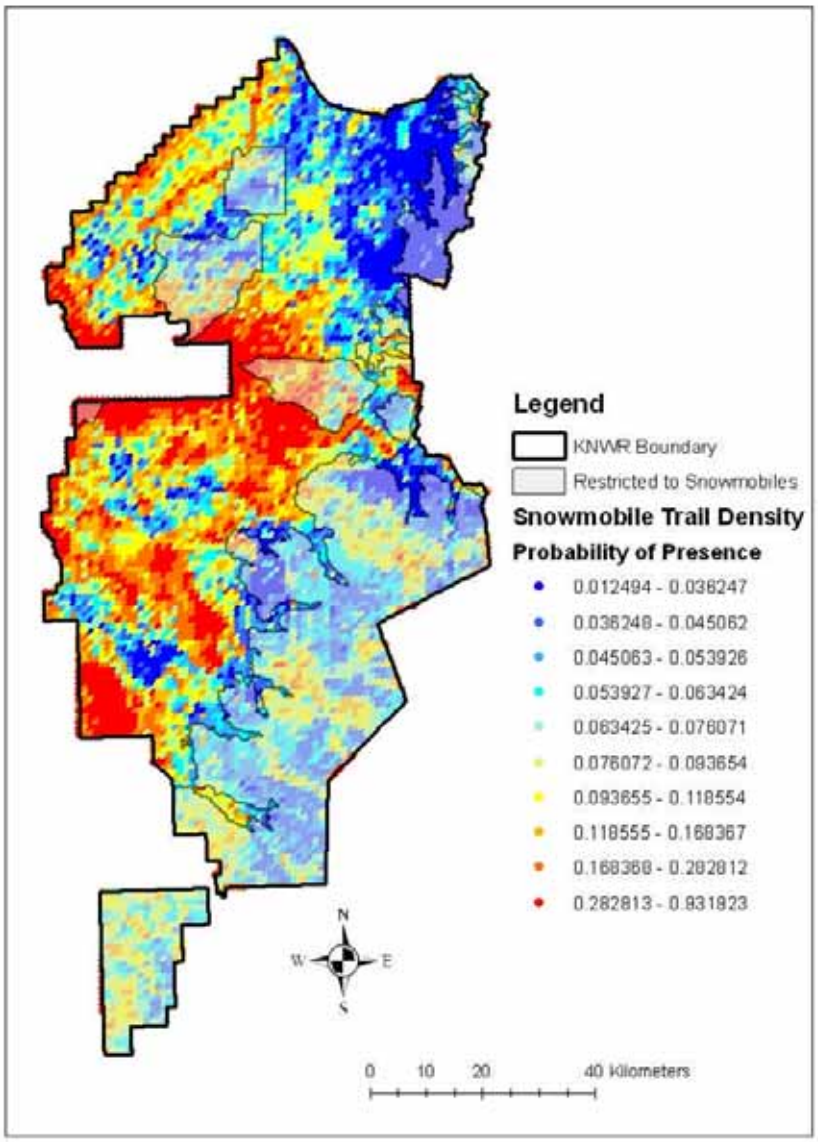



Figure 10. – Example of how the probability of snowmobile trails occurring within the KENWR will be modeled using videography data. Data were taken from 2006 aerial surveys.

Figure 11. – Example images of a Larson Davis 831(top) and a Larson Davis 820 (bottom) sound level meters.


Figure 12. – Image of a Wildlife Acoustics SM-2 digital sound recorder (top) and an example of a sonogram (bottom) produced from ambient sounds recorded from the SM-2. Sonogram shows frequency ranges of biophonic and anthrophonic sound sources (taken from Pijanowski et al. in press).

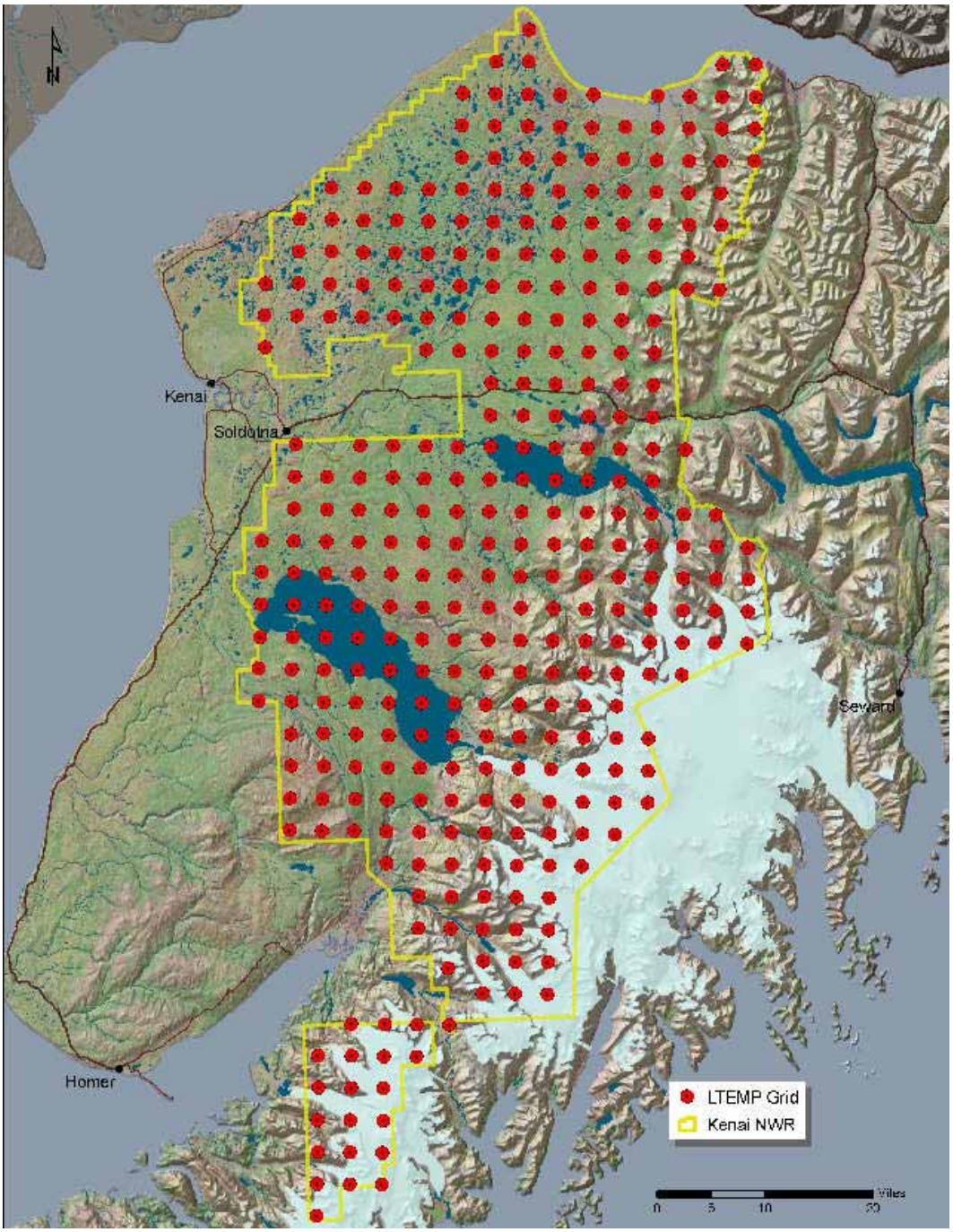



Figure 13. – Distribution of the 255 LTEMP sites in the KENWR that will be used to systematically select aerial photography stations for sampling mammal track distributions.

Figure 14. – Aerial view of the five vegetation sampling transects.

Figure 15. – Woody vegetation ≥ 30 cm in height that are tagged with yellow zip ties to identify individuals in winter.

Figure 16. – Vegetation sampling using “pin-board.”

Table 1. – Average heights of two woody species across five transects sampled at 130 line intercepts in August 2010. Standard deviations are in parentheses.

| | Transect | | | | |
|---|---|---|---|---|---|
| Species | 1 | 2 | 3 | 4 | 5 |
| *Betula nana* | 37.00 (7.31) | 35.89 (4.27) | 35.18 (3.57) | 38.00 (8.37) | 37.32 (5.60) |
| | n = 27 | n = 17 | n = 11 | n = 19 | n = 28 |
| *Myrica gale* | 38.5 (5.73) | 34.22 (2.94) | 40.20 (6.42) | 36.07 (3.47) | 35.17 (3.97) |
| | n = 18 | n = 9 | n = 5 | n = 15 | n = 12 |

Table 2. – Frequency of species and other ground cover variables occurring at 125 sample plots in August 2010 among five transects.

| Species | Transect | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| *Andromeda polifolia* | 0.187 | 0.220 | 0.183 | 0.147 | 0.184 |
| *Betula nana* | 0.191 | 0.144 | 0.113 | 0.131 | 0.109 |
| *Drosera anglica* | 0.000 | 0.000 | 0.000 | 0.001 | 0.004 |
| *Drosera rotundafolia* | 0.007 | 0.012 | 0.007 | 0.001 | 0.005 |
| *Empetrum nigrum* | 0.009 | 0.023 | 0.008 | 0.000 | 0.008 |
| *Ledum palustre* | 0.063 | 0.084 | 0.083 | 0.044 | 0.037 |
| Lichens | 0.008 | 0.015 | 0.009 | 0.003 | 0.001 |
| Litter | 0.260 | 0.289 | 0.227 | 0.139 | 0.144 |
| Mosses | 0.696 | 0.639 | 0.747 | 0.749 | 0.753 |
| Mushrooms | 0.003 | 0.003 | 0.001 | 0.004 | 0.003 |
| *Myrica gale* | 0.076 | 0.069 | 0.045 | 0.063 | 0.045 |
| *Pedicularis labradorica* | 0.005 | 0.005 | 0.004 | 0.001 | 0.003 |
| *Rubus chamaemorus* | 0.001 | 0.019 | 0.012 | 0.001 | 0.003 |
| Sedges | 0.283 | 0.196 | 0.229 | 0.227 | 0.244 |
| Unknown Shrub | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| *Vaccinium oxycoccos* | 0.293 | 0.333 | 0.316 | 0.225 | 0.176 |
| *Vaccinium uliginosum* | 0.001 | 0.000 | 0.000 | 0.000 | 0.003 |
| Water | 0.083 | 0.077 | 0.031 | 0.120 | 0.107 |

Table 3. – P-values of species frequency among five vegetation transects and their significant difference (α = 0.05) between transects.

| **Species** | **Significantly different (P-value)** | **Differences between transects** |
|---|---|---|
| *Andromeda polifolia* | 0.24 | |
| *Betula nana* | 0.04* | 1 and 5 |
| *Drosera anglica* | 0.24 | |
| *Drosera rotundafolia* | 0.20 | |
| *Empetrum nigrum* | 0.19 | |
| *Ledum palustre* | 0.09 | |
| Lichens | 0.20 | |
| Litter | 0.01** | 2 and 4; 2 and 5 |
| Mosses | 0.22 | |
| Mushrooms | 0.90 | |
| *Myrica gale* | 0.49 | |
| *Pedicularis labradorica* | 0.68 | |
| *Rubus chamaemorus* | 0.16 | |
| Sedges | 0.23 | |
| *Vaccinium oxycoccos* | 0.00** | 2 and 5; 3 and 5 |
| *Vaccinium uliginosum* | 0.55 | |
| Water | 0.01 | 3 and 4 |

* - significance < 0.05
** - significance < 0.01

Table 4. – Frequency of species living and dead among five vegetation sample plots (n = 125).

| Species | Frequency | |
|---|---|---|
| | Living | Dead |
| *Andromeda polifolia* | 0.18 | 0.04 |
| *Betula nana* | 0.14 | 0.01 |
| *Drosera rotundafolia* | 0.01 | 0 |
| *Empetrum nigrum* | 0.01 | 0 |
| *Ledum palustre* | 0.06 | 0 |
| *Myrica gale* | 0.06 | 0.06 |
| *Rubus chamaemorus* | 0.01 | 0 |
| Sedges | 0.24 | 0.67 |
| *Vaccinium oxycoccos* | 0.27 | 0.01 |

Appendix 1. – Example of a woody vegetation sampling data sheet used to document the type of species and height of that species among vegetation transects.

**WOODY VEGETATION SAMPLING DATA SHEET**

**Date:** _____ (Created 03 August 2010)
**Observer:** _____
**Recorder:**_____

PRE-TREATMENT

**Transect:** _____

| Line | Species | Height | Notes |
|---|---|---|---|
| | | | |
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Appendix 2. – Example of a vegetation "pin-baord" sampling data sheet used to document species occurrence, status (living or dead), height (0-20 dm), and presence of inflorescence among 125 sample plots.

## VEGETATION SAMPLING PIN-BOARD DATA FORM

**Date: _____** Pretreatment

**Observer: _____ Recorder: _____**

**Transect No.**
**_____**

**Plot:**

| Point | Species | Status | Height | Inflorescence |
|---|---|---|---|---|
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Appendix 3A. – R code for conducting a Shapiro-Wilks analysis for normality of data collected from 125 vegetation plots among five transects.

```
wd <- "H:/AKstudy/Veg_Sampling_2010/VEG_DATA"
setwd(wd)

source("freq_plots.R")

aa <- freq_array[1,1,] ##transect 1, species 1, all plots

shapiro.test(aa)

for (this.transect in 1:5) ##loop for species 1
 {
 for (this.species in 1:19)
  {
  print(this.transect)
  print(this.species)
  cc <- freq_array[this.transect,this.species,]
  print(shapiro.test(cc))
  }
}
## above loop did not work due to zeros in transects

for (this.transect in 1:5) ##loop for transects
 {
 for (this.species in 1:19)
  {
  print(this.transect)
  print(this.species)
  cc <- freq_array[this.transect,this.species,]
  if(sum(cc)!=0)
   {
   results <- shapiro.test(cc)
   print(results)
   }
  }
}
```

Appendix 3B. – R code for conducting a Kruskal-Wallis non-parametric test for significance among five vegetation transects.

```
setwd(wd)

source("freq_plots.R")

t1 <- as.vector(t(freq_array[1,1,]))

t2 <- as.vector(t(freq_array[2,1,]))

t3 <- as.vector(t(freq_array[3,1,]))

t4 <- as.vector(t(freq_array[4,1,]))

t5 <- as.vector(t(freq_array[5,1,]))

k.results <- kruskal.test(list(t1,t2,t3,t4,t5))

p.values <- NA
for (this.species in 1:19)
  {
  t1 <- as.vector(t(freq_array[1,this.species,]))

  t2 <- as.vector(t(freq_array[2,this.species,]))

  t3 <- as.vector(t(freq_array[3,this.species,]))

  t4 <- as.vector(t(freq_array[4,this.species,]))

  t5 <- as.vector(t(freq_array[5,this.species,]))

k.results <- kruskal.test(list(t1,t2,t3,t4,t5))
print(this.species)
print(k.results)
p.values[this.species]<- k.results$p.value
  }
write.csv(p.values, "Kruskal_pvalues.csv")

##Now that we've found some species to be signif different lets see which transects
f <- as.vector(t(freq_array[,2,]))

transect <- c(rep(1,25), rep(2,25), rep(3,25), rep(4,25), rep(5,25))

require(pgirmess)

ksig <- kruskalmc(resp = f, categ = transect)
```

Appendix 3C. – R code for conducting a Kruskal-Wallis multiple comparison test to determine which species were different among which transects.

```
wd <- "H:/AKstudy/Veg_Sampling_2010/VEG_DATA"
setwd(wd)

source("freq_plots.R")

##Now that we've found some species to be signif different lets see which transects
## For BENA (2)
f <- as.vector(t(freq_array[,2,]))

transect <- c(rep(1,25), rep(2,25), rep(3,25), rep(4,25), rep(5,25))

require(pgirmess)

ksig <- kruskalmc(resp = f, categ = transect)

## For Litter (8)
f <- as.vector(t(freq_array[,8,]))

transect <- c(rep(1,25), rep(2,25), rep(3,25), rep(4,25), rep(5,25))

require(pgirmess)

write.csv(ksig, "BENA_transect_differences.csv")

write.csv(ksig8, "LTR_transect_differences.csv")

write.csv(ksig16, "VAOX_transect_differences.csv")

write.csv(ksig18, "WATER_transect_differences.csv")

ksig8 <- kruskalmc(resp = f, categ = transect)

## For VAOX (16)

f <- as.vector(t(freq_array[,16,]))

transect <- c(rep(1,25), rep(2,25), rep(3,25), rep(4,25), rep(5,25))

require(pgirmess)

ksig16 <- kruskalmc(resp = f, categ = transect)

## For Water (18)
f <- as.vector(t(freq_array[,18,]))

transect <- c(rep(1,25), rep(2,25), rep(3,25), rep(4,25), rep(5,25))

require(pgirmess)

ksig18 <- kruskalmc(resp = f, categ = transect)
```

## Appendix 4. – R code for krigging snow depth data from 30 snow benchmarks.

```
wd <- "I:/BIOLOGY/Temp/mullet/Snow_benchmarks/Krigging_data"
setwd(wd)

SBdata <- read.csv("Benchmark_snowdepth_data_2009_2010_UTM.csv")

library(geoR)

sbgeo <- as.geodata(SBdata, coords.col = 2:3, data.col = 4:8, na.action = "none")

##Plot data from March (column 4)

plot(sbgeo, col.data=4)

##Create a variogram

sbvar <- variog(sbgeo, data=sbgeo$data[,4])

##Now plot variogram

plot(sbvar)

##Now let's fit a line to the model variogram

ml <- likfit(sbgeo, ini = c(1, 8000), data = sbgeo$data[,4], cov.model = "exp", fix.nugget = TRUE, nugget = 0)

plot(sbvar)

lines(ml)

##That worked well!  Let's keep it.

## Now we need a prediction grid in ArcMap
## Make a finer scaled grid (1000 m^2 grid)
## Bring grid coordinates into R

wd <- "I:/BIOLOGY/Temp/mullet/Snow_benchmarks/Krigging_data/Grids"
setwd(wd)

SBgrid <- read.csv("1000Grid_Clip.csv")

pred.grid <- SBgrid[,2:3]

##Now lets Krige!

krig1 <- krige.control(obj.model = ml)
krig3 <- krige.conv(sbgeo, data = sbgeo$data[,4], locations = pred.grid, krige = krig1)

plot(pred.grid, type = "n")

points(pred.grid, cex = krig3$predict/30)

## Awesome!  We Krigged it!  But doesn't include elevation as covariate yet!

## Now lets make csv to put into Arcmap

SBpred <- cbind(pred.grid, krig3$predict)

write.csv(SBpred, "SBpredictions_March2010_2.csv")

SBsd <- cbind(pred.grid, (krig3$krige.var)^0.5)

write.csv(SBsd, "SBprediction_errors_March2010_2.csv")
```