FINAL STUDY PLAN – 20 August 2000

PROJECT TITLE: Assessing wildland fire impacts on the winter habitat use and distribution of caribou within Alaska's boreal forest ecosystem

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SUMMARY

The US Geological Survey-Alaska Biological Science Center (USGS) and the Alaska Department of Fish and Game-Division of Wildlife Conservation (ADF&G) will conduct a 5-year investigation of the impact of boreal forest fires on the Nelchina Caribou Herd (NCH) in south-central and interior Alaska. This collaborative effort will evaluate relationships between fire history and lichen abundance; caribou habitat selection relative to lichen abundance; and caribou nutritional performance relative to habitat selection, lichen abundance, and spatial distribution. Results of this study will provide information directly applicable to caribou and fire management in Alaska.

PROBLEM STATEMENT

Caribou wintering in boreal forest ecosystems of Alaska forage primarily on "climax" stage fruticose lichens. Wildland fires, however, chronically burn boreal forests, reducing the availability of forage lichens for decades. In addition, prescribed fires have been implemented to reduce fire hazards, restore biodiversity or enhance moose habitat.

Since the early 1900s, wildland fire has been implicated in caribou population declines. Numerous studies reveal reduced lichen availability, long lichen recovery periods, and caribou avoidance of recently burned winter ranges. However, direct evidence for fire induced population declines is notably lacking. Moreover, researchers have long debated the importance of lichens to caribou. Although lichens dominate winter diets when available, examples of robust caribou populations utilizing lichen-poor ranges suggest that high-quality summer range or alternate winter forages can supplant lichen-rich winter range.

In addition, numerous investigators suggest that fire may rejuvenate older lichen ranges by favorably altering moss-lichen relationships, reducing overstory, or removing decadent lichens. Fire may also alter caribou movement patterns, thereby allowing recovery of over-grazed lichen ranges. Lastly, fire likely enhances summer range through nutrient turnover and increased quality and abundance of vascular forages. Contrary to assertions that fire is detrimental to caribou, these mechanisms suggest that wildland fire may play a role in maintaining caribou winter range or enhancing nutritional status.

The NCH provides ideal opportunities to investigate many aspects of the influences of boreal forest fires on caribou. The NCH ranges over a large portion of south-central Alaska that is influenced by a variety of prescribed and wildland fire management regimes. During the last 2 decades, the herd shifted its primary winter range from an area of very low fire frequency to a highly fire-influenced system north of the Alaska Range. This current winter range has limited vegetation diversity other than that generated by wildland fire occurrence. In addition, 2 prescribed fires to enhance moose habitat have recently been conducted on this winter range and another is scheduled for a portion of the summer range. These characteristics, along with a substantial history of research and relatively good accessibility, make the NCH a logical choice for investigating the relationships between fire and caribou.

Management of the NCH generates substantial public interest because of its accessibility to a large portion of the Alaskan public for both subsistence and general uses. Understanding caribou/fire relationships on ranges of the NCH will provide information for herd management locally, and fire management throughout the boreal forest ecosystem of Alaska and Yukon.

OBJECTIVES

The overall goal of this research is to improve our understanding of the effects of fire on caribou populations utilizing boreal forest winter ranges. To reach that goal we provide the following specific objectives and hypotheses:

1. Determine the relationships between fire history and forage lichen abundance and condition.

H1. Forage lichen abundance and productivity increases with stand age to roughly 50-100 years, then declines.

H2. Fire promotes lichen growth by reducing overstory or moss and increasing soil temperatures in declining and grazing-depleted lichen stands.

2. Investigate the importance of lichen, and therefore fire history, in determining caribou habitat selection.

H3. Historic winter ranges in the Nelchina Basin have lower lichen abundance than currently used winter ranges north of the Alaska Range.

H4. Caribou avoid burned areas for decades post-fire and select for older stands with abundant forage lichens.

H5. Winter movement patterns are influenced by lichen abundance.

3. Evaluate relationships between winter habitat selection of caribou and their nutritional performance.

H6. Caribou utilizing lichen-rich winter ranges gain more or lose less weight than caribou utilizing lichen-poor ranges.

H7. Caribou weight gain on preferred winter ranges is independent of caribou density on those ranges.

H8. Weight change is related to the proportion of lichen in the winter diet of caribou calves.

H9. Winter weight change is independent of summer weight gain.

4. Evaluate the influences of various fire management regimes on caribou.

H10. Altering the frequency of fire recurrence (return interval) on winter range influences caribou through changes in availability of forage lichens.

BACKGROUND

SUMMARY OF CARIBOU/FIRE/LICHEN RESEARCH

Fires are normal, recurring events in boreal forest ecosystems and are instrumental in maintaining productivity and biodiversity. The importance of fires in shaping the vegetative landscape of interior Alaska cannot be overestimated. Fire recurrence relates to age of vegetation, physiography and local environmental conditions (Rowe *et al.* 1974). Patterns of post-fire succession (Van Cleve and Viereck 1981 and 1983) and fire cycle effects on the forest mosaic are well described for boreal forests (Bergeron and Dansereau 1993). The effects of these processes on caribou populations, however, are poorly understood.

Lichens, particularly *Cladina* spp. ("caribou lichens"), are a major source of winter food for most continental populations (Kelsall 1960, Miller 1976, Klein 1980, Russell and Martell 1984, Thomas and Barry 1991, Thomas et al. 1998b). On Alaskan winter ranges, lichens comprise 60-80% of the winter diet (Adams and Connery 1983, Boertje 1984, Boertje and Gardner 1998). Wildland fire reduces abundance or kills forage lichens and lichen woodlands are susceptible to frequent burning (Auclair 1983). Moreover, caribou forage lichens are associated with late stages of boreal forest succession (Klein 1982) and require long periods of recovery following fire or other disturbance (Viereck and Schandelmeier 1980, Thomas and Kiliaan 1998).

Research in the 1960s in northern Canada suggested that fires had a detrimental effect on caribou populations due to loss of mature forest stands with substantial standing crops of lichens (Kelsall 1960, Thomas 1969, Scotter 1965, 1970). Conversely, studies reported by Skoog (1968) and Bergerud (1972) for Alaska and Newfoundland, respectively, indicated little or no impact of fire on population dynamics of caribou. These divergent findings precipitated evaluations of the influence of fire-depletion of lichen ranges on winter habitat use (Miller 1976, 1980, Thomas 1991, Thomas et al. 1998a).

Several researchers suggested that caribou shift their distribution in response to burn patterns. Thomas *et al.* (1998a) found that caribou of the migratory Beverly Herd in the Northwest Territories readily traveled through most burns, but spent little time in them and avoided very large burns (>50,000 ha) on the periphery of the winter range. The authors suggested that the herd expanded its range to replace burned portions of the traditional range. Schaefer and Pruitt (1991) studied effects of fire on resident woodland caribou in Manitoba and concluded that quality and accessibility of winter forages in burned upland habitats declined. They attributed this decline to loss of lichens (*Cladina* spp.), increased thickness and hardness of snow, and accumulation of deadfalls. By five years post-fire, caribou had abandoned burned areas completely and remnant lichen populations were exhausted. During this post-fire period, they observed a three-fold increase in area used during winter and a decline in caribou population size. They concluded that areas burned within 50 years were not suitable winter habitat. These results suggest substantial negative impacts of fire on caribou through increased migratory costs and reduced foraging efficiency.

Other researchers argue that positive impacts of fire outweigh the loss of lichen stands. Because extremely old stands have reduced lichen productivity, Klein (1982) asserted that fire is essential in the recycling of nutrients and maintaining vegetative productivity and ecological diversity. In addition, because caribou may avoid recent burns, fire may maintain the productivity or allow recovery of winter ranges (Lutz 1956, Ahti and Hepburn 1967, Rowe et al. 1975, Kershaw 1977). Fire also can enhance the quality and abundance of summer forages (Schaefer and Pruitt 1991). Thus, it seems that the availability of various successional stages throughout caribou range, such as may occur under natural disturbance regimes, assures long-term productivity of the ecosystem for caribou.

The existing body of research clearly indicates that wildland fire has enduring influences on lichen abundance in boreal forests. Following decades of extensive fire suppression efforts, there can be little doubt that past fire management policies influenced the present winter habitats of many Alaskan caribou herds. Although suppression policies adopted in the mid 1980s promise a return to natural fire regimes for remote areas, suppression and management efforts inevitably increase with human settlement and development. Consequently, fire management policies will, at a minimum, continue to be relevant to caribou management. Yet despite these considerations, the net impacts of fire on forage lichen abundance remain debatable. The effects of lichen abundance on caribou distribution are, likewise, poorly understood. Moreover, no attempt has been made to link fire-influenced variation in lichen abundance or caribou distribution to the fitness of individual caribou or the dynamics of caribou populations.

FIRE AND ABUNDANCE OF FORAGE LICHENS

Abundance of forage lichens is closely related to post-fire stand-age, however, regional colonization and growth rates vary substantially (Thomas and Kiliaan 1998). Lichens exhibit distinct periods of growth and lichens in the oldest growth stage die at the base at rates equal to or faster than the accumulation of new growth at the tips (Andreev 1954). Thus, lichen abundance increases with stand-age for several decades after colonization. Numerous investigators suggest that forage lichen abundance eventually declines in very old black spruce stands due to increased moisture and muskeg formation or shading from closure of the spruce/shrub canopy (Andreev 1954, Kershaw and Rouse 1976, Maikawa and Kershaw 1976, Miller 1976b). Depending on fire frequency, declining lichen abundance in very old stands could tremendously influence winter forage availability. Empirical data addressing these relationships are lacking for Alaskan spruce forests and time-scales vary widely among locales (Andreev 1954, Tengwall 1928 cited in Hale 1973).

Specific data regarding colonization, growth characteristics, and abundance of lichen following fire are fundamental to understanding fire-influenced changes in winter forage availability for caribou. Gathering this data in a reasonable time frame entails comparing lichen characteristics in stands that vary in age post-fire, but are otherwise very similar. The current winter range of the NCH is particularly suited to that task. It consists of a mosaic of black spruce stands across a large area of gentle topographic relief. Age of a stand post-fire is likely the dominant landscape characteristic influencing lichen abundance.

Caribou grazing also influences lichen abundance (Miller 1976a, Ouellet et al. 1993). Similar to fire-depleted stands, intense grazing and trampling can reduce live lichen biomass for decades. However, the persistence of lichen fragments and intact plants in grazing-depleted stands may short-cut the early succession and colonization stages characteristic of fire-depleted stands. Therefore lichen biomass on grazing-depleted stands may recover more quickly than on fire-depleted stands.

Conversely, Viereck and Schandelmeier (1980) suggested that fire increases lichen abundance in old stands where moss layers or shrub and spruce overstory competitively inhibit lichen growth. Under this scenario, competition is expected to slow or stop the recovery of grazing-depleted stands. Because fire would mitigate the competitive effect, fire might actually expedite, or even be requisite, in the recovery of some grazing-depleted lichen ranges. While existing data allows only rudimentary speculation, it is apparent that grazing and the dynamics of associated vegetation may fundamentally influence the consequences of fire on forage lichen availability. Investigating these processes can be accomplished through *in situ* experiments that evaluate lichen growth rates for various fire and grazing treatments.

LICHEN ABUNDANCE AND CARIBOU HABITAT SELECTION

Pruitt (1959) and Bergerud (1974) asserted that habitat selection should be based primarily on forage abundance and secondarily on environmental conditions. Thomas and Kiliaan (1998) described a clear peak and decline in forage lichen biomass as post-fire age of jackpine stands increased in Canada. Given these relationships, caribou should select for stands in lichen-rich age ranges and avoid younger or older stands. Strong selection for stands of certain ages implies that various fire management regimes can greatly influence the accessibility of caribou to humans, if not the dynamics of caribou populations. Conversely, lack of selectivity for lichen abundance would suggest minimal impact of fire management decisions on caribou.

To date, studies of barren-ground caribou distribution indicate mere avoidance of recent burns rather than strong selection for lichen abundance. Ouellet et al. (1993), Saperstein (1993), and Thomas et al. (1996) explained that caribou foraging dynamics and environmental variation substantially influenced habitat suitability. For example, heterogeneity in lichen distribution likely affects foraging efficiency and foraging risk, which in turn influence habitat selection. Such factors may indeed influence habitat selection more than lichen abundance.

Other environmental variation may obscure selectivity for lichen abundance. Avoidance of recent burns by woodland caribou was partially attributed to increased foraging and movement costs due to increased deadfall trees and snow hardness (Schaefer and Pruitt 1991). The winter range currently used by the NCH consists of low hills and lowlands dominated by open canopy black spruce. For this winter range, deadfalls may not affect habitat selection because of the small size and low densities of trees and the tendency for burned trees to remain standing. Likewise, snow characteristics may not vary dramatically with stand-age (Schaefer 1996). Reduced variation in these factors should make selectivity for lichen abundance more detectable. Lack of selectivity for lichen abundance on this range would provide strong testimony for the importance of factors other than lichen abundance in determining caribou habitat selection and distribution.

Detecting selection for lichen abundance becomes difficult if additional factors influence habitat selection, but on different spatial scales. No single spatial scale is likely appropriate for all of the relevant ecological processes (Bowers 1997). Moreover, strong interaction among two co-factors may be expressed on a third spatial scale. For example, if wolf predation risk and post-fire stand-age equally influence habitat selection, the appropriate scale becomes the intersection of the pack territory and burn mosaics. Because the resulting scale is finer, evaluating habitat selection at the scale of either factor might be inconclusive, even though each strongly influences habitat selection. For evaluating the influence of lichen abundance on habitat selection, this problem can be dealt with by exploring selectivity on a variety of spatial scales. The likelihood of Type II error from scalar effects of co-factors is reduced by bracketing the spatial scales at which selectivity for the main effect is evaluated.

The size and variability of annual ranges and the mobile nature of large barren-ground caribou herds also complicate analyses of caribou habitat selection. For example, the NCH ranges over 68,000 km^2 consisting of diverse habitats ranging from forested lowlands to the alpine tundra of 3 mountain ranges. Large portions of this range are greater than 50 km from the few year-around roads and trails. Caribou distribution across this area can vary dramatically within and among years.

These conditions complicate the estimation of habitat use required for robust analyses of habitat selection (Thomas and Taylor, 1990). Aerial surveys (Jakimchuk and McCourt 1975, Stardom 1975), conventional radio-telemetry (Miller *et al.* 1975), and satellite telemetry (Pank *et al.* 1985, Harris *et al.* 1990) have all been used, however, all have analytical or logistical shortcomings. Conventional aerial telemetry and aerial surveys provide data for only a very short time period or time of day, when habitat use over a longer period, such as a season or year, is usually desired. Satellite telemetry provides frequent locations, but accuracy is poor, information on activity and group size cannot be obtained, and the number of animals in the sample is usually low. GPS telemetry has many of the same limitations as satellite telemetry, but can be very accurate. An approach employing a combination of conventional and GPS telemetry can mitigate many of these shortcomings and provide additional flexibility in assessing the effects of spatial scale.

Assessing lichen availability for caribou is similarly challenging. Data at appropriate spatial scales are required for very large areas (Adams and Connery 1983). Ground-based estimations of availability are time intensive and thereby limited to small areas and fine spatial scales. Satellite-based remote sensing data is often implemented to mitigate those limitations (Russell et al. 1983, Adams and Connery 1983), however it is unclear whether that technology can adequately sense low biomass groundcover such as forage lichens. Digital applications of fine-scale aerial imagery have recently been implemented as efficient and flexible methods for assessing vegetation coverage over large areas. Forage lichens are highly visible from small aircraft and lichen biomass strongly correlates with coverage (Thomas and Kiliaan 1998). Developing aerial videography and photography techniques appropriate for forage lichens should provide useful methods for estimating lichen availability for caribou. In addition, the application of those methods would provide a data set suitable for the evaluation of satellite-based techniques.

WILDLAND FIRE AND CARIBOU NUTRITIONAL STATUS

Evidence that fire influences barren-ground caribou population dynamics is circumstantial and no direct mechanisms for population change have been demonstrated. Poor nutritional condition resulting from reduced lichen availability is the most obvious potential consequence of fire on winter range, but selection for particular habitats or forages does not necessarily indicate direct nutritional consequences. If alternate food resources provide sufficient nutrition, fires on winter range may affect distribution without negatively impacting nutritional status.

Determining whether lichen availability influences winter nutritional status is problematic. First, the scale at which availability might influence nutrition is unknown. Where should lichen abundance be measured: the entire caribou range or within late-winter feeding craters? Furthermore, local snow conditions and numerous other spatially explicit factors also affect nutritional status. Identification of an appropriate spatial framework is simply impossible. A hierarchical approach that first identifies important spatial scales is warranted (Coulson et al. 1997). Essentially, it is first determined if there are spatial patterns in nutritional performance at *any* spatial scale. Once identified, spatial trends in causal factors, such as lichen abundance, are evaluated relative to the observed patterns in nutritional performance.

One such spatial scale can be identified *a priori*. During the last several years, roughly 80% of the NCH has wintered on relatively lichen-rich ranges north of the

Alaska Range. The remainder of the herd continues to use historically heavily grazed and currently lichen-poor winter ranges in the Nelchina Basin (Lieb et al. 1984). Comparisons of the nutritional performance of caribou and lichen abundance on these two ranges will provide useful insight to the importance of lichen forages on a very broad scale. Identification of other spatial trends in nutritional performance will invite appropriate evaluations of lichen availability, as well as other factors, across the observed trends.

With the application of stable isotope analyses of blood samples collected from individual caribou, it may be possible to categorize winter lichen consumption and relate that to nutritional performance of individual caribou. Stable isotope analysis, a rapidly emerging technology, is based on the differential use of naturally-occurring elemental isotopes in biological processes (Tieszen 1991). Carbon cycling in lichens differs from other caribou forages that employ the C_3 photosynthetic pathway. Similar to plants using the C_4 pathway, reduced depletion of ^{13}C in lichens should result in a unique isotopic signature (Tiezen et al. 1998). Therefore, variation in the ratios of carbon isotopes from caribou blood samples (L. Adams, unpubl. data) should reflect the proportion of lichen in their winter diets. Although these underlying relationships need to be validated, this technique shows promise and would allow for direct comparisons of winter lichen consumption with weight change among individual caribou.

Growth of young females (5-17 months-of-age) is a sensitive and therefore desirable indicator of nutritional performance because their body weight changes rapidly through a single season and their nutrition is largely free of maternal influence. Further, age of sexual maturity is strongly influenced by body weight at 17 months-of-age (Adams and Dale 1998). For caribou, substantial variation in weight gain among individuals and among cohorts has been observed in this sex-age class. Individual variation in seasonal growth rates within cohorts should reflect quality and availability of food experienced by each individual, while variation among cohorts should reflect population-wide trends of or influences of stochastic environmental variation on nutrition during a particular season.

Determining winter weight dynamics of female calves will require the capture and handling of individuals prior to the onset of winter (at 5 months of age, early October) and again at the end of winter (at 11 months of age, mid April). The initial weight at 5 months of age will also allow for comparing the interactions of nutritional performance of calves during their first summer with that over the winter. Summer nutritional performance may carry through and have greater influence on late winter condition than winter foraging conditions and may influence winter habitat selection. Summer nutritional performance alone has been linked to substantial population declines (Couturier et al. 1988).

Winter nutritional performance may also influence subsequent summer weight gains and ultimately reproductive performance of individuals (Adams and Dale 1998). By weighing individuals again at 17 months (early October), we will have the full suite of information necessary to evaluate the importance of winter nutritional performance and habitat quality relative to summer nutrition.

Impacts of fire on caribou may not be limited to nutritional consequences. Caribou employ specific spatial strategies to reduce risk of predation and changes in caribou distribution may influence survival rates (Bergerud 1980, Dale et al. 1994). Spatial strategies such as predator “swamping” or “spacing away” imply strong trade-offs between predation avoidance and nutritional performance. However, virtually nothing is known about these relationships. Fire clearly influences spatial distribution on winter range as evidenced by avoidance of recent burns and expanded winter use areas. Selection for particular age stands would indicate even greater influence of fire on spatial distribution, especially during late winter when caribou vulnerability is high. Identifying spatial patterns in nutritional performance and survival of caribou, and linking those patterns to habitat characteristics, provides the ecological framework necessary to evaluate influences of fire, or other environmental disturbance, on caribou populations.

EVALUATION OF FIRE MANAGEMENT REGIMES ON CARIBOU POPULATIONS

The data collected in this study will provide information for modeling various caribou/fire/lichen relationships. Spatially explicit models of influences of fire management regimes on lichen abundance will be particularly useful for managers. In addition, this study will provide data for modeling a variety of processes, from deterministic models of lichen abundance and caribou weight gain, to stochastic time-series models of interactions among fire, weather and caribou dynamics. Our research approach is especially conducive to these types of evaluations because, fire, lichen abundance, habitat selection, nutritional performance, and survival are simultaneously evaluated within a very flexible spatial framework.

STUDY AREA

The NCH numbered more than 70,000 in the early 1960's (Siniff and Skoog 1964), but declined through the early 1970's, reaching a low of approximately 7,000 individuals in 1972 (Bos 1975, Lieb et al. 1984). The herd again rebounded to 45,000 by 1992 (McCarthy 1992). The herd is currently estimated at about 31,000 caribou (R. Tobey, unpubl. data.). The mechanisms behind these population fluctuations have been topics of vigorous debate (Van Ballenberghe 1985, Bergerud and Ballard 1988). Factors that have been suggested are range degradation, severe weather, predation, and hunting (Bergerud 1978, Doerr 1979, Van Ballenberghe 1985, Bergerud and Ballard 1988).

The range of the Nelchina herd is generally bounded by the Talkeetna Mountains to the west, the Alaska Range to the north, the Wrangell Mountains to the east and the Chugach Mountains to the south. This area is commonly known either as the Copper River or Nelchina Basin (elevation 500 – 600m). Two major river systems, the Copper and Susitna, drain the basin. Caribou are commonly found at elevations up to 1,500m (Van Ballenberghe 1985). The current range of the NCH encompasses approximately 68,000 km^2. For the last several years, the majority of the herd has wintered northeast of the Alaska Range. These wintering grounds were not used historically by the NCH (Lieb et al. 1984). In early spring, the herd leaves the wintering grounds and heads west to the calving grounds. Calving typically takes place in late May in the Oshetna and Black River drainages on the east side of the Talkeetna Mountains. After the post-calving aggregation, the herd has a tendency to spread out in late summer and fall, and can be found almost anywhere in the Nelchina Basin. Grouping begins again in late September when the herd starts migrating for the winter range.

The summer range is primarily above timberline. Shrub and alpine communities dominate this section of the range. Low topographic variation, relatively low elevation, numerous lakes, ponds, and streams, and extensive black spruce stands characterize the historic winter range in and around the Lake Louise flats. Lichen, once abundant in the region, is now considered sparse (Lieb et al. 1984). Wildland fires in the Nelchina Basin are infrequent due to a cooler and wetter climate that results in fewer lightning-caused ignitions and poor burning conditions. Most of the herd currently winters northeast of the Alaska Range in the Ladue and Dennison River drainages, as well as the Northway flats. The Ladue and Dennison drainages can be characterized as rolling hills with typical boreal forest vegetation. Alpine communities are present, but they are not common. The Northway flats also contain boreal forest, but muskegs are more common due to elevation and topography. Large fires occur frequently in these wintering grounds, as they do throughout boreal forests of interior Alaska and Yukon.

The continental climate of the Nelchina Basin provides between 59 and 116 frost-free days, with snowfall accumulation from 84 to 417 cm (Bergerud and Ballard 1988). Snow depths vary greatly from year to year and place to place depending altitude, aspect, and other topographic characteristics, but generally reach depths of 25 cm by mid-November, 50 cm by December, and 75 cm irregularly (Skoog 1968). Temperatures can vary throughout the year from –50 to 32^{O} Celsius.

METHODS

FIRE AND ABUNDANCE OF FORAGE LICHENS

Lichen abundance – stand age data will be collected at 120 caribou locations and 120 random locations throughout the winter range. Forage lichen biomass and productivity will then be modeled as functions of coverage, depth and age of stand.

Age of each stand will be determined from sections of spruce trees (Madany et al. 1982, McBride 1983, DeVolder 1999) and Alaska Fire Service (AFS) maps and databases. Lichen cover will be estimated at 2m line intercepts along 60m transects, with coverage being classified as either open to the sky or covered by taller vegetation.

Depth of forage lichen mats will be determined in all ground-truthed sites by collecting and later measuring 5cm diameter plugs of forage lichens taken closest to the midpoint of each line intercept. Length and age of living and dead thalli from the *Cladina* spp. lichens will be measured and related to the ages of stands as determined from BLM fire histories or from ages of spruce within the stands.

Development of digital imagery techniques

We will evaluate aerial imagery to determine which image format (photography or videography), image size (altitude), spectral ranges and airspeeds best allow estimation of forage lichen coverage. This work will be done in conjunction with determining lichen abundance – stand age relationships in road accessible stands. To evaluate the technique, we will compare estimates of lichen cover from aerial images to lichen cover estimates obtained from ground sampling. A square block of 9 adjacent 10x10m quadrats will be established in each of 5-7 stands representing a broad range of lichen abundance. The nine adjacent 10x10m quadrats will provide a nested series of 10x10, 20x20, and 30x30m plots for efficient evaluation of aerial images at different scales.

The corners of the center quadrat of each cluster will be marked with surveyor's section flagging so as to be distinguished from the air. Lichen cover and biomass will be estimated as described above. The center 10x10m quadrat, 20x20m and 30x30m nested clusters will then be recorded by videography from a helicopter hovering at altitudes from 30 – 200 feet. The nested clusters will also be photographed with a 9x9mm high-speed camera and high-speed color film, as well as videography, from 500, 1200, and 2000 feet from a fixed-wing aircraft. Altitudes above ground level will be determined by radar altimeter. Images will be geo-referenced by ADF&G software (Photoman) or GPS and video clock times. Film negatives will be scanned at 1000dpi and saved to CD ROM. Lichen coverage will then be determined by conventional photo interpretation or by digital classification.

Total coverage and variability of estimates from imagery will be compared with those of ground samples to determine the highest altitude and means by which a minimum coverage of about 10-15% can be detected. Once the aerial imagery technique is selected, it will be ground-truthed across the study area. Aerial images will be taken near each of the 120 random and caribou location ground transects (see above). Estimates of lichen cover from imagery will then be compared to cover and biomass estimates collected during ground sampling. If necessary, other variables, such as shrub or tree cover or topography, may be used to improve lichen estimates from aerial imagery via appropriate regression techniques.

Factors influencing lichen recovery and regeneration.

Possible effects of organic substrates and nature of disturbance on early lichen recovery will be examined experimentally by "seeding" lichen fragments into burned and unburned sphagnum moss; burned and unburned duff or mor; and spruce-shaded and unshaded duff or mor. All plots will be selected for uniformity in vegetation type, microtopography, and exposure. Burned plots will be prepared under uniform conditions and exposure to a weed burner. A portion of unburned plots will be cleared of existing lichens to make room for placement of fragments. Existing mats of *Cladina* spp. will be left undisturbed in a portion of each plot to provide a reference to growth rates of established lichen. Two types of fragments of *C. rangiferina*, and *C. arbuscula/mitis* will be prepared by cutting 1cm lengths of photosynthetically active tips and 1cm lengths of 5- to 10-year-old thallus. Fragments will then be spaced at 5 cm intervals in 1 m lines and protected by cages constructed of concrete reinforcement mesh. Fragments will be measured with calipers about the end of June annually. Vegetation cover in the protected plots and in adjacent unprotected, paired plots will be determined from digital imagery or by point grid sampling when lichens are measured for growth.

GIS development

Numerous GIS themes will be developed and/or implemented in this research project. The GIS platform is especially appropriate for evaluating habitat characteristics across the large and diverse areas used by Nelchina caribou.

Fire history mapping: Substantial fire history information is already available from AFS as digital map products and databases. We will fine tune the existing GIS coverage by searching AFS files for additional fires and adding them to digital coverages. An effort to map all fires greater than 4.05 km^2 (1000 acres) will be made. However, information about numerous fires has been lost over the years and fires under 4.05 km^2 (1,000 acres) in size were often not recorded. Almost no information is available for fires dating before 1950. Potential for cooperative agreements with other agencies, such as NASA (Kasischke et al. 1993, Kasischke and French 1995), to develop fire history maps using remote sensing techniques are being pursued.

Landcover databases: Numerous existing databases developed by USGS, FWS, NPS, and NASA cover portions of the NCH range. Vegetation maps based on AVHRR (1 km resolution), Landsat TM (30m resolution), and/or Landsat MSS (50m resolution) data may be used to analyze habitat use in relation to availability.

Topographic databases: Twelve USGS 1 degree Digital Elevation Models (DEMs) will be projected into a seamless, 30m grid using cubic convolution sampling in Arc/Info. This DEM will then be used to derive other products, such as a slope and aspect grids and a shaded relief using both Arc/Info and ArcView.

Lichen distribution: The possibility of developing a model to map lichen distribution across the range of the NCH will be investigated. This model would likely incorporate most, if not all, of the aforementioned GIS coverages. Vegetative analyses conducted during this project will provide information about the importance of fire history, habitat type, elevation, slope, and aspect to lichen abundance. The categories (i.e., a particular stand age) of each of the individual coverages would be ranked in terms of lichen abundance. The ranked coverages would then be overlaid to develop a separate coverage modeling where high lichen abundance is predicted.

LICHEN ABUNDANCE AND CARIBOU HABITAT SELECTION

We plan to utilize GPS telemetry and conventional telemetry to gather information on seasonal distribution and movements of caribou. That data, in concert with GIS coverages described above and additional sampling of forage lichen abundance utilizing fine-scale aerial imagery, will allow us to evaluate habitat selection by caribou on a variety of spatial scales.

Caribou capture, handling and telemetry

Capture and Handling. Caribou will be captured via standard helicopter chemical immobilization techniques (Adams et al. 1995, 1997). Caribou will be weighed via electronic load cell and skeletal measurements will be taken. Rump fat depths of adult females will be determined by ultrasonography (Stephenson et al. 1998) to assess nutritional condition. Blood samples will be taken for disease screening, analysis of stable isotopes (Tiezen 1991) and pregnancy determination. Each individual will be fitted with a conventional or GPS radiocollar.

GPS telemetry. GPS telemetry will be employed for estimating habitat selection at temporal scales that are not possible with conventional telemetry and evaluating the influences of relocation frequency on our estimates of caribou distribution and habitat selection. Beginning in October 1999, we will maintain a sample of 20-25 female caribou fitted with GPS radiocollars that also have conventional mortality-sensing telemetry beacons. Onboard GPS receivers will collect locations every 7 hours and store those locations to memory included in the collar. In April and October, GPS-instrumented caribou will be recaptured to download stored location data and to replace batteries.

Conventional telemetry. In addition to the GPS instrumented individuals, we will maintain a sample of about 100 caribou with conventional radiocollars. Therefore, our sample of caribou instrumented for conventional telemetry should equal about 120 animals in each winter of the study. In addition, approximately 80 instrumented caribou from the Mentasta herd, which shares winter range with the Nelchina herd, will be used to augment sample sizes where necessary. All instrumented caribou will be located at least monthly by aerial radiotelemetry. Observers will record location, as determined by aircraft-born GPS units, and group size for all observations of instrumented caribou. Mortalities will be noted during radiotracking flights and mortalities will be investigated via helicopter as soon as practical.

Habitat selection

Selectivity will be evaluated on three scales. The broadest scale will be range-wide and will address the role of lichen abundance in the shift to the current winter range from winter ranges used in the early 1980s in the Nelchina Basin. The intermediate scale will address the influence of fire on winter range by evaluating selection for particular aged stands within the current winter range. The finest scale will examine how lichen abundance influences movement patterns of caribou within winter range.

*Habitat Selection and lichen abundance on range-wide scale***.** Habitat use will be determined by late winter (Feb – Mar) conventional telemetry locations collected during this study and from 1980-85 (Pitcher 1982). Availability of habitat types at a scale of 1 km^2 will be determined from the AVHRR vegetation classification map of Alaska.

Lichen abundance will be compared among the most preferred and most utilized vegetation types for the 1980s data and the current study. Lichen abundance will be estimated from aerial images or on-site quadrats within late winter caribou concentration areas as defined by the 50% probability contour of kernel home range estimates for each sampling period. Arc-sine transformed estimates of lichen cover estimates among current and early 1980s winter ranges will be evaluated by ANOVA.

Selectivity for post-fire age of stand. Although a complete understanding of fire history over the 68,000 km^2 range of the NCH is unattainable, we have substantial information on fire history, particularly in the winter ranges currently being used north of the Alaska Range. We believe the resulting GIS coverage of fire history, although incomplete, will be adequate for evaluating selectivity relative to stand-age.

Both GPS and conventional telemetry data, in separate analyses, will be used to estimate use among known-age stands. To estimate the availability of various post-fire age classes, we will delineate the extent of winter range north of the Alaska Range as the area enclosed by the 99% utilization distribution of all locations during November-March. Selectivity relative to post-fire stand age will be estimated annually and evaluated relative to factors that may induce variability among years (e.g. snow conditions or other weather characteristics). If appropriate, analyses will be pooled over all years. Selectivity analyses will follow Manly et al. (1993). Lichen abundance-stand age relationships will be estimated via aerial imagery to compare selectivity related to stand age with patterns of lichen abundance. Ultimately, a logistic regression model will be constructed to evaluate influences of lichen abundance, stand age, land cover, landform, and environmental parameters on selectivity.

Movement patterns and lichen abundance. To evaluate selection for lichen abundance at a finer scale, we will explore relationships between observed caribou movement patterns and lichen abundance. Preliminary data from GPS collars deployed on caribou in the Fortymile Herd (K. Joly, unpubl. data) indicate that winter caribou movements can be categorized based on the direction and distances traveled between sequential locations. Hourly relocations revealed directional travel (migration-like movements that lasted several days to several weeks), short-term localization (non-directional movements within a small area lasting 1 day to 1 week), and long-term localization (non-directional movement lasting a month or more). We hypothesize that lichen is more abundant in areas where caribou localize.

Utilizing data from the movements of GPS-instrumented caribou during winter, we will categorize locations by movement pattern as reflected in relative densities of sequential point locations. Locations of individual animals will be mapped and fixed-width kernel density estimates will be calculated at each location (Silverman 1986). The width of the smoothing factor will be adjusted so that a frequency plot of the density estimates reveals about 3 modes which will describe the mid points of the movement categories. If the frequency plots indicate a lack of modality locations will be stratified into categories defined by standard deviations from the mean density. Missing point locations will be estimated by interpolation from the next successful attempt. Although this will introduce error into the analysis, bias in habitat or topographic related failure of GPS satellite acquisition would be reduced.

Following categorization, we will randomly select 50 locations from each movement category. Lichen abundance will be determined at each of these locations via aerial imagery. We will use ANOVA to evaluate whether arc-sine transformed lichen cover estimates vary among movement categories.

In addition, we will use these data to test the hypothesis that lichen cover at a caribou location influences the distance and change in bearing traveled to the caribou's subsequent location. For this analysis, we will employ multiple regression techniques thereby facilitating the incorporation of other variables, such as temperature, snow pack depth, and time-of-day, into the model. Indicator variables will be transformed as appropriate for least-squares regression and evaluated via stepwise selection (Neter et al. 1985). The response variable will be a vector consisting of the distance traveled divided by the relative change in heading (0-180 degrees) from the previous movement.

NUTRITIONAL PERFORMANCE OF CARIBOU CALVES

As part of our conventional telemetry sample, we will annually capture and radiocollar approximately 40 5-month-old female calves using standard methods described above. These animals will be weighed, measured, and blood-sampled. They will be recaptured in mid-April at 11-months-old and processed similarly. Weight change of these calves, expressed as weight gain/loss or percent change over winter and arc-sine transformed for parametric statistical analyses, will be the basis of our evaluations of habitat effects on nutritional performance. Weight change data will first be evaluated to detect variation among cohorts (ANOVA) or relationships between fall body weight (i.e. summer weight gain) and subsequent winter weight change (least-squares regression).

At the broadest scale, we will compare nutritional performance of caribou calves that winter in the Nelchina Basin, on lichen-depleted ranges, with those that winter north of the Alaska Range where forage lichens are expected to be more abundant (ANOVA). At the next level, caribou calves will be grouped based on their within-season spatial distribution through hierarchical cluster analysis with average linking (Coulson et al. 1997). Variation in weight change among clusters will be evaluated by ANOVA with arc-sine transformation of the dependent variable (Neter et al. 1985). In these analyses, scale can be adjusted by varying the number of clusters. If regional variation in nutritional performance is detected, then that variation will be evaluated relative to lichen abundance based on models developed from satellite imagery and/or fine-scale aerial imagery collected for selectivity analyses. At the finest scale, we hope to be able to categorize the importance of lichen in the winter diets of individual calves, based on stable isotope analyses of blood samples, and compare that to their weight change.

Regardless of scale, analyses to further explore variation in caribou nutritional performance will include other factors that may affect weight change. These variables include summer nutritional performance, relative caribou density, and environmental variables and will be incorporated into the cluster analysis through ANCOVA or evaluated separately through least-squares regression. Fall body weight will serve as a measure of nutritional performance during the preceding summer. An index of relative density will be developed for each individual by averaging the fixed kernel density estimates of each caribou among all monthly winter locations. Environmental variables will be derived from weather data collected by NOAA and FAA weather stations in Tok, Northway, Paxson, Glennallen, Eureka, Palmer, Talkeetna, and Cantwell and remote fire weather stations throughout the area.

EVALUATION OF FIRE MANAGEMENT REGIMES ON CARIBOU POPULATIONS

Appropriate models will be developed to evaluate the influence of fire management regimes on lichen abundance, suitability of boreal forest as caribou winter range, caribou movements and distribution, nutrition and survival trade-offs, seasonal range trade-offs, and caribou population dynamics. These models will incorporate data from this and other research where appropriate. The specific types of models constructed will necessarily reflect the nature and significance of relationships identified in this research effort (Starfield and Bleloch 1991).

A spatially explicit time-series model of the influence of various fire management regimes on lichen abundance will be particularly useful for managers. Fire recurrence will be varied over seasonal ranges of the NCH to simulate the effects of various fire suppression regimes. Fires will vary stochastically in size and shape within the parameters of previous fires within that locale thereby creating a complete mosaic of stand-age polygons. Lichen abundance within stands will reflect the age of the stand and the area of boreal forest within the stand as determined from AVHRR or other vegetation classification maps. Lichen removal from grazing will be simulated using rates estimated by Arseneault (et al. 1997) adjusted for herd size and distributed among stands following stand-age selection models developed from this study. Range-wide abundance of forage lichens in boreal forests within the range of the herd will be calculated for varying fire recurrence intervals. Caribou nutritional status and population dynamics may be incorporated into the model where appropriate.

This model will provide managers a tool to evaluate the abundance of caribou forage lichens expected under various fire recurrence regimes. In addition, because of the spatially explicit structure, it allows evaluation of variation in fire recurrence among specific portions of the NCH range. Because it is a time-series model, it allows evaluation of shorter-term temporal effects of changes in fire recurrence.

ROLES AND RESPONSIBILITIES OF INVESTIGATORS

Tom McCabe and Lisa Saperstein, formerly with the USGS, Alaska Biological Science Center, developed the original proposal for this study. Significant portions of their effort have carried forward to this study plan.

USGS-ALASKA BIOLOGICAL SCIENCE CENTER

Layne Adams will serve as project director and will be responsible for the overall coordination and conduct of this research program. He will participate in fieldwork, data analysis, and report writing as needed. He will be responsible for reviewing reports and other products produced as part of this research and ensuring their timely submission to funding agencies.

Kyle Joly will be responsible for acquiring or developing necessary GIS coverages, analyzing remotely sensed data, and managing and analyzing GPS-telemetry and conventional radiotelemetry data. He will assist with all project fieldwork. He will be responsible for developing an annotated bibliography and serve as senior author on manuscripts on habitat selection and factors influencing movements and distribution of caribou.

ALASKA DEPARTMENT OF FISH AND GAME

Bill Collins will be responsible for vegetation analysis aspects of this research program and for developing manuscripts on these topics. He will be responsible for conducting related fieldwork, and will assist with other project fieldwork.

Bruce Dale will serve as principal investigator responsible for integrating all components of the research program. He will have primary responsibility for caribou capture and radiotelemetry related fieldwork and assist with other fieldwork. He will be responsible for developing progress reports and the final report with appropriate assistance from other project personnel. He will have senior authorship responsibility on all aspects of the project not previously specified.

REPORTS

Annual progress reports will be provided to all cooperating agencies by 1 March 2001-2003. Progress reports will include a summary of research activities and significant accomplishments during the previous year, and a description of research activities planned for the upcoming year.

A final report will be provided to all cooperating agencies by 30 September 2004. The final report will include an overview of research activities, synthesis and interpretation of research results, a discussion of management implications of the completed work, and an annotated bibliography.

Manuscripts for publication will be developed as a result of this research. Project collaborators will share authorship.

LITERATURE CITED

Adams, L.G. and B.W. Dale. 1998. Reproductive performance of female Alaskan caribou. J. Wildl. Manage. 62(4):1184-1195.

Adams, L.G. and B.A. Connery. 1983. Buckland River reindeer/caribou conflict study final report. BLM-AK Open File Report 8. 169 pp.

Adams, L.G., P. Valkenburg, and J.L. Davis. 1987. Efficacy of carfentanil citrate and naloxone for field immobilization of Alaskan caribou. Proceedings of the North American Caribou Workshop 3:167-168.

Adams, L.G., B.W. Dale and L.D. Mech. 1995. Wolf predation on caribou calves in Denali National Park, Alaska. Pages 245-260 in L.N. Carbyn, S.H. Fritts, and D.R. Seip, eds. Ecology and conservation of wolves in a changing world. Canadian Circumpolar Institute Occasional Publication 35.

Ahti, T. and R.L. Hepburn. 1967. Preliminary studies on woodland caribou range, especially on lichen stands, in Ontario. Ontario Dept. of Lands and Forests, Res. Rept. No. 74. 134 pp.

Andreev, V.N. 1954. Growth of forage lichens and methods of regulating it. Trudy Botanicheskogo Instituta im. V.L. Komarova Akademiia Nauk SSSR, Series III, Geobotanika 9:11-74.

Auclair, A.N.D. 1983. The role of fire in lichen-dominated tundra and forest-tundra. Pages 235-256 *in* R.W. Wein and D.A. MacLean, eds. The role of fire in northern circumpolar ecosystems. John Wiley and Sons, Ltd., Chichester.

Arseneault, D.N., Villeneuve, C. Boismenu, Y. Leblanc and J. Deshaye. 1997. Estimating lichen biomass and caribou grazing on the wintering grounds of northern Quebec: an application of fire history and Landsat data. J. Applied Ecology 34(1):65-78.

Bergeron, Y. and P.R. Dansereau. 1993. Predicting the composition of Canadian southern boreal forest in different fire cycles. J. Veg. Science. 4:827-832.

Bergerud, A.T. 1972. Food habits of Newfoundland caribou. J. Wildl. Manage. 36:913-923.

Bergerud, A.T. 1974. The role of environment in the aggregation, movement and disturbance behavior of caribou. In: Geist, V. and F Walther (eds.) The behavior of ungulates and its relation to management. IUCN Bull. 24:522-584.

Bergerud, A.T. 1978. Caribou. In: Schmidt, J.L. and D.L. Gilbert (eds.) Big game of North America, ecology and management. Stackpole/Harrisburg, PA. pp83-101.

Bergerud, A.T. 1980. A review of the population dynamics of caribou and wild reindeer in North America. Proc. Int. Reindeer/Caribou Symp. 2:556-581.

Bergerud, A.T. and W.B. Ballard. 1988. Wolf predation on caribou: The Nelchina Herd case history, a different interpretation. J. Wildl. Manage. 52:344-357.

Boertje, R.D. 1984. A study of caribou range use and potential in and near Denali National Park and Preserve. Synthesis rept. to the Natl. Park Serv., Contract No. CX-9000-7-E080. 118 pp.

Boertje, R.D. and C.L. Gardner. 1998. Factors limiting the Fortymile caribou herd. Fed. Aid Final Rep. Study 3.38. Alaska Dep. Fish Game, Fairbanks. 37 pp.

Bos, G.N. 1975. A partial analysis of the current population status of the Nelchina caribou herd. Proc. Int. Reindeer and Caribou Symp. 1:120-180

Bowers, M.A. 1997. Mammalian landscape ecology. Ecology 78(4):997-998.

Coulson, T., S. Albon, F. Guiness, J. Pemberton and T. Clutton-Brock. 1997. Population substructure, local density, and calf winter survival in red deer. Ecology 78(3):852-863.

Couturier, S., J. Brunelle and G. Lapointe. 1988. Decline of the physical condition and decrease of recruitment in the George River Caribou Herd. Proc. 3rd N. Amer. Caribou Workshop. Alaska Dept. Fish Game, Tech. Bull. 8:35-37.

Dale, B.W., L.G. Adams and R.T. Bowyer. 1994. Functional response of wolves preying on barren-ground caribou in a multiple-prey ecosystem. J. Anim. Ecol. 63:644-652.

Degrandpre, L., D. Gagnon, and Y. Bergeron. 1993. Changes in understory of Canadian southern boreal forest after fire. J. Veg. Science. 4:803-810.

Doerr, J. 1979. Population analysis and modeling of the Western Alaska caribou herd with comparisons to other Alaskan *Rangifer* populations. M.S. Thesis, Univ. Alaska Fairbanks. 340pp.

Hale, M.E. 1973. Growth. Pages 473-492 in V. Ahmadjian and M.E. Hale, eds., The Lichens. Academic Press, N.Y. 697 pp.

Harris, R.B., S.G. Fancy, D.C. Douglas, G.W. Garner, S.C. Amstrup, T.R. McCabe, and L.F. Pank. 1990. Tracking wildlife by satellite: Current systems and performance. U. S. Fish & Wild. Serv. Tech. Rep. 30. 53 pp.

Jakimchuk, R.D. and K.H. McCourt. 1975. Distributions and movements of the Porcupine caribou herd in the northern Yukon, pp.140-154 *in* Luick, J.R., P.C. Lent, D.R. Klein, and R.G. White. Proc. 1st Intern. Reindeer/Caribou Symp. Fairbanks, Alaska. 551pp.

Kasischke, E.S., N.H.F. French, P. Harrell, N.L Christensen, Jr., S.L. Ustin, and D.L. Barry. 1993. Monitoring of wildfires in boreal forests using large area AVHRR NDVI composite image data. Remote Sens. Environ. 45:61-71.

Kasischke, E.S., and N.H.F. French. 1995. Locating and estimating areal extent of wildfires in Alaskan boreal forests using multiple-season AVHRR NDVI composite data. Remote Sens. Environ. 51:263-275.

Kelsall, J.P. 1960. Cooperative studies of barren-ground caribou 1957-58. Can. Wildl. Manage. Bull. Ser. 1, No. 15.

Kershaw, K.A. 1977. Studies on lichen-dominated systems. XX. An examination of some aspects of the northern boreal lichen woodlands in Canada. Can. J. Bot. 55:393-410.

Kershaw, K.A. and W.R. Rouse. 1976. The impact of fire on forest and tundra ecosystems. Final Rept. No. QS-8117-000-EE-A1. Dept of Ind. Affairs and North Develop. Ottawa, Ontario, Canada. 54pp.

Klein, D.R. 1980. Range ecology and management- progress made and directions for the future. Pages 4-9 in E. Reimers, E. Gaare, and S. Skjenneberg, eds. Proc. of the 2nd Intern. Reindeer/Caribou Symp., Røros, Norway, 17-21 Sept. 1979. Trondheim, Norway.

Klein, D.R. 1982. Fire, lichens, and caribou. J. Range Manage. 35:390-395.

Lieb, J.W., R.W. Tobey, and S.H. Eide. 1984. Analysis of Nelchina caribou range. Big game investigations. AK Dept. Fish & Game, Fed. Aid Wildl. Rest. Final Rept. Proj. W-17-3. 143pp.

Lutz, H.J. 1956. Ecological effects of forest fires in the interior of Alaska. USDA Tech. Bull. 1133. 121 pp.

Maikawa, E. and K.A. Kershaw. 1976. Studies on lichen-dominated systems. XIX. The postfire recovery sequence of black spruce-lichen woodland in the Abitau Lake Region, N.W.T. Can. J. Bot. 54:2679-2687.

Miller, D.R. 1976a. Biology of the Kaminuriak population of barren-ground caribou. Part 3: Taiga winter range relationships and diet. Can. Wildl. Serv. Rep. Ser. 36. 41pp.

Miller, D.R. 1976b.Wildfire and caribou on the taiga ecosystem of northcentral Canada. PhD thesis. Univ of Idaho. Moscow, Idaho. 131pp.

Miller, D.R. 1980. Wildfire effects on barren-ground caribou wintering on the taiga of north-central Canada. pp. 84-89 *in* Reimers, E.,E. Gaare, and S. Skjemneberg (eds.) Proc. 2nd Int. Reindeer/Caribou Symp. Roros, Norway, 1979.

Miller, F.J., F.W. Anderka, C. Vithayasai, and R.L. McClure. 1975. Distribution, movements, and socialization of barren-ground caribou radio-tracked on their calving and post-calving areas, pp.423-435 *in* Luick, J.R., P.C. Lent, D.R. Klein, and R.G. White. Proc. 1st Intern. Reindeer/Caribou Symp. Fairbanks, Alaska. 551pp.

McCarthy, T.M. 1992. Nutritional status of the southern Alaska Peninsula, Nelchina and other southcentral Alaska caribou herds. Fed. Aid in Wildl. Rest. Progress Rept. Project W-23-5 Study 3.36. AK Dept. Fish and Game, Fairbanks. 11pp

Neter, J., W. Wasserman and M.H. Kutner. 1985. Applied linear statistical models. Irwin, Homewood, Illinois. 1127pp.

Ouellet, J.-P., D.C. Heard, and S. Boutin. 1993. Range impacts following the introduction of caribou on Southampton Island, Northwest Territories, Canada. Arct. And Alp. Res. 25:136-141.

Pank, L.F., W.L. Regelin, D. Beatty, and J.A. Curtolo. 1985. Performance of a prototype satellite tracking system for caribou. pp 97-118 in R. W. Weeks and F. M. Long (eds.) Proc. 5th Intern. Conf. Wildl. Biotelemetry. Laramie, Wyoming.

Pitcher, K.W. 1982. Susitna hydroelectric project, phase I final report. Big game studies. Vol. 4. Caribou. AK Dept. Fish & Game, Spec. Rep. to AK Power Authority, Anchorage. 101pp.

Pruitt, W.O. 1959. Snow as a factor in the winter ecology of barren-ground caribou. Arctic 12:159-179.

Rowe, J.S., J.L. Bergsteinsson, G.A. Padbury, and R. Hermesh. 1974. Fire studies in the Mackenzie Valley. Indian and Northern Affairs Publication No. QS-1567-000-EE-A1.

Rowe, J.S., D. Spittlehouse, E. Johnson, and M. Jasieniuk. 1975. Fire studies in the Upper Mackenzie Valley and adjacent Precambrian uplands. Indian and Northern Affairs Publication No. QS-8045-000-EE-A1. 123 pp.

Russell, D.C. and A.M. Martell. 1984. Winter range ecology of caribou *(Rangifer tarandus*). In: R.Olsen, F. Gedde and R. Hastings (eds.). Northern ecology and resource management. Univ of Alberta Press. pp117-144.

Saperstein, L.B. 1993. Winter forage selection by barren-ground caribou: effects of fire and snow. M. Sc. Thesis. Univ. Alaska-Fairbanks. 79pp.

Schaefer, J.A. and W.O. Pruitt, Jr. 1991. Fire and woodland caribou in southeastern Manitoba. Wildl. Monogr. 116. 39pp.

Schaefer, J.A. and F. Messier.1991. The implications of environmental variability on caribou demography: theoretical considerations. Rangifer, Special Issue No. 7:53-59.

Schaefer, J.A. 1996. Canopy, snow and lichens on woodland caribou range in southeastern Manitoba. Rangifer, Special Issue No. 9, 239-244.

Scotter, G.W. 1965. Study of the winter range of barren-ground caribou with special reference to the effects of forest fires. Can. Wildl. Serv. Prog. Rep. No. 3. 18pp.

Scotter, G.W. 1970. Wildfires in relation to the habitat of barren-ground caribou in the taiga of northern Canada. Ann. Proc. Tall Timbers Fire Ecol. Conf. 10:85-106.

Silverman, B.W. 1986. Density estimation for statistics and data analyses. Chapman and Hall, London. 175pp.

Siniff, D.B., and R.O. Skoog. 1964. Aerial censusing of caribou using stratified random sampling. J. Wildl. Manage. 28:391-401.

Skoog, R.O. 1968. Ecology of caribou in Alaska. Ph. D. Diss., Univ. California-Berkley.

Stardom, R.R.P. 1975. Woodland caribou in southeast Manitoba. pp.324-341 *in* Luick, J.R., P.C. Lent, D.R. Klein, and R.G. White. Proc. 1st Intern. Reindeer/Caribou Symp. Fairbanks, Alaska. 551pp.

Stephenson, T.R., K.J. Hundertmark, C.C. Schwartz, and V. Van Ballenberghe. 1998. Predicting body fat and body mass in moose with ultrasonography. Can. J. Zool. 86:717-722.

Starfield, A.M. and A.L. Bleloch. 1991. Building models for conservation and wildlife management. 2nd edition. Macmillon/Burgess, MN. 253pp.

Tengwall, T.Å. 1928. Renlavarnal tillväxt och biologi i Torne och Lule Lappmarker. Sv. Bot. Tidskr. 22:18-32.

Tieszen, L.L. 1991. Natural variations in the carbon isotope values of plants: Implications for archaeology, ecology, and paleoecology. J. Archaeol. Sci. 18:227-248.

Tieszen, L.L., L. Stretch and J. Vander Kooi. 1998. Stable isotopic determination of seasonal dietary patterns in Bison at four preserves across the great plains. In: Int. Symp. on Bison Ecol. and Manage in North Amer. Eds L. Irby and J. Knight, pp.130-140. Montana State Univ., Bozeman MT

Thomas, D.C. 1998. Fire-caribou relationships: (V) Winter diet of the Beverly herd in northern Canada, 1980-1987. Tech. Rep. Series No. 313. Can. Wildl. Serv., Prairie & Northern Reg., Edmonton, Alberta. 41 pp.

Thomas, D.C. 1991. Adaptations of barren-ground caribou to snow and burns. pp. 482-500. *in* Butler, C. E. and S. P. Mahoney (eds.) Proc. 4th Nor. Amer. Caribou Workshop, St. John's, Newfoundland.

Thomas, D.C. 1969. Population estimates of barren-ground caribou March to May. 1967. Can. Wildl. Serv. Rep. Ser. 9.

Thomas, D.C. and H.J. Armbruster. 1998. Fire-caribou relationships: (VI) Fire history of winter range of the Beverly herd. Tech. Rep. Series No. 314. Can. Wildl. Serv., Prairie & Northern Reg., Edmonton, Alberta. 94 pp.

Thomas, D.C. and H.P.L. Kiliaan. 1998. Fire-caribou relationships: (IV) Recovery of habitat after fire on winter range of the Beverly herd. Tech. Rep. Series No. 312. Can. Wildl. Serv., Prairie & Northern Reg., Edmonton, Alberta. 115 pp.

Thomas, D.C., S.J. Barry, and G. Alaie. 1996. Fire-caribou relationships in northern Canada. Rangifer 16:57-67.

Thomas, D.C. and S.J. Barry. 1991. Microhistological analyses of caribou diet: fecal versus rumen samples and other variables. pp. 516-529

Thomas, D.C., H.P.L. Kiliaan, and T.W.P. Trottier. 1998. Fire-caribou relationships: (III) Movement patterns of the Beverly herd in relation to burns and snow. Tech. Rep. Series No. 311. Can. Wildl. Serv., Prairie & Northern Reg., Edmonton, Alberta. 176 pp.

Thomas, D.L. and E.J. Taylor. 1990. Study designs and tests for comparing resource use and availability. J. Wildl. Manage. 54:322-330.

Valkenburg, P., J.L. Davis, and R.D. Boertje. 1983. Social organization and seasonal range fidelity of Alaska's western arctic caribou: preliminary findings. Acta Zool. Fenn. 175:125-126.

Valkenburg, P., D.G. Kelleyhouse, J.L. Davis, and J.M. Ver Hoef. 1994. Case history of the Fortymile caribou herd, 1920-1990. Rangifer 14:11-22.

Van Ballenberg V. 1985. Wolf predation on caribou: the Nelchina herd case history. J. Wildl. Manage. 53:243-250.

Van Cleve, K. and L.A. Viereck. 1981. Forest succession in relation to nutrient cycling in the boreal forest of Alaska. Pages 185-211 *in* D.C. West, H.H. Shugart, and D.B.

Botkin (eds.) Forest Succession: Concepts and Application. New York, Springer-Verlag.

Van Cleve, K. and L.A. Viereck. 1983. A comparison of successional sequences following fire on permafrost-dominated and permafrost-free sites in interior Alaska, pp.1286-1291 *in* Permafrost: Proc.4th Intern Conf.. Washington, D. C. National Academy Press.

Viereck, L.A. and L.A. Schandelmeier. 1980. Effects of fire in Alaska and adjacent Canada - a literature review. BLM-AK Tech. Rept. 6. 124 pp.

SCHEDULE

Schedules are presented by the federal fiscal year commencing 1 October. State of Alaska fiscal years commence 1 July.

FY99 - Initiate field work

Deploy conventional collars
Monitor group size, movements, and distribution
Evaluate nutritional performance of caribou

FY00 – Development of Study Plan and Field Research

Finalize study plan
Develop GIS coverages
Deploy GPS and conventional collars
Monitor group size, movements, and distribution
Evaluate nutritional performance of caribou
Evaluate lichen abundance and distribution

FY01 - Field Research

Analyze field data collected
Deploy GPS and conventional collars
Monitor group size, movements, and distribution
Evaluate nutritional performance of caribou
Evaluate lichen abundance and distribution
Annual Progress Summary

FY02 - Field Research

Analyze field data collected
Deploy GPS and conventional collars
Monitor group size, movements, and distribution
Evaluate nutritional performance of caribou
Evaluate lichen abundance and distribution
Annual Progress Summary

FY03 - Field Research, Data Analysis, Manuscript Preparation

Analyze field data collected
Deploy GPS and conventional collars
Monitor group size, movements, and distribution
Evaluate nutritional performance of caribou
Annual Progress Summary

FY04 – Data Analysis, Field Research, Manuscript Preparation

Analyze field data collected
Evaluate nutritional performance of caribou
Prepare Final Report