WORK PLAN: FY2013-2015

PROJECT TITLE: Evaluating the "bottom up" effects of changing habitats: climate changes, vegetative phenology, and the nutrient dynamics of ungulate forages in the Alaskan Arctic

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JUSTIFICATION

Climate changes are affecting populations of northern ungulates through altering the abundance and phenology of vegetation in the Arctic (Martin et al. 2009). Increasing temperatures (>2°C) and shifts in hydrologic regimes have facilitated the conversion of tussock tundra to shrubs (Tape et al. 2006), increased the biomass of vegetation in the Arctic biome (Martin et al. 2009), and have advanced the onset and extended the duration of the growing season (Goetz et al. 2005). For northern ungulates, the high seasonal variation in plant abundance and quality accentuates the need to replenish body stores during a short growing season that is critical for reproduction and winter survival (Cameron et al. 1993, Barboza and Hume 2006). Indeed, the predominant effects of climate changes to populations of northern herbivores are likely to be nutritionally mediated through vegetative changes (Klein et al. 2005).

Changes in the onset and duration of the growing season and vegetation productivity are affecting the timing of nutrient (i.e., energy and nitrogen) availability for northern ungulates (Lenart et al. 2002, Cebrian et al. 2008). The nutritional demands for energy and protein are highest for reproductive females during early lactation (White et al. 1989, Barboza and Parker 2008). For caribou (*Rangifer tarandus*), parturition generally occurs during the period of plant emergence or "green up", which allows females to offset the peak nutrient demands of lactation through the availability of highly digestible forages (White 1983, Barboza and Parker 2008). Emerging plants are an excellent source of digestible protein due to the limited structural and chemical defenses in growing tissues (Johnstone et al. 2002). As growth slows and plants mature, defensive tissues and compounds increase (Robbins et al. 1987a) with concomitant decreases in digestibility (Finstad 2008). Plant maturation coincides with peak forage production and increasing forage intake by large herbivores (White 1983). In Greenland, observations suggest that the onset of the growing season is occurring earlier while the timing of migration and parturition in caribou remains static. Thus, possibly creating a "mismatch" between peak nutrient availability and peak nutritional demands of lactating females and potentially affecting productivity of this population (Post and Forchhammer 2008). However, peak nutrient intake is

a product of forage availability, intake, and nutrient concentration and digestibility, so peak nutrient availability may not occur during plant emergence, but, rather, during the period of peak forage biomass (Griffith et al. 2010). Therefore, increases in vegetative productivity and extended growing seasons associated with warming (Martin et al. 2009), coupled with the ability of herbivores to forage selectively (White 1983) may result in substantial nutritional benefits for northern ungulates (Griffith et al. 2010). Although if vegetation biomass shifts from graminoid to shrub-dominated tundra (Martin et al. 2009), increases in shrub biomass may decrease the availability of nutrients to herbivores due to the increased ratio of lignified to green tissues and chemical defenses, or anti-nutrients, common in shrubs (Robbins et al. 1987a, Robbins et al. 1987b).

To elucidate these potential "bottom up" effects of climate changes to Arctic ungulates and evaluate the trophic mismatch hypothesis, we will incorporate the calving and summer range of the Western Arctic caribou herd (WAH) into an ongoing inter-agency research and monitoring effort to examine the influences of climate change on the nutrient dynamics of caribou forages (Fig. 1). The WAH is the largest herd in the state (~325,000) and ranges over northwestern Alaska (Joly et al. 2007). Over 40 communities in the region have been shaped by the availability of these caribou for harvest. Although the mechanism is uncertain, recent counts suggest that the WAH may be declining (Dau 2009). Many factors contribute to changes in caribou populations (Joly and Klein 2011), but changes in habitat quality and availability have the largest potential to influence the distribution and (or) abundance of this population.

OBJECTIVES

This work is leveraging existing projects on the North Slope of Alaska that are primarily funded through the U.S. Geological Survey's Changing Arctic Ecosystems Initiative (CAE). Current work on the spatio-temporal characteristics of summer habitats for the Teshekpuk and Central Arctic caribou herds commenced in May 2011 and will continue until September 2013; these efforts are fully funded through the USGS and ADF&G (Fig. 1). Research in northwest Alaska will 1) expand the scope and inference of these current habitat monitoring efforts; 2) facilitate spatio-temporal comparisons of habitat characteristics among ranges of caribou; and 3) improve the empirical framework for bio-climate models that will help to evaluate the potential nutritional implications of a warming Arctic to important subsistence resources, such as caribou and other ungulate populations, throughout the North Slope. In the summers (May-August) of 2013-2015 we will do the following:

1. ***Establish an environmental monitoring network in northwest Alaska.***
   We will establish and maintain a network of remote environmental monitoring stations in northwest Alaska. We will deploy one station per soil and vegetation monitoring plot (i.e., macroplot, see below) in 2013 with plans for expanding the network in 2014-15. Stations will monitor, log, and transmit the hourly wind speed, air temperature, photosynthetically active radiation, solar radiation, and normalized difference vegetation index (NDVI) via a satellite-uplinked, secure internet portal. Additionally, we will use time-lapse photography to monitor local conditions and snow, vegetative, and animal phenology. Data from these stations will help to establish the empirical relationships between forage characteristics and environmental variables necessary to examine the potential influences of climate changes to the quality of caribou habitats in northwest Alaska.

2. ***Examine nutrient abundance and availability for caribou forages across spatial and temporal gradients.***
   We will monitor a suite of soil, vegetation, and environmental characteristics (***Objective 1***) at 7 macroplots (Fig. 2). We will measure the thaw depth, temperature, pH, moisture, and nutrient concentration of soils. Vegetative phenology, biomass, and quality will be estimated at each macroplot. We will collect forages within each macroplot to estimate the spatial and temporal dynamics of nutrient concentration and availability. Subsamples of each forage species by macroplot, sampling period, and year will be assayed *in vitro* for digestibility at the University of Alaska Fairbanks, Fairbanks, AK. We will document forage biomass and quality over time and use forage characteristics to estimate the spatio-temporal availability of energy, N, and minerals for each macroplot, physioregion, sampling period, and year in relation to current and projected environmental conditions.
3. ***Acquire, analyze, and summarize the historic and predicted climatic data for northwestern Alaska.***
   We will obtain historic climate data from Point Lay (1973-current) and Red Dog Mine (1998-current). Projected climate data (current-2069) for 2 emissions scenarios (A2, B1) will be acquired from the Scenarios Network for Alaska and Arctic Planning. Historic and projected climate data will be summarized at the finest spatio-temporal resolution possible and used to describe several characteristics of the growing season. These historic and projected data will provide context for the period of data collection on forage and environmental characteristics as well as assist in estimating the influences of climate changes to the quality of calving and summer habitats for caribou in northwest Alaska.
4. ***Quantify the spatio-temporal availability of forage proteins of caribou throughout the growing season under the current and projected climatic regimes on the North Slope of Alaska***
   We will incorporate these data on soil and forage characteristics (***Objective 2*****)** within the calving and summer range of the WAH into an existing Bayesian network (BN) model framework that is describing the current (2000-2012) and projected (2060-69) influences of temperature and precipitation on the habitat characteristics that affect protein availability throughout the growing season in the primary forages of caribou within the Central and Teshekpuk caribou herds. Model outcomes are expected to estimate the changes in the availability of protein in respone to climate shifts, and thereby, examining the potential for a trophic mismatch in forage resources for caribou while informing managers of likely responses in the calving, summer, and fall habitats of caribou populations on the North Slope.

METHODS

Logistics

Field work will be based out of Red Dog Mine (Fig. 2). Air travel and shipping to the mine, lodging, and meals will be provided by Teck Resources Limited. Air travel to and from the mine for a crew of two will occur on the Wednesday and Saturday flights (Table 1) chartered by Teck Resources Limited (Alaska Airlines or Northern Air Cargo); shipping will occur as needed on chartered flights. Crew will be stationed at the lower housing unit at Red Dog (by air strip) and will abide by all rules and regulations required of them by Teck Resources Limited.

Flight protocols

Travel to field sites from Red Dog will be via R-44 helicopter chartered by the U.S. Geological Survey. Fuel for helicopter flights will be purchased from Red Dog Mine at their cost ($6-8 per gallon). To avoid potential disturbances to wildlife and people, flights to and from field sites will be on the most direct route at the highest elevation possible given the terrain and weather conditions and limitations of the aircraft. Upon observing wildlife or people, flight paths and landing zones will be altered as much as possible to minimize disturbance.

Environmental monitoring

We will establish an environmental monitoring station at each macroplot in early May (Table 1). Solar-powered data logging stations (DataGarrison Satellite Systems, Upward Innovations, Falmouth, MA) will be mounted on 2-m tripods secured to the ground with guy lines (M-TPB-KIT, Onset Computer Corporation, Bourne, MA) and protected with a solar-charged and battery powered 120-cm 4-strand bear fence that is directly grounded. Stations will monitor hourly air temperature (°C; S-TMB-M002, Onset), wind ($m \cdot s^{-2}$; S-WSET-A, Onset), and NDVI (S-LIB-M003 and S-LIA-M003, Onset) at each macroplot from 4 May to 25 September (Table 1, Fig. 4). To minimize heating from direct sunlight, the temperature sensor will be housed in a solar radiation shield (RS3, Onset). The NDVI will be corrected for variation in ambient light conditions and calculated from raw reflectance data to be compatabile with the Moderate Resolution Imaging Satellite (Reed 2006). Each station will uplink with the satellite network weekly to transmit environmental data to a secure online database. Alternatively, hourly soil temperature (°C) will be monitored with store-on-board data loggers (UA-002-64, Onset). Small holes will be augered in the frozen soil next to the station. We will tie flagging tape on loggers and deploy loggers at an approximate depth of 10 cm and cover with frozen soil. Loggers will be recovered in late September.

As an index of growing conditions for plants, all temperature data will be converted to thaw degree days (TDD). Thaw degree days (air at 1 m and soil at 10 cm) equals the degrees above 0°C for a Julian date with an average temperature > 0°C. Cumulative TDD are the sum of TDD up to a Julian date.

Time-lapse photography will be used to acquire a near continuous record of environmental conditions that will be used to document snow, vegetative, and animal phenology (Tape and Gustine, unpublished data). Plot Stalker cameras (Moultrie, Lafayette, LA) with 16 GB memory cards and powered by 4 lithium AA batteries will be mounted on the top of each station tripod. Directions and angles of cameras will be adjusted at each macroplot to maximize the area recorded by the camera. Digital photos will be taken at 15-minute intervals throughout the sampling period (Table 1). A snow gauge (1-m steel stake divided into 10 cm increments) will be driven into the snow and frozen soil within 50 m of the station; distance from camera will be recorded at deployment. Although this approach is still developing, some of the data we will acquire from these camera traps includes rate and date of snow disappearance, leaf flush, presence of wildlife, and migration phenology of caribou (Tape and Gustine, unpublished data).

Soil and vegetation

Soil and vegetation characteristics will be monitored at 7 macroplots in 3 physiographic regions from 8 June to 25 September along the Kokolik-Utukok drainages in northwestern Alaska (Fig.

2) in 2013-2015. Macroplots (100 x 500 m) will be located at the approximate latitudes of the other macroplots in the Teshekpuk and Central Arctic herd ranges and are identified as "N" through "T" (south to north; Fig. 1). A macroplot size of 0.05 km^2 is necessary to provide an area that is large enough to provide adequate spacing of sampling plots (approx. 10 m; Walker et al. 2003) and the repeated, destructive sampling of soils and vegetation within and among years. The approximate orientation of each macroplot was estimated from site visits in July 2012 and Landsat Enhanced Thematic Mapper (ETM) imagery (Fig. 3), but actual locations and orientations of macroplots will be determined in the field in June 2013. Macroplots will be positioned to minimize the effects of topography (Nellemann and Thomsen 1994); encompass the representative vegetation of the area (Williams and Rastetter 1999); and minimize the proportion of the macroplot that is covered by permanent water bodies. Macroplots will be divided into 5 100 x 100-m quadrats (Fig. 4). A grid of potential sampling points will be established at 10-m intervals within the macroplot in a geographic information system (GIS; ArcGIS 10, ESRI, Redlands, CA). For each sampling period, a random sample (without replacement) of 5 locations will be stratified among (Fig. 4). Plots (0.25×0.25 m^2) will be located with a global positioning system (GPS) unit (Juno SD, Trimble, Sunnyvale, CA). Universal Transverse Mercator coordinates (WGS 1984), general vegetation, temperature, relative humidity (Oakton Instruments, Vernon Hills, IL), and the presence, depth, and condition of snow and water will be noted or measured prior to assessing abiotic and biotic characteristics for each plot.

Soil characteristics

We will measure thaw depth for each sampling period. Plots will be delineated by collapsible frame made of polyvinyl chloride (PVC) tubing (0.25×0.25 m) and the lower-left corner of each plot will be placed on the plot coordinates (Fig. 4). Thaw depth (Auerbach et al. 1997) will be measured at the center of the plot with a steel probe (1-m long, 1.27 cm diameter; ER-AS481/2F, Blacksmith Company, Monroe, NY).

The nutrient content of soil will be estimated at one sampling period in late summer (22-27 July; Table 3). Soils from the upper 10 cm of the organic horizon from the 5 plots in each macroplot will be collected with a soil corer (7 cm in diameter, AMS Sampling, American Falls, ID; Kielland 1995), placed in a zip-top plastic bag, kept cool in the field, and then frozen until processing. Soils will be oven-dried (40°C), sieved (2 mm), sub-sampled (15 g), and assayed for pH, C (%), N (%), and S (%) as well as total Cu, Zn, Fe, Mo, NH_4-N, and NO_3-N in ppm (University of Alaska Anchorage, Agriculture Experiment Station, Palmer, AK).

Vegetation characteristics

Phenology, biomass, nutrient composition and availability (quality), and browsing intensity of vegetation will be measured at 5 plots within each macroplot for each sampling period. Phenology will be recorded for the 7 forage species of interest (i.e., *Eriophorum vaginatum, Carex aquatilis* and *bigewloii, Pedicularis langsdorfii, Salix pulchra, Salix richardsonii, and Betula nana*) within each plot. Phenological classification will be according to protocols established by Cebrian et al. (2008; Table 4). If the specie(s) of interest does not occur within a plot, the phenological stage of the nearest plant will be recorded. For deciduous shrubs, we will also measure height and note evidence of browsing and calculate browsing class (McArt et al. 2009).

Aboveground biomass of vascular vegetation (biomass) will be assessed for species of interest (see above) and functional groups (graminoids, forbs, and deciduous shrubs). Biomass of current annual growth ($g \cdot m^{-2}$) will be directly measured by removal of vascular plant tissues at the 5 0.25 × 0.25 m plots in a macroplot. For each sample period, live (green) tissues will be collected by species of interest and functional group into paper bags and labeled with an indelible marker. Herbaceous plants will be clipped (Felco Model 11, Kirkland, WA) or pulled at the surface of the ground, water, or moss; only the leaves of shrubs will be collected. Due to the small size and often staggering abundance of horsetail (*Equisetum* spp.), these species will be collected in one random quadrant (0.125 × 0.125 m) of the plot. Sample labels will consist of date, macroplot, plot, and species or functional group identifiers. Species of interest typically do not occur in sufficient quantities for nutritional analyses within each plot, therefore, forage quality samples will be collected adjacent to the macroplot (Fig. 4). Samples will be stored in paper bags in dry locations with constant air flow until processing. To assess total phenol concentration and protein-precipitating capacity, small sub-samples of shrubs (approx. 5 g) transferred to plastic-zip top bags and frozen until processing. Upon return from the field, samples will be dried in a forced-air oven at 40°C to constant mass (Servello et al. 2005). Dried samples will be weighed to the nearest 0.0001 g in each paper bag. Samples for functional groups will be transferred to vacuum-sealed bags for archiving. Samples for each species of interest will be transferred to plastic storage bags, while sub-samples of shrubs assayed for phenols and protein-precipitating capacity will be lyophilized.

Forage quality will be determined for each species of interest for a macroplot by quantifying nutrient content and availability. Sample preparation and nutrient analyses will occur the winter after collection. Samples will be ground through a 1-mm screen in a Wiley mill (Arthur Thompson Company, Philadelphia, PA). Analysis of nutrient composition (i.e., analytical dry matter, ash, proximate analyses, carbon and nitrogen content, gross energy, and macro- and trace mineral content) will be as in Peltier et al. (2003). For the shrubs, phenol concentration and protein-precipitating capacity will be determined as in McArt et al. (2006).

We will assess digestibility of N, energy, and minerals by an *in vitro* method using purified cellulase and pepsin (De Gabriel et al. 2008) that has been validated by *in sacco* digestion in the rumen of fistulated reindeer followed by treatment with acid-pepsin (Person et al. 1980, Ihl and Barboza 2007). Dry residues from the digestions will be used to estimate dry matter digestibility in the rumen. The dried residues from the acid digestion will be used to estimate digestibility in the whole digestive tract. The dried residues will be assayed for ash, fiber fractions, gross energy, N, and macro- and trace minerals.

Climate data

Historic, current, and projected climate data will be used to estimate the potential influences of climate changes to the quality of calving and summer habitats for caribou in northwest Alaska. Historical and current climate data for Point Lay (1973-current) and Red Dog Mine (1998-current) will be acquired from the National Climatic Data Center. All temperatures will be converted to Celsius, precipitation to millimeters, and dates and times to Alaska Standard Time. Hourly temperature and precipitation data will be summarized by day, week, and month (minimum, mean, and maximum). As above, these data will be converted to TDD and summarized as cumulative TDD by year. Other growing season metrics, such as days of thaw

and freeze and length of growing season will be derived from these temperature data. Days of thaw and freeze will be calculated using the regression of mean daily temperature (T_{Mean}) on day of the year. The day of thaw is the day of the year when the linear estimate of $T_{Mean} > 0°C$, while the day of freeze is when the linear estimate of $T_{Mean} < 0°C$. Length of the growing season is the day of freeze minus the day of thaw.

Projected climate data (current-2069) for the 5-model averaged global circulation model for 2 emissions scenarios (A2, B1) in northwest Alaska will be acquired from the Scenarios Network for Alaska and Arctic Planning (http://www.snap.uaf.edu/data.php). Projected climate data will be summarized for 2060-69 for monthly (temperature) and annual (temperature, days of freeze and thaw, and length of growing season) variables.

Projecting climatic influences

We will use spatially and temporally appropriate climate projections (see ***Climate data***) and an existing, peer reviewed Bayesian network (BN; USGS, Fig. 5) to project the effect of climatic changes to the availability of proteins in the common forages of caribou throughout growing season on the North Slope. The BN (Fig. 5) integrates an evolving empirical dataset of forage characteristics of caribou habitats (USGS, 2011-current), existing datasets (e.g., NRCS and Toolik Lake), and published literature on temperature, precipitation, forage characteristics in the region with expert knowledge to identify uncertainties pertaining to abiotic and biotic factors that influence protein availability to caribou throughout the growing season; and project future outcomes on the phenology and extent of protein availability in caribou habitats across the growing season for caribou. More detailed documentation on the creation and parameterization of these BNs is available upon request.

We will estimate the amount of available protein (kg/ha) for current and projected climatic conditions in 3 vegetation communities and 4 periods within the growing season. Vegetation communities are the low shrub tussock tundra, tussock sedge tundra, and wet sedge tundra (Raynolds et al. 2005). Low shrub tussock tundra (68.5-69.0° N at 400-900 m) is within the Brooks Range Ecoregion and is found on acidic soils that are dominated by *Salix* spp. and *Betula* nana. Common graminoids include *E. vaginatum* and *C. bigelowii* with mosses in the understory. The growing season commences earlier here than in other regions, often as much as 2-3 weeks earlier than the furthest north community (i.e., wet sedge tundra). The tussock sedge tundra (69.0-69.5° N at 100-500 m) is within the Arctic Foothills Ecoregion are moist acidic (pH < 5.5) tussock-tundra complexes that are dominated by graminoids. Dominant plants include *E. vaginatum-Sphagnum* and *C. bigelowii-Sphagnum*. The wet sedge tundra (69.5-70.4° N at 5-50 m) are wetland complexes interspersed with ice-wedge polygons and slightly acidic to neutral soils. Typically these areas are dominated by *C. aquatilis*, *E. angustifolium* and *triste*, mosses, and *S. pulchra* and prostrate shrubs on hummocks.

The growing season periods are Spring (1 May-14 Jun), Early Summer (15 Jun-14 Jul), Summer (15 Jul-14 Aug), and Fall (15 Aug-30 Sep). Spring encompasses the entire calving period for caribou as well as the onset of growing season in the 3 vegetation types. It is a period of rapid increases in forage biomass and N concentration within low shrub and tussock tundra communities. Early summer includes peak lactational demands for reproductive caribou and is a period of rapid change in forage biomass and N concentration, especially within the wet sedge

tundra. Summer includes the period of peak harassment from parasitic insects and encompasses peak forage biomass as well as the initiation of plant senescence in low shrub and tussock tundra communities and some species within the wet sedge tundra. Fall is a period of peak forage intake and late lactation for reproductive females; plant senescence is initiated for wet sedge tundra and is completed for all vegetation communities.

To account for spatio-temporal differences in temperature, phenology, composition, and productivity of vegetation, we designed a specific BN for each vegetation and period of the growing season (n = 12) that is parameterized with spatially and temporally appropriate data. Each BN will be used to describe protein availability in forages for current conditions (2000-2011) as well as 2 greenhouse gas emission scenarios (A2 and B1) for the 5-model averaged global circulation model for 2060-2069.

We will use monthly temperature and precipition projections for each emission scenario to estimate distributions of likely temperature and precipitation scenarios for each BN. Mean projected values with historical estimates of variance will be used to construct distributions of temperature and precipitation probabilities (e.g., Fig. 6) that will be the primary inputs to the BNs to estimate the availability of protein in the forages of caribou in 2060-69. We will use distributions of current and future availabilities in forage proteins to calculate a range of outcomes for the change in forage protein availability given the above warming scenarios. A matrix of change in available forage proteins by vegetation by season by emissions scenario (e.g., Table 3) will be used to evaluate the capacity for a trophic mismatch to occur for reproductive female caribou on the North Slope of Alaska.

Data management

All data and associated products will have complete metadata, be handled and archived according to Alaska Science Center (ASC) protocols, and be stored on the existing CAE servers at the ASC. The extensive dataset on environmental conditions and the spatio-temporal dynamics of forage characteristics will be made available to state, federal, and university cooperators through online resources (e.g., ASC or Arctic LCC portal).

ROLES AND RESPONSIBILITIES

Dave Gustine: Holds primary responsibility for completion of all aspects of this study including: 1) establish environmental monitoring network, 2) planning and conduct of fieldwork to assess changes in plant phenology and forage quality, 2) development of reports and products in collaboration with other project personnel, 3) coordination and collaboration with state, federal, and university contacts to ensure overall efficiency and productivity of the broader program, and 4) co-advise graduate student on fieldwork, analyses, and thesis/manuscript preparation.

Perry Barboza: Will provide expertise and collaboration on forage analyses and modeling and advise graduate student on fieldwork, analyses, and thesis/manuscript preparation.

Kyle Joly: Will provide expertise and collaboration on habitat modeling and logistics as needed as well as co-advise graduate student on fieldwork, analyses, and thesis/manuscript preparation.

PRODUCTS AND TIMELINE

Progress reports summarizing the previous summers activities will be provided by 1 March 2014-2016. Several scientific products will result from this work. We will provide a final report in March 2016. We anticpate at least 3 manuscripts for publication in peer-reviewed journals will result from this effort. The final authorship of scientific products will be shared among a student and project collaborators as appropriate. Tentative topics of these products include:

1. A pan-Alaskan comparison of phenology and nutrient dynamics in the summer forages of caribou;
2. Assessing the nutritional implications of climate changes: foraging windows for migratory caribou in summer; and
3. Characteristics of the growing season in the Arctic: trends and implications to Arctic herbivores.

Timeline

Phase 1: FY2013 (Oct 2012 – Sep 2013)	
Oct–Dec 2012	• Announce, interview, and enroll graduate (Ph.D.) student at UAF; prepare work plan for field work to be initiated in May 2013; draft and finalize study plan; and contract helicopter vendor for fieldwork
Dec 2012	• Initiate permitting process; submit final work plan for peer review
Jan–May 2013	• Organize logistics for fieldwork; acquire permits as necessary; order and test all equipment; finalize and amend data collection protocols; complete safety training
Mar 2013	• Finalize work plan for field work to be initiated in May 2013; committee meeting for student, outline graduate study plan
May–Sep 2013	• Conduct first year of fieldwork; catalog samples and structure databases
Phase 2: FY2014 (Oct 2013 – Sep 2014)	
Oct 2013	• Acquire and analyze environmental data for the 2013 growing season
	• Submit forage samples for nutritional analyses
Nov 2013	• Submit completed report and data products on Phase 1 for environmental monitoring (BLM); meet with collaborators and reexamine data collection protocols to increase efficiency of data collection and management; and contract helicopter vendor for fieldwork
Dec 2013	• Submit completed report and data products on Phase 1 for forage characteristics (USFWS); initiate permitting process; amend work plan as necessary; receive forage nutritional analyses results for samples collected during 2013 fieldwork
Jan–May 2014	• Organize logistics for fieldwork; refurbish, order, and test equipment; amend data collection protocols; and complete safety training for all crew
Mar 2014	• Amend work plan as necessaryfor field work to be initiated in May 2013; committee meeting for student, review progress, and course requirements
May–Sep 2014	• Complete second year of fieldwork
Phase 3: FY2015 (Oct 2014 – Sep 2015)	
Oct 2014	• Acquire and analyze environmental data for the 2014 growing season
	• Submit forage samples for nutritional analyses

Nov 2014	• Submit completed report and data products on Phase 2 of environmental monitoring (BLM); meet with collaborators and reexamine data collection protocols to increase efficiency of data collection and management
Dec 2014	• Submit completed report and data products on Phase 2 for forage characteristics (USFWS); initiate permitting process; amend work plan as necessary; receive forage nutritional analyses results for samples collected during 2014 fieldwork
Jan–May 2015	• Organize logistics for fieldwork; refurbish, order, and test equipment; amend data collection protocols; and complete safety training as needed
Mar 2015	• Complete progress report covering project activities through Dec 2014; committee meeting for student, review progress, establish dates for comprehensive exams
May–Sep 2015	• Complete third and final year of fieldwork
FY2016 (Oct 2015 – Sep 2016)	
Oct 2015	• Acquire and analyze environmental data for the 2015 growing season
	• Submit forage samples for nutritional analyses
Dec 2015	• Submit completed report and data products on Phase 1-3 on environmental monitoring (BLM); receive forage nutritional analyses results for samples collected during 2015 fieldwork
Mar 2016	• Submit Final Report and data products on Phases 1-3 of forage characteristics (USFWS); committee meeting for student, review progress, and outline dissertation
Apr–Oct 2016	• Draft and submit manuscripts as student progress allows

LITERATURE CITED

Auerbach, N. A., M. D. Walker, and D. A. Walker. 1997. Effects of roadside disturbance on substrate and vegetation properties in arctic tundra. Ecological Applications 7:218-235.

Barboza, P. S., and I. D. Hume. 2006. Physiology of intermittent feeding: integrating responses of vertebrates to nutritional deficit and excess. Physiological and Biochemical Zoology 79:250-264.

Barboza, P. S., and K. L. Parker. 2008. Allocating protein to reproduction in Arctic reindeer and caribou. Physiological and Biochemical Zoology 81:835-855.

Cameron, R. D., W. T. Smith, S. G. Fancy, K. L. Gerhart, and R. G. White. 1993. Calving Success of Female Caribou in Relation to Body-Weight. Canadian Journal of Zoology 71:480-486.

Cebrian, M. R., K. Kielland, and G. Finstad. 2008. Forage quality and reindeer productivity: Multiplier effects amplified by climate change. Arctic Antarctic and Alpine Research 40:48-54.

Dau, J. 2009. Units 21D, 22A-E, 23, 24, and 26A caribou management report. Alaska Department of Fish and Game, Juneau, AK.

De Gabriel, J. L., I. R. Wallis, B. D. Moore, and W. J. Foley. 2008. A simple, integrative assay to quantify nutritional quality of browses for herbivores. Oecologia 156:107-116.

Finstad, G. 2008. Applied range ecology of reindeer (*Rangifer tarandus tarandus*) on the Seward Peninsula, Alaska. Dissertation, University of Alaska-Fairbanks, Fairbanks, AK.

Goetz, S. J., A. G. Bunn, G. J. Fiske, and R. A. Houghton. 2005. Satellite-observed photosynthetic trends across boreal North America associated with climate and fire disturbance. Proceedings of the National Academy of Sciences 102:13521-13525.

Griffith, B., L. G. Adams, D. C. Douglas, C. Cuyler, R. G. White, A. Gunn, D. E. Russell, and R. D. Cameron. 2010. E-Letter in response to Post et al.: No evidence of trophic mismatch for caribou in Greenland. *in* Science.

Ihl, C., and P. S. Barboza. 2007. Nutritional value of moss for arctic ruminants: a test with muskoxen. Journal of Wildlife Management 71:752-758.

Johnstone, J., D. Russell, and B. Griffith. 2002. Variations in plant forage quality in the range of the Porcupine caribou herd. Rangifer 22:83-92.

Joly, K., P. Bente, and J. Dau. 2007. Response of overwintering caribou to burned habitat in northwest Alaska. Arctic 60:401-410.

Joly, K., and D. Klein. 2011. Complexity of caribou population dynamics in a changing climate. Alaska Park Science 10:27-31.

Kielland, K. 1995. Landscape patterns of free amino acids in arctic tundra soils. Biogeochemistry 31:85-98.

Klein, D. R., L. M. Baskin, L. S. Bogoslovskaya, K. Danell, A. Gunn, D. B. Irons, G. P. Kofinas, K. M. Kovacs, M. Magomedova, R. H. Meehan, D. E. Russell, and P. Valkenburg. 2005. Management and conservation of wildlife in a changing arctic environment. Pages 597-648 *in* C. Symon, L. Arris, andB. Heal, editors. Arctic Climate Impact Assessment. Cambridge University Press, New York, NY.

Lenart, E. A., R. T. Bowyer, J. V. Hoef, and R. W. Ruess. 2002. Climate change and caribou: effects of summer weather on forage. Canadian Journal of Zoology 80:664-678.

Martin, P. D., J. L. Jenkins, F. J. Adams, M. T. Jorgenson, A. C. Matz, D. C. Payer, P. E. Reynolds, A. C. Tidwell, and J. R. Zelenak. 2009. Wildlife response to environmental arctic change: predicting future habitats of Arctic Alaska. U. S. Fish and Wildlife Service.

McArt, S. H., D. E. Spalinger, W. B. Collins, E. R. Schoen, T. Stevenson, and M. Bucho. 2009. Summer dietary nitrogen availability as a potential bottom-up constraint on moose in south-central Alaska. Ecology 90:1400-1411.

McArt, S. H., D. E. Spalinger, J. M. Kennish, and W. B. Collins. 2006. A modified method for determining tannin-protein precipitation capacity using accelerated solvent extraction (ASE) and microplate gel filtration. Journal of Chemical Ecology 32:1367-1377.

Nellemann, C., and M. G. Thomsen. 1994. Terrain Ruggedness and Caribou Forage Availability during Snowmelt on the Arctic Coastal-Plain, Alaska. Arctic 47:361-367.

Peltier, T. C., P. S. Barboza, and J. E. Blake. 2003. Seasonal hyperphagia does not reduce digestive efficiency in an Arctic grazer. Physiological and Biochemical Zoology 76:471-483.

Person, S. J., R. E. Pegau, R. G. White, and J. R. Luick. 1980. In vitro and nylon-bag digestibilities of reindeer and caribou forages. Journal of Wildlife Management 44:613-622.

Post, E., and M. C. Forchhammer. 2008. Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. Philosophical Transactions of the Royal Society B-Biological Sciences 363:2369-2375.

Raynolds, M. K., D. A. Walker, and H. A. Maier. 2005. Plant community-level mapping of arctic Alaska based on the Circumpolar Arctic Vegetation Map. Phytocoenologia 35:821-848.

Reed, B. C. 2006. Trend analysis of time-series phenology of North America derived from satellite data. GIScience and Remote Sensing 43:24-38.

Robbins, C. T., T. A. Hanley, A. E. Hagerman, O. Hjeljord, D. L. Baker, C. C. Schwartz, and W. W. Mautz. 1987a. Role of tannins in defending plants against ruminants:reduction in protein availability. Ecology 68:98-107.

Robbins, C. T., S. Mole, A. E. Hagerman, and T. A. Hanley. 1987b. Role of tannins in defending plants against ruminants: reduction in dry-matter digestion. Ecology 68:1606-1615.

Servello, F. A., E. C. Hellgren, and S. R. McWilliams. 2005. Techniques for wildlife nutritional ecology. Pages 554-590 *in* C. E. Braun, editor. Techniques for wildlife investigations and management. The Wildlife Society, Bethesda, MD

Tape, K., M. Sturm, and C. Racine. 2006. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. Global Change Biology 12:686-702.

Walker, D. A., H. E. Epstein, G. J. Jia, A. Balser, C. Copass, E. J. Edwards, W. A. Gould, J. Hollingsworth, J. Knudson, H. A. Maier, A. Moody, and M. K. Raynolds. 2003. Phytomass, LAI, and NDVI in northern Alaska: relationships to summer warmth, soil pH, plant functional types, and extrapolation to the circumpolar Arctic. Journal of Geophysical Research 108:8169.

White, R. G. 1983. Foraging patterns and their multiplier effects on productivity of northern ungulates. Oikos 40:377-384.

White, R. G., D. F. Holleman, and B. A. Tiplady. 1989. Seasonal body weight, body condition, and lactational trends in muskoxen. Canadian Journal of Zoology 67:1125-1133.

Williams, M. D., and E. B. Rastetter. 1999. Vegetation characteristics and primary productivity along an arctic transect: implications for scaling up. Journal of Ecology 87:885-898.

Table 1. Sampling schedule to assess soil, vegetation, and environmental variables within the historic calving and summer range of the Western Arctic caribou herd in northwest Alaska, May-September, 2013-15.

Feature	Variable	Level				Sampling period						
		Macroplot	Plot	Functional group	Species of interest	4-8 May	8-12 Jun	22-26 Jun	20-24 Jul	10-14 Aug	24-28 Aug	21-25 Sept
Soil	Thaw depth	X	X				X	X	X	X	X	X
	Temperature	X	X						X			
	pH	X	X						X			
	Moisture	X	X						X			
	Nutrients	X	X						X			
Vegetation	Phenological stage	X	X		X		X	X	X	X	X	X
	Herbivory pressure (class)		X	X	X		X	X	X	X	X	X
	Shrubs: height		X	X	X		X	X	X	X	X	X
	Biomass: live vascular tissues	X	X	X	X		X	X	X	X	X	X
	Quality: nutrient composition	X			X		X	X	X	X	X	X
	Quality: digestible energy, nitrogen, and minerals	X			X		X	X	X	X	X	X
	Quality: plant secondary metabolites	X			X		X	X	X	X	X	X
Environment	Wind speed (hourly)	X				X	X	X	X	X	X	X
	Soil temperature (hourly)	X	X			X	X	X	X	X	X	X
	Air temperature (hourly)	X				X	X	X	X	X	X	X
	Photosynthetically active radiation (hourly)	X				X	X	X	X	X	X	X
	Solar radiation (hourly)	X				X	X	X	X	X	X	X
	NDVI (hourly)	X				X	X	X	X	X	X	X
	Snow/water depth	X	X			X	X	X	X	X	X	X
	Relative humidity	X	X			X	X	X	X	X	X	X
	Time-lapse photography	X				X	X	X	X	X	X	X

Table 2. A classification of reproductive phenology by growth stage in reindeer forages, as established by Finstad and Kielland (unpublished) and presented in Cebrian et al. (2008).

Growth stage	Description
0	Dormant, no new floral buds or floral buds closed
1	Floral buds forming or swelling
2	Inflorescences opening
3	Full inflorescence/anthesis
4	Post inflorescence, fruit or pod developing (females), pollen has been shed (males)
5	Mature fruit/seed set (females), inflorescences senesced (males)
6	Fruits, seeds dispersed (females), inflorescences senesced (males); fruits (females), inflorescences (males) may have fallen off plant

Table 3. Hypothetical matrix that could be used to evaluate the potential influences of climatic shifts (temperature and precipitation) under 2 emissions scenarios (B1 and A2) to the availabilities of proteins within caribou forages in 3 vegetation communities on the North Slope of Alaska, 2011-2015. The matrix is currently filled out with *hypothetical* positive (+), negative (-), or null(+/-) outcomes; real output will be a distribution of outcomes that are produced by the Bayesian network.

Season	Change in available protein (kg/ha) from 2000-2012 to 2060-69					
	B1			A2		
	Low shrub tundra	Tussock tundra	Wet sedge tundra	Low shrub tundra	Tussock tundra	Wet sedge tundra
Spring	+	+	+	+	+	+
Early Summer	+	+	+	+	+	+
Summer	+/-	+/-	+/-	+/-	+/-	+/-
Fall	-	-	-	-	-	-

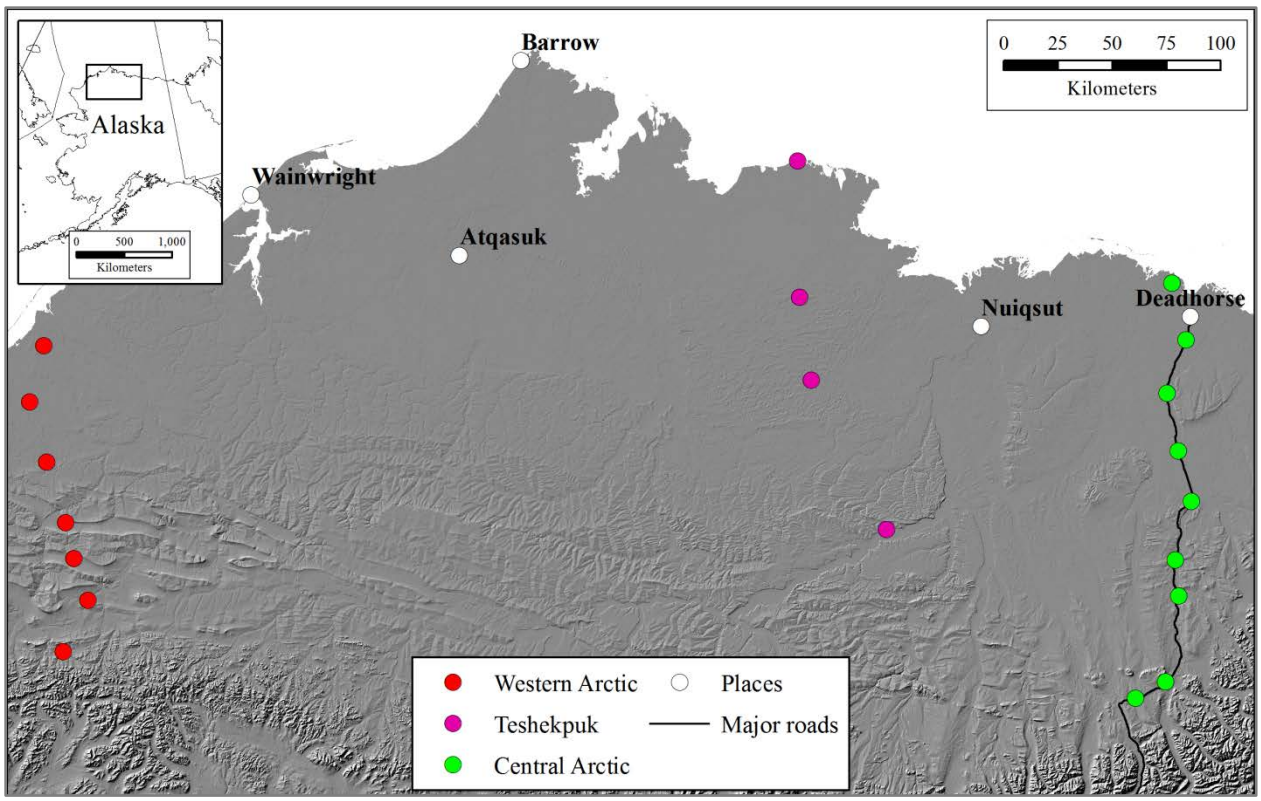


Figure 1. Plots to monitor the environmental conditions and the phenology, nutrient dynamics, and productivity of forages within the summer ranges of the Western Arctic, Teshekpuk, and Central Arctic caribou herds on the North Slope, Alaska 2011-15.

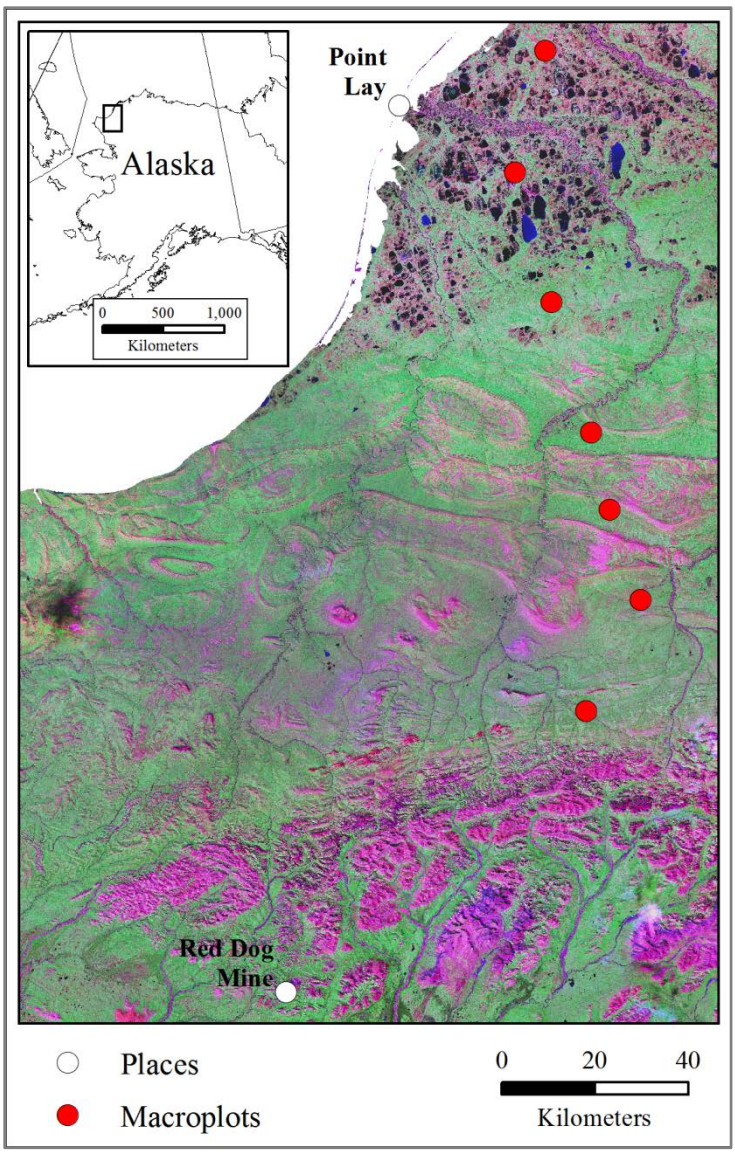


Figure 2. Plots to monitor the environmental conditions and the phenology, nutrient dynamics, and productivity of forages for the Western Arctic caribou herd in northwest Alaska,May-September 2013-15.

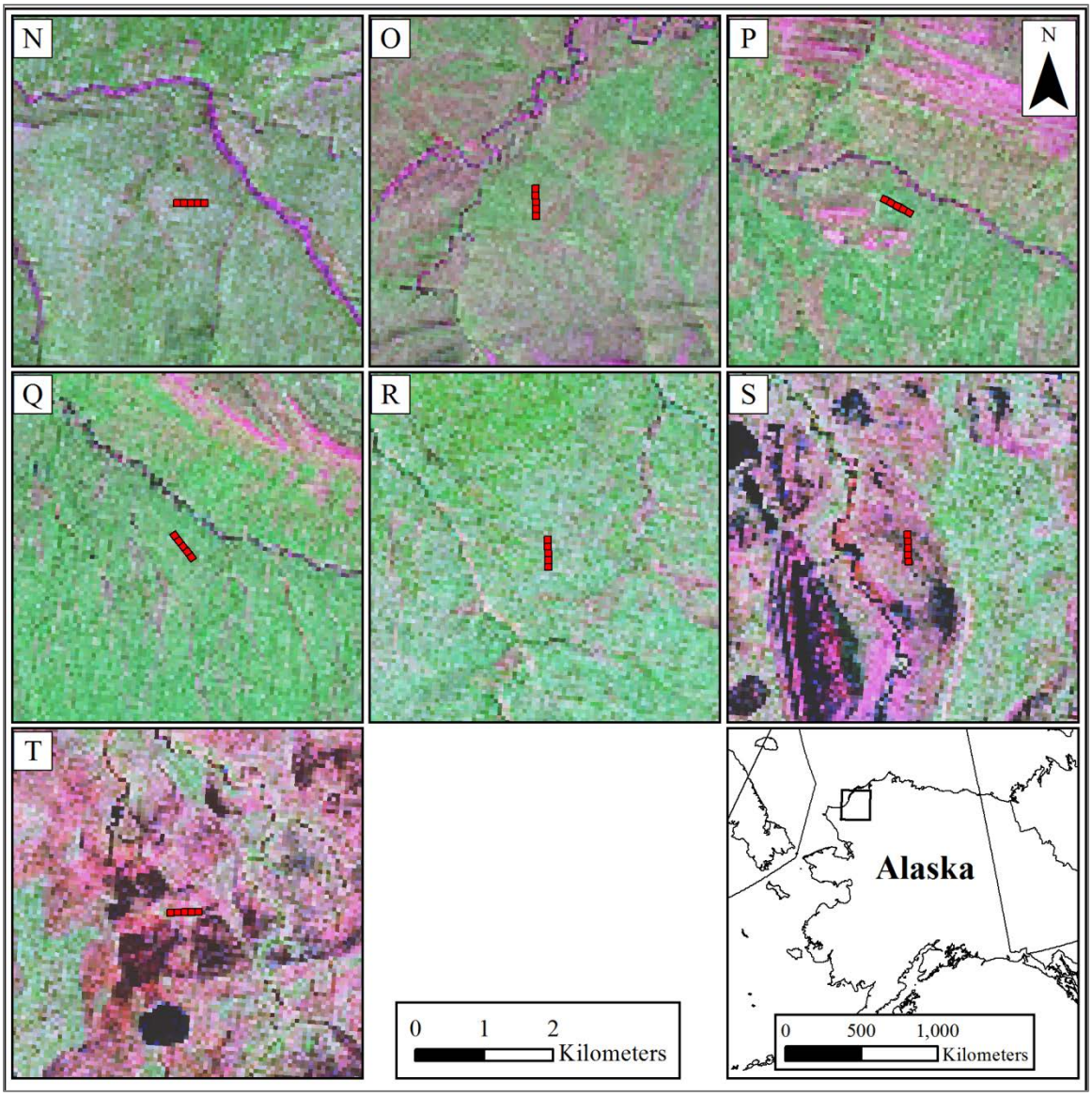


Figure 3. The macroplots (N-T) to assess the environmental, soil, and vegetative characteristics of the calving and summer range of the Western Arctic caribou herd in northwest Alaska, May-September, 2013-15.

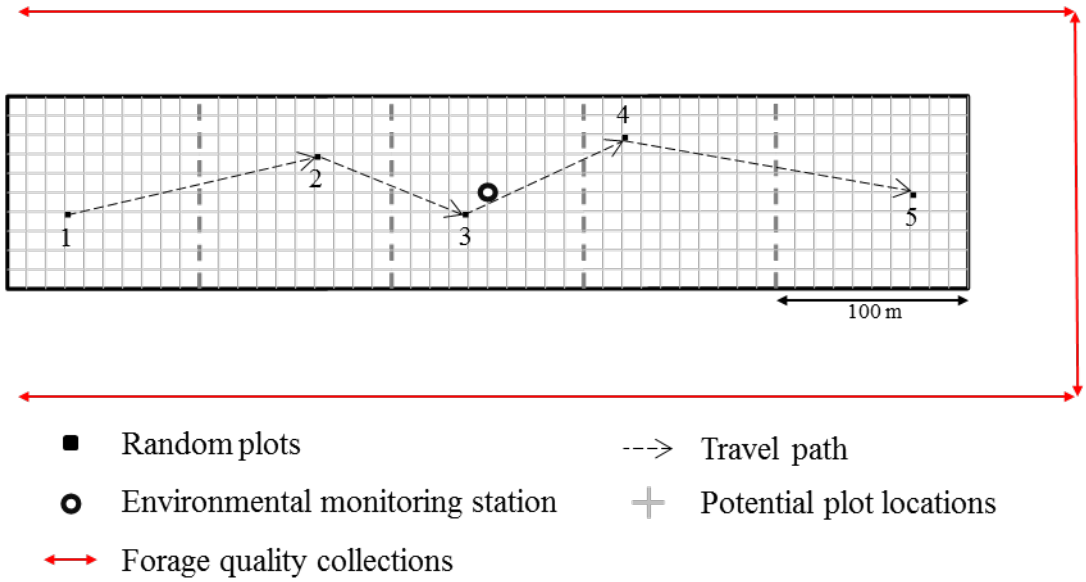


Figure 4. Schematic of a macroplot to assess the soil, vegetative, and environmental characteristics of calving and summer range of the Western Arctic caribou herd in northwest Alaska, May-September, 2013-15.

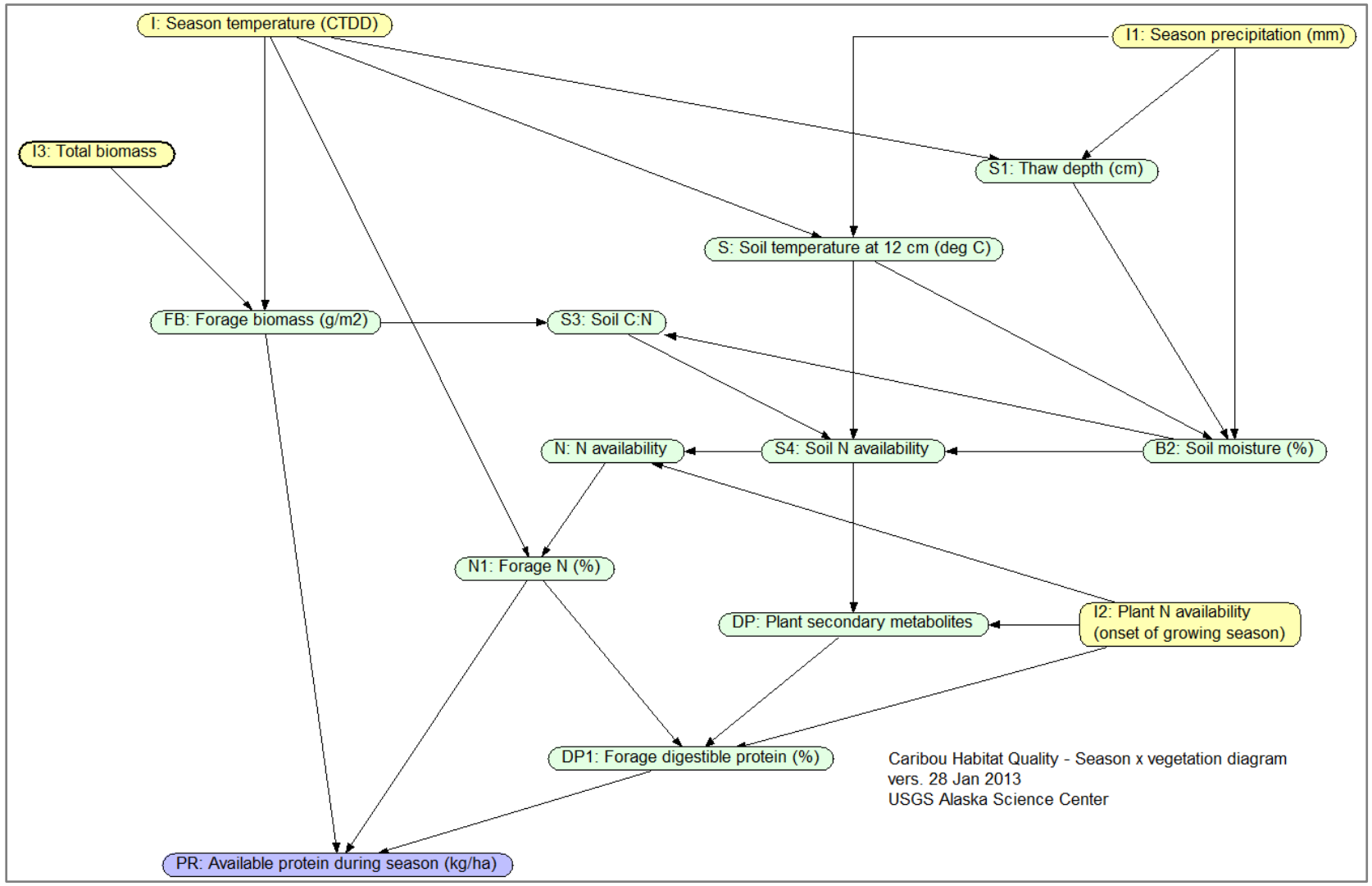
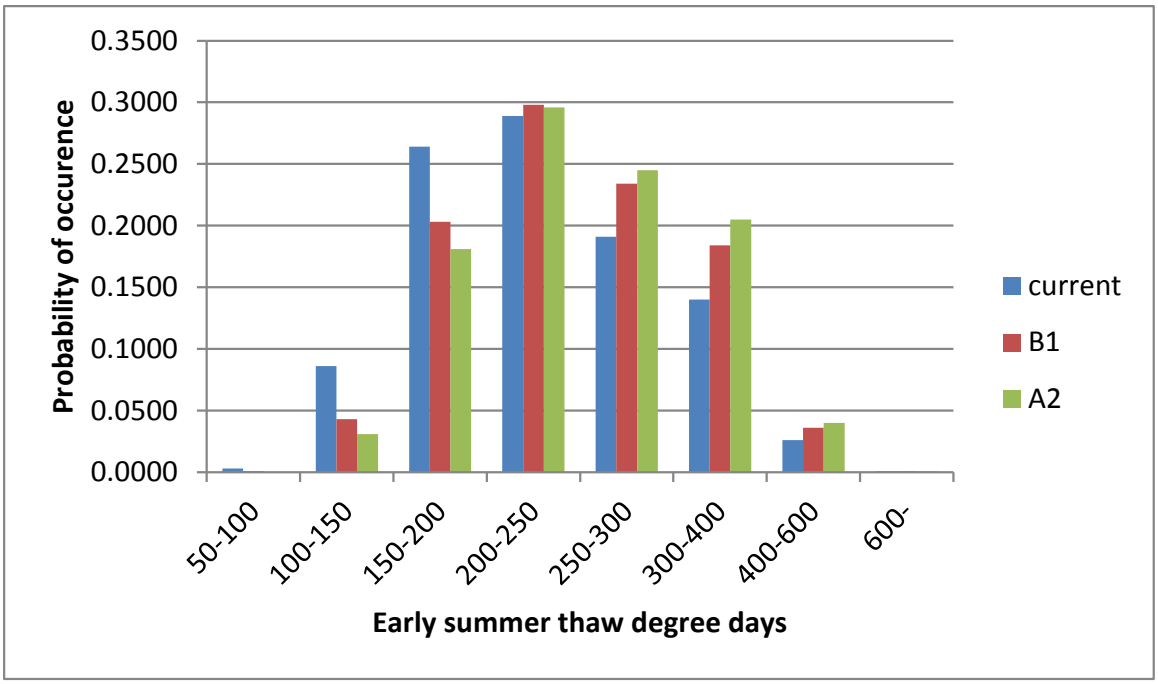


Figure 5. Template of a simplified influence diagram for the Bayesian network to quantify the spatio-temporal availability of forage proteinsfor caribou throughout the growing season under the current and projected climatic regimes on the North Slope of Alaska.



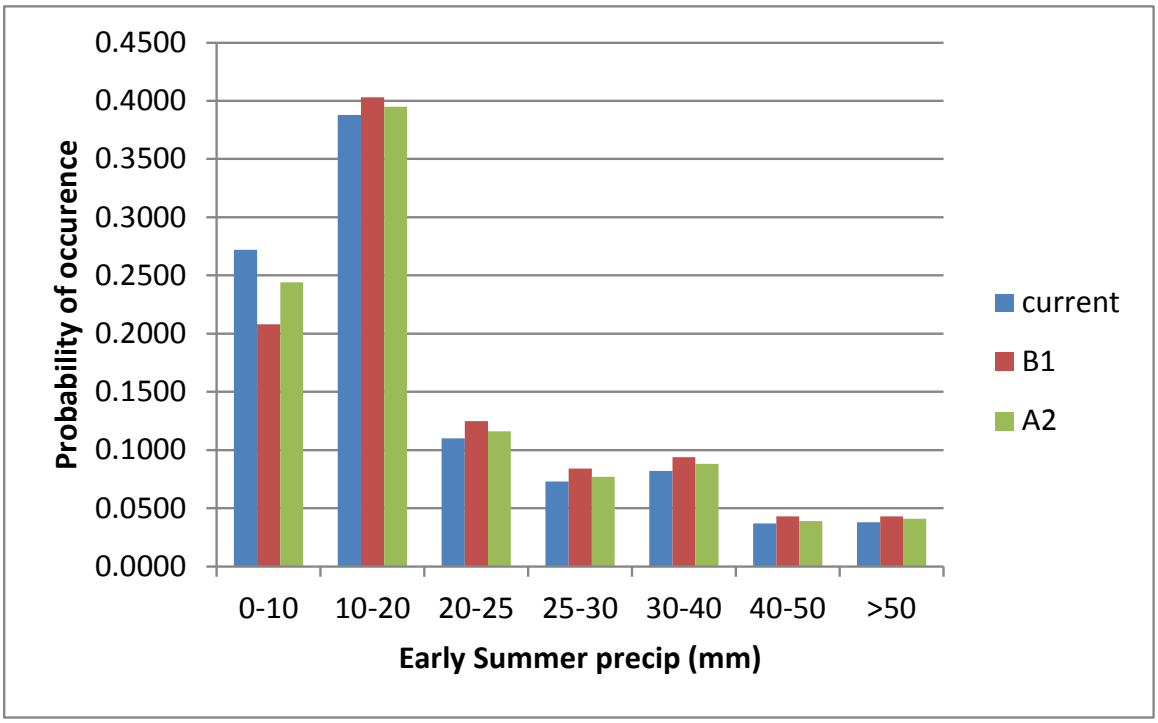


Figure 6. An example of *a priori* conditional probabilities for temperature (top panel) and precipitation (bottom panel) states for the current and projected climate scenarios (B1 and A2 emissions) within the Bayesian network to quantify the spatio-temporal availability of forage proteinsfor caribou in the early summer (15 June-14 July) in the low shrub tussock tundra on the North Slope of Alaska.