THE STUDY OF HUMAN-CARIBOU SYSTEMS IN THE FACE OF CHANGE:

USING MULTIPLE DISCIPLINARY LENSES

By

Archana Bali

RECOMMENDED:

A. David McGuire, Ph.D.

Donald E. Russell, M.S.

Robert G. White, Ph.D.

Gary Kofinas, Ph.D.
Advisory Committee Chair

Peter Fix, Ph.D.
Chair, Department of Natural Resources Management

APPROVED:

David Valentine, Ph.D.
Director of Academic Programs
School of Natural Resources and Extension

John C. Eichelberger, Ph.D.
Dean of the Graduate School

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Date

THE STUDY OF HUMAN-CARIBOU SYSTEMS IN THE FACE OF CHANGE:

USING MULTIPLE DISCIPLINARY LENSES

A

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Archana Bali, M.S.

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Abstract

Barren-ground caribou herds are part of social-ecological systems that are of critical importance to northern Indigenous Peoples of the Arctic, contributing to nutritional, cultural, and spiritual well being that are today undergoing significant changes. This dissertation uses multiple disciplinary lenses to understand the dynamics of these systems and to clarify methods for studying them. Chapter 1 focuses on a prediction of summer (June 1- August 31) mosquito activity and potential insect harassment of caribou in response to a changing climate. The Mosquito Activity Index (MAI) was based on daily ambient temperature and wind velocity obtained from the North American Regional Reanalysis dataset (NARR) from 1979 to 2009 for summer ranges of Alaska's four Arctic herds: Western Arctic Herd (WAH), Teshekpuk Caribou Herd (TCH), Central Arctic Herd (CAH), and Porcupine Caribou Herd (PCH). Mean MAI was lowest for TCH, followed by WAH and PCH and highest for CAH. Over 31 years there was an increasing trend in MAI that affected the summer habitat of TCH and PCH, but a decreasing trend for WAH. Intra-annual patterns in MAI among herds differed in peak MAI. Chapter 2 presents a novel method of participatory videography to document the knowledge and experiences of Caribou People. Ninety-nine interviews were videoed in six arctic communities of North America in the summer of 2008 as part of the International Polar Year. Chapter 3 presents "Voices of Caribou People," a composite film of those interviewed, portraying the range of topics reported. Chapter 4 presents the results of an open-coding content analysis of a sample of 34 of the Voices Project interviews. Interviews described people's rich memories of the past, aspects of their traditional knowledge and practices, the changes they have observed, the challenges they face, and what they perceive as their needs to meet present and future challenges. A key finding of the analysis is that while the research community and funding agencies are highly focused on climate change, Caribou People expressed greater concern about their social, economic, and political challenges. Caribou people noted that more studies undertaken in full partnership with caribou user communities along with community authority in decision-making are needed to sustain their human-caribou systems.

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Figure 1. Archana Bali presenting a gift of appreciation from the University of Alaska Fairbanks to Jim Murtaugh (right) and George Schaller (left), representing the Liz Clairborne and Art Ortenberg Foundation in May 2014. (Photo: Martin Robards.)

Many supported Archana's PhD studies and research.

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Archana touched lives wherever she went, whomever she encountered. She travelled India extensively while working at Greenpeace along with her compatriot Brikesh Singh. Archana was very spiritual. Friends who enriched her life in this way were Surinder Singh Bunty who introduced her to Rumi's Poetry, Sanjeev Shrivastava, and Bashobe Majumdar.

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– her cousins – together they were the Evil Gang, inseparable until her last breath; their spouses Elizabeth, Karthikeyan, Saumya, Sheetal & Vinodh; and the host of nieces and nephews who always brought the biggest smiles – Aadi, Tubhyam, Aarya, Orion, Ribhya, Om, Sadha, Keya, Sushara. Archana's lighthouse of inspiration and pillar of strength was her grandmother, Maaji; Archana was very fond of her encouraging family in India – Uncle Yousuf, Dilip-Rekha-Rohan, Rajen, Daddy & Taiji, and her cousins Jeet, Rahul, Rashmi, Purva, Leena, Punita, Kalika, Dimple, Shivani, Shyam, Paul, Vikas and their families.

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Preface

There were only six months between Archana Bali's untimely death and the expected completion date of her PhD dissertation. Consequently, completing chapters of the dissertation and formatting were left to her academic committee and Dr. Martin Robards, Archana's partner and fiancé.

Archana matriculated into the Interdisciplinary Studies PhD Program at the University of Alaska Fairbanks (UAF) in Autumn, 2007, having traveled to study in the North from her home in India. She came to UAF as the first George Schaller Student Fellow, and in a short time was enchanted with the Arctic, its wildlife, and its people. As a student of the Resilience and Adaptation Program (RAP), UAF's graduate program in sustainability, Archana made significant contributions to RAP's interdisciplinary community of student and faculty scholars, raising questions, challenging assumptions, and embarking on unique and interesting PhD research that drew on her sharp intellect, creative spirit, imagination, and endless energy.

In her blog "Arctic Winds" she introduced herself with:

> *"There is no happiness for him who does not travel! I love traveling or may I say, I live to travel... to read and learn from the pages of this book called the world!!"*

Archana used all of her senses to experience the world in a holistic and encompassing way. Her awareness of how sensory inputs fit together to tell stories were at the heart of who she was. At the start of her PhD studies, she described a formative time on a Sea Ice film course at Barrow, Alaska. These early writings of her experiences epitomize how she confronted her entire PhD. She naturally saw stories in what she experienced – and her research was correspondingly, and very naturally viewed through a variety of interdisciplinary lenses. Archana wrote:

> *"Prior to starting this course work, I did a google search for Visual Anthropology that produced the following definition: 'A subfield of cultural anthropology that developed out of the study and production of ethnographic photography, film and new media.' The word 'ethnography' stuck in my mind. I had a perception about the culture that anthropologists would generally find attractive and worth their time and effort. I had an image of a prototype community that often features in the anthropological literature – a relatively homogeneous one as compared to the society that I am a part of. An ideal target community would be an isolated tribe, untouched by the 'outside' world; the one with an exotic culture, language, clothes, food and even a different shade of skin color. This was my myopic point of view, given my limited understanding of anthropology as well as the word culture.*

While my appreciation for these two terms increased during this field course, so did the image of a 'scientist' that I have always held. My perception of a 'scientist' did not change, albeit got a bit glorified, partly because I considered myself more of a scientist than a filmmaker. However, the definition I held of a 'community' has changed significantly, inspired by two starkly different communities that I had the opportunity to not only interact with, but also be a part of them interchangeably in last couple of weeks. Firstly, and most obviously, it was the focused look at scientists as a community, or more precisely, the culture of the mixed-culture group of the sea-ice scientists from all over the world who encouraged me to broaden the definition I held. The second and a very subtle experience was the culture of filmmakers themselves.

The Barrow experience, as I would call it, had me in a paradox for a good amount of time. On the one hand I knew the language and culture of the scientific community since I have always considered myself a part of it. But for the first time, I was taking a look at this culture from outside – as an anthropologist this time. They were the subjects and I was the observer's eye. On the other hand, I was foreign to the culture of filmmakers, yet I was supposed to be behaving like one myself. I was an outsider, now a part of it. And I did not know how to be the eyes. To complicate this more, there was a confusion for I did not know if I am to really behave and think as an anthropologist, who is in turn a scientist himself, or just see and record as a camera. So whose eye are they, anyway?

Taking the Barrow experience as an example, there are several obvious as well as subtle differences in the visual culture of sea-ice people versus sea-ice scientists. There are many basic distinctions in the way the two cultures think, behave and respond. These differences are embedded in a subject of interest to each group and their ways of data collection and analysis. It is quite analogous to the difference between the disciplines of science and art itself.

Science is essentially methodological while art is inherently creative. While at the crux of sea-ice culture (researchers) was to learn and adhere to the correct process of investigation; for the sea-ice community (filmmakers), the spirit of the effort was entirely oriented towards the end product, whichever way you get at it. It is probably because, the art of filmmaking has more to do with individual perceptions of the person behind the camera and hence the 'truth' becomes subjective. For instance, almost everyone in the film crew had an independent perception towards the subject of interest and still all these independent points of views were valid at the same time. We took different kinds of shots *and different styles of doing things were apparent; and this was not only acceptable but it was also encouraged during the course. On the other hand, the research students were expected to get somewhat homogenized in their ways of doing things. Everyone must follow the protocol A-B-C; this is how to hold the drill; and here is the correct procedure to take measurements!! For them the "truth" is in objectivity. Irrespective of everyone's opinions, there is one standard way; it is the tested and efficient way, and is the right methodology. The purpose was to train them all in this standard methodology of answering research questions.*

Now, take one step back and despite of all these distinctions, one can find parallels between the two cultures. After all there is the same driving force behind both – human curiosity! Hence, both cultures have a similar nature of being experimental and curious, the sea-ice researchers as well as the see-ice filmmakers. I chanced upon a quote by famous spiritual author Merton – "Art enables us to find ourselves and lose ourselves at the same time" (Thomas Merton, 1953-1968). Come to think of it, is it not true for the scientific pursuits?

Hmmm… it all depends of which side of the line you are, I tell myself. Personally for me this experience was very interesting and enriching, because, as I mentioned earlier, I often found myself caught between the two cultures, ready to jump fences. For instance, right in the beginning, when we were made aware that among various research modules, there would be one on tagging ringed seals and one on whale hunting; I couldn't help getting distracted by this idea of handling or observing animals. It was sheer excitement of such opportunities for my wildlife-student self that keep pushing my new film-student self aside. And still, when the camera came in my hands for the first time, the response of my senses was overwhelming. There were mixed feelings – a feeling of empowerment by this new tool in my hands, and nervousness about using it at the same time. The excitement of being on boom for the first time, writing my first shot-list, going through the checklists on the action packers… all these activities were suddenly so engaging that the film-student me got better of the science-student me in no time. At another instance, as a see-ice person, I am participating in filming an interview of a sea-ice researcher, and while asking interview questions about his research, I easily got drifted to the other culture; because, for me, it was an effortless conversation in the same language that I was used to speaking.

I am sure that my experience of finding myself on the other shore is not a unique one. At *several times, subscribers of these two distinct cultures crossed boundaries. Teamwork and discipline were the key words for both the cultures. Just as many other human communities in several distinct cultures have it, even here cooperation was absolutely crucial, not only within each group, but also across the two communities. This was the way forward for both the teams to complement each other and successfully attain their individual objectives.*

Archana saw her world as a series of complex and beautiful stories. Being outside with her was always a happy adventure and a place of learning. Going for a hike one day, she saw wolf scat alongside the trail. For Archana this wasn't an isolated note of an animal that passed. It was a window into trophic relationships, social relationships, of wolves' relationship to us, and the world around us. That fascination with the world around her was at the heart of why she was such a good scientist, storyteller and conservationist.

In working through the focus and organization of her dissertation research, Archana thought deeply about the art and practice of interdisciplinary research, discussing and ultimately formulating a personal philosophy on interdisciplinarity. On February 16, 2011 at a RAP seminar she articulated many of her ideas on this topic. At that seminar she described the complexity and steps needed when engaging in the interdisciplinary enterprise. Drawing from her lecture notes, she said:

"A good start is when you put your horse before the cart. I say this because I did not. I started off with the idea that I want to do interdisciplinary research, without having a question at that time. I had background training in wildlife biology, and interest in climate change and the Indigenous Peoples of Alaska, but did not know what else to throw in to make my curry interdisciplinary. What question was I to ask to fit this prescription?

"It took me time to get there and here is my four-step process:

1. *Start by asking a question (not by what approach you want to take, or method you want to use). Let the question drive you through the process of answering it.*

2. *Formulate the question and then make a complete conceptual model of the phenomenon. Put EVERYTHING on the table, and then scope it out to decide exactly you are going to study and what you will leave out.*

3. *If each part of the remaining model falls within a specific discipline, then you'll know how disciplinary, transdisciplinary, multidisciplinary, and or interdisciplinary your work is going to be.*

4. *Don't worry about what interdisciplinary is. Instead, focus your question and how to answer it. For me, I had a core set of disciplinary works, but drawing from, or involving multiple disciplines."*

5. *My final task was to integrate information across the core disciplinary pieces by triangulating on my questions about caribou ecology and local access to those caribou – this is a process of putting the pieces together. This is the 'holy grail' of interdisciplinarity"*

Archana described the components of her dissertation research on human-caribou systems, the sub-questions asked for each component, and how they would complement each other to improve understanding of the system.

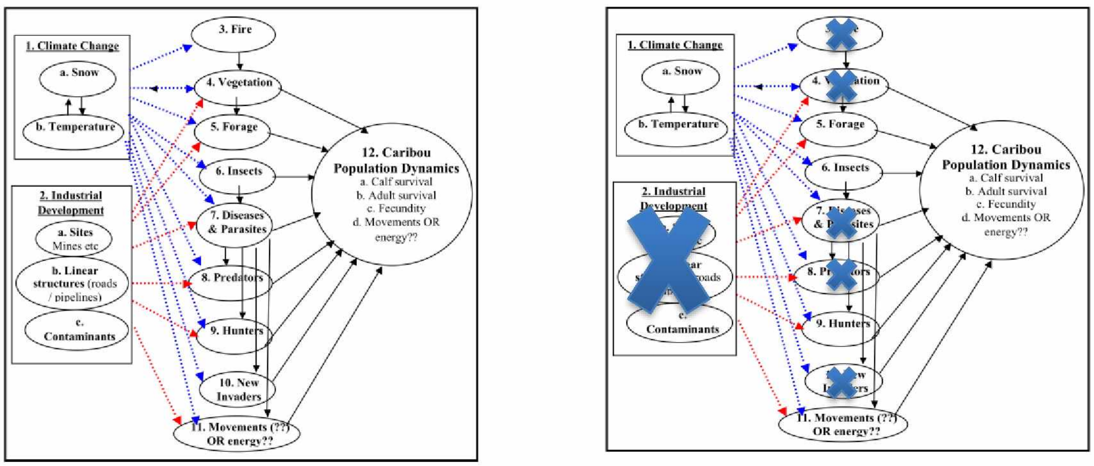

Figure 2. Archana's Step 2 and 3 as she developed her multi-disciplinary lenses to assess a conceptual social-ecological model.

Perhaps the most brilliant and powerful message of that seminar related to her ideas on the integration of knowledge systems, the extent to which the integration of disciplines is even possible, and how the use of multiple disciplinary lenses is complementarity and offers a more holistic understanding than working with just one lens. Archana's work documenting the perspectives of Caribou People using videography in ways that respected the people's desire to deliver an unfiltered message as well as her innovative efforts to integrate meteorological analysis with caribou ecology are how she realized her philosophy in the chapters of this dissertation.

This dissertation is presented as four stand-alone chapters. Chapter 1, "Modeling seasonal mosquito activity index for summer habitat of caribou herds of arctic Alaska, 1979 to 2009" overlays the outputs of the model with the distribution of caribou herds. It demonstrates the utility of using meteorological data at a regional scale to study wildlife biology question. The interdisciplinarity of this research was achieved through her close collaboration with experts of remote sensing and caribou ecology.

Chapter 2, *Voices of the Caribou People: A participatory videography method to document and share local knowledge from the North American Human-Rangıfer Systems,* took Archana, the wildlife ecologist, to become Archana, the film-maker and anthropologist. "Voices of the Caribou People" is a legacy participatory videography project of the International Polar Year, documenting the history, experiences, challenges, and needs of Indigenous peoples who identify as Caribou People. The project was undertaken as Archana's internship for RAP during the summer of 2008 in which she traveled to six Indigenous caribou-user communities from Alaska to Quebec. That summer Archana recorded 99 interviews with Caribou People about ecological, cultural, spiritual, and nutritional aspects of their relationship with caribou. Critical to the success of the Voices project was Archana's disarming manner and interpersonal skills, which resulted in strong partnerships in all communities. Because of Archana's skill engaging with men, woman, and youth in all six villages, their interviews provided a complete picture of the Caribou People, and thus fulfilled communities' wishes of telling their own stories with their own voices, without the filter of a researcher's constructs, frameworks, or survey instruments. This chapter outlines the methodology and underlying philosophy that guided the Voice's Project.

Chapter 3, *Voices of Caribou People: The Film,* is the 20-minute video described above. This edition of Voices of the Caribou People was produced in the last year of her life and presented at a special session honoring her at the North American Caribou Workshop, held in Whitehorse, Yukon, Canada.

Chapter 4, *In the Words of Caribou People: Local Perspectives on Changing Human-Caribou Systems of North America,* represents a process of listening to what Caribou People reported to Archana in the Voices Project interviews. Thirty-four of 99 Voices interviews were coded for what people said about their past, traditional knowledge, social-ecological changes, communities' responses to changes, challenges faced, and needs of communities for responding to change. The findings highlight how the emphasis on Arctic climate change research by funding agencies and the scientific community contrasts highly with challenges and needs as expressed by Caribou People, who are more concerned with economic hardships, jobs, social issues, and the potential impacts of extractive industrial activities on caribou and caribou availability.

Together, the chapters of the dissertation bridge the chasm between Archana the storyteller and Archana objective scientist, leaving a legacy of publications about caribou ecology, participatory videography, knowledge, concerns, and needs of Caribou People, and an award-winning film.

Archana Bali passed away on Sept 8th 2014. Her departure was too soon, but her impact is great.

Chapter 1

Modeling Seasonal Mosquito Activity Index for Summer Habitat of Caribou Herds of Arctic Alaska, 1979 To 2009[1]

ABSTRACT

Climate plays an important role in regulating population dynamics of wild animals. For barren-ground caribou (*Rangifer tarandus)*, insect harassment is an important factor related to local weather conditions, and has significant implications for caribou productivity and seasonal distribution. Temperature and wind are important abiotic drivers of insect activity. In this study we use algorithms of mosquito activity based on ambient temperature and wind velocity. Previous estimates of mosquito activity have not represented the entire summer range of a caribou herd. Given the warming that has occurred in recent decades in the Arctic and the projections of continued warming, a possible increase in mosquito abundance is possible. For both long-term and spatial analysis of potential mosquito activity, we applied a model of mosquito activity driven by meteorological data to the summer ranges of four herds: Western Arctic Herd (WAH), Teshekpuk Caribou Herd (TCH), Central Arctic Herd (CAH), and Porcupine Caribou Herd (PCH). We used 3 hourly surface air temperature and wind speed data (1979-2009) from North American Regional Reanalysis dataset (NARR; 0.33°latitude/longitude) to determine the patterns in abiotic drivers of mosquito activity. For each herd, we calculated a daily spatially explicit "Mosquito Activity Index" (MAI), a theoretical measure of relative mosquito harassment potential at a given site and produced a 31-y mean MAI landscape and trends in MAI. Mean MAI was lowest for TCH (6.43) followed by WAH (9.49), PCH (9.53) and CAH (10.04). The MAI landscape analysis revealed an increasing trend in MAI for the coastal landscape that affected the TCH and PCH, but the landscape analysis indicated a decreasing trend in MAI for the summer habitat of WAH. Although summer ranges showed similar intra-annual patterns in mosquito activity among herds, peak mosquito activity differed in magnitude among the ranges. Temperatures were highly variable over time while wind was highly variable over space. Measures of MAI are associated with productivity trends in the four herds.

[1] Prepared for publication in *Arctic*, authored by Archana Bali, Vladimir Alexeev, Robert G. White, Don E. Russell, A. David McGuire, and Gary Kofinas.

INTRODUCTION

Harassment by flying parasitic insects including mosquitoes (*Aedes spp*., *Culicidae*), black flies (*Simuliidae*) and oestrid flies *(Oestridae*) can affect the health and wellbeing of caribou and reindeer (*Rangifer tarandus*) by disturbance to feeding activity and an increase in energy-costly behavior (Skjenneberg & Slagsvold 1968; Kelsall 1968; Skoog 1968; Reimers 1980, Folstad et al. 1991; Syroechkovski 1995). Mosquitoes, warble flies (*Hypoderma tarandi*) and nasal bot flies (*Cephenemyia trompe*) hinder *Rangifer* feeding (Zhigunov 1968; Thomson 1971; White et al. 1975) by causing displacement to potentially less productive habitats (White et al. 1975; Walsh et al. 1992; Russell et al. 1993; Witter et al. 2012); i.e. to areas that provide insect-relief, but offer lower quality or quantity of forage. In addition energy costs related to movement as part of the insect avoidance behavior (White et al. 1975, Reimers 1980, Folstad et al. 1991; Russell et al. 1993, Weladji et al. 2003), can result in decreased weight gain through decreased energy and protein balances (Fancy 1986; Russell et al. 1993) and in body weights of calves (Helle and Tarvainen 1984; Weladji et al. 2003). In addition, mosquitoes cause further stress on body condition in summer by blood sucking (Zhigunov 1968) and warble/bot fly larvae complete development in the host before being shed in spring-early summer (Kelsall 1968; Nilssen and Haugerud 1994). This latter cost can stress both fat and protein reserves (Cuyler et al. 2012) and under extreme conditions can cause death of young age cohorts (Davis et al. 1980; Helle 1980; Folstad, et al. 1991). Consequences of harassment can be host-specific, and could differ for adult males, pregnant and non-pregnant females, and calves (Dau 1986; Cuyler et al. 2012; Witter et al. 2012). Females have higher energy requirement due to lactation and foetus development, therefore similar levels of harassment would have differential implications for productivity by males and females.

Whether disturbance behaviors of reindeer and caribou can be initiated and sustained by mosquitoes in the absence of oestrid flies has been cast into doubt by studies that find the contribution of mosquitoes minor compared with other insects (Downes et al. 1986; Mörschel & Klein 1997; Anderson et al. 2001; Hagemoen and Reimers 2002; Witter et al. 2012). There is little doubt the effects of oestrid and black flies either alone or in combination with mosquitoes will cause major effects (Mörschel & Klein 1997; Anderson et al. 2001; Hagemoen and Reimers 2002; Bergerud et al. 2008; Witter et al. 2012), and it may be almost impossible to differentiate the mosquito evoked responses separate from oestrids. However, the abundance of mosquitoes and oestrid flies vary temporally from the post-calving through the summer period (Dau 1986; Bergerud et al. 2008; Witter 2010 reported by Witter et al. 2012), and the general abundance of mosquitoes depends on distributions of breeding habitats (Shone et al. 2006). Incidence and abundance of mosquitoes appear earlier than warble flies and nasal bot flies in tundra habitats at Prudhoe Bay (Dau 1986) and George River (Bergerud et al. 2008) with black flies and warbles appearing around late June to early July (Russell et al. 1993). Early post-calving aggregations of over thousands of animals in maternity groups have been observed (Skoog 1968; Clough et al. 1987) and these and others authors attribute them to an effort to reduce harassment by mosquitoes (Pruitt 1960; Kelsall 1968; Curatolo 1975; Roby 1978; Bergerud et al. 2008). The availability of suitable breeding habitat affects mosquito abundance, with lake basins, low centered polygonal tundra and wet sedge meadows being prime sites (MacLean 1975). In early summer caribou at Prudhoe were observed to avoid sites and microhabitats highest in mosquitoes for feeding (White et al. 1975). Thus, to some extent effects on caribou can be attributed to the distribution of mosquito breeding habitats. Also, years with low precipitation that cause drying of tundra breeding habitats can result in low mosquito numbers (Keskitalo 2008; White & Trudell 1980), while the same drier tundra is ideal for incubation of warble and bot fly pupae (Karter et al. 1992). White et al. (1975), Walsh et al. (1992) and Dau (1986) report significant effects of mosquitoes on activity budgets that support earlier observations (Skoog 1968; Clough et al. 1987). However, Hagemoen and Reimers (2002) and Witter et al. (2012) found responses attributed to mosquitoes to be minimal and they attribute all major adverse responses to warble, bot flies, and black flies. There is little doubt from these studies that the disturbance to grazing behavior and increase in erratic activity represent harassment by warble, bot and black flies. However, we argue that the early post-calving period before these flies become abundant, from late June-early July, is critical to caribou productivity (Griffith et al. 2002; Bergerud et al. 2008), and justifies an evaluation of potential changes in the effects of mosquito activity across the landscape and through time and space.

Insect levels and therefore harassment to *Rangifer* are spatially and temporally dynamic, both within a season and between years (Thomson 1971; Dau 1986; Bergerud et al. 2008; Witter et al. 2012). Prior research has demonstrated that temperature and wind influence the activity of both mosquitos and oestrid flies, with warm and less windy days being more favorable for mosquitoes; the ideal conditions for mosquito harassment are days with temperatures greater than 6 °C and wind speed less than 6 m/s (Thomson 1971; White et al. 1975, Walsh et al. 1992; Russell et al. 1993), while warble flies tolerate wind speeds up to 20 m/s (Saval'ev 1961, Russell et al.1993, Nilssen & Anderson 1995; Mörschel & Klein 1997; Anderson et al. 2001; Hagemoen and Reimers 2002; Witter et al. 2012). Over the last few decades, temperature in the Arctic has increased at almost twice the rate as the global mean (ACIA 2005, IPCC 2007), and spring and summer temperatures have risen in Arctic Alaska (Stafford et al. 2000; Shulski and Wendler 2007). Scenarios for future climate project a continued warming for all of the Arctic (ACIA 2005). A warmer climate could lengthen the temporal window of mosquito activity, depending on wind conditions conducive for mosquito activity, but less so for warble flies. Thus, there is a potential for increased insect harassment for caribou with climate warming. However, warming is not uniform temporally or spatially, hence there is a need for long-term spatially and temporally explicit assessments to understand the magnitude of change and the range of variability over space and time for specific herds, and within the summer habitats of those herds.

Our current knowledge about insect harassment of northern Alaska herds is limited to estimates for the Central Arctic herd (White et al. 1975; Dau 1986) and the Porcupine caribou herd (Russell et al. 1993; Walsh et al. 1992) in certain years, and these estimates have not been generalized to the entire summer ranges of herds. The process of scaling to the summer ranges includes accounting for variance in topography, hydrology and vegetative cover that affect mosquito breeding areas and daily abundance due to microsite conditions for hatching. We propose that summer drought also should result in lower mosquito abundance as breeding sites dry up. In addition, there can be overlap in conditions that favor mosquito and warble/nasal bot fly activity once fly larvae complete incubation on the tundra. Thus, distinguishing between such effects is problematic.

In this study, we developed a model capable of performing a long-term and spatially explicit analysis of the occurrence of the abiotic conditions (*i.e.* temperature and wind velocity) in specific climate zones (Figure 1) that are potentially conducive for mosquito activity in summer (June 1-August 31). Such assessments are often constrained by availability of climate data, but in our case, the availability of long-term, gridded meteorology datasets provide the opportunity to develop a spatial landscape distribution of MAI that could be compared with seasonal distributions for herds. An initial analysis of this modeling approach based on spatial representation within the entire summer ranges of caribou indicated herd differences that warranted a more complete study of the temporal components throughout each year (Bali et al. 2013). From the temporal analysis of MAI for each summer habitat we investigated if there has been a trend towards earlier onset and/ or increase in the length of mosquito-activity season in response to warming summers. These analyses were conducted for the four barren-ground caribou herds in Northern Alaska – Western Arctic Herd (WAH), Teshekpuk Caribou Herd (TCH), Central Arctic Herd (CAH), and Porcupine Caribou Herd (PCH) (Figure 2).

The objectives of this study were to introduce and develop a mosquito activity index for northern Alaska based on summer (June 1-August 31) temperature and wind speed from available spatially distributed products to:

a) Develop a landscape map of potential mosquito activity,
b) Determine what regions of northern Alaska changed in mosquito activity over three decades,
c) Relate landscapes of temperature, wind velocity and mosquito activity indices to summer habitats of the four herds of caribou of arctic Alaska,
d) Determine the seasonal pattern of intensity of mosquito activity for the summer range of each caribou herd,

e) Assess the relative vulnerability of each herd to mosquito harassment, and

f) Test whether the level of mosquito activity index is related to caribou productivity in northern Alaska.

METHODS

Site Description

Climate zones: For description and analysis of climatic data we used climate zones as described by Shulski & Wendler (2007) and Wendler et al. (2010) (Figure 1). The Arctic zone, comprising the elevation divide of the Brooks Range in the south to the Arctic coast to the north, thus encompassing the foothills of the Brooks Range and the North Slope, between the foothills and the coast (Bieniek et al. 2012). The western coastline from Pt. Lay in the north to the Aleutian chain constitutes the Western climate zone and the Interior climatic zone is composed of a region from the Arctic climate Zones southern boundary in the north to the northern slopes of the Alaska Range in the south and west to the delineated Western climate zone. For the Arctic and Interior climate zones the USA-Canada border delineates the eastern extent. Balance of Alaska to the south and east of the Arctic, Western and Interior zones constitutes the South/Southeastern zone. For this analysis, reported climate data are restricted mainly to the Arctic zone with some reference to the Western and Interior zones.

Ranges of the four caribou herds based on shape files: Mosquito activity was analyzed for the summer ranges of four caribou herds included in this study (Figure 2). Calving grounds of the Western Arctic Herd (WAH, Davis et al. 1980; Kelleyhouse 2001), Teshekpuk Caribou Herd (TCH, Kelleyhouse 2001), Central Arctic Herd (CAH, Whitten and Cameron 1985; Fancy and Whitten 1991; Wolfe 2000; Wolfe et al. 2000) and Porcupine Caribou Herd (PCH, Fancy et al. 1992; Whitten et al. 1992; Russell et al. 1993; Whitten 1996; Griffith et al. 2002) in northern Alaska, are mainly within the Arctic climate zone (Figure 2), with the exception of PCH that also calves in the north Yukon Territory, Canada (Fancy et al. 1994). Summer ranges are generally adjacent to calving grounds (Skoog 1968; Lawhead 1988; Pollard et al. 1996; Kelleyhouse 2001). To establish the geographical distributions of summer to winter ranges we obtained shape files for summer and winter ranges of the four herds (Source: CircumArctic *Rangifer* Monitoring and Assessment (CARMA) Network (www.carma.caff.is) (Figure 2). Summer range of the WAH approximates 377,000 km^2 of northwestern Alaska (Dau 2005). TCH occupies approximately 115,000 km^2 of coastal and upland tundra and riparian systems around the north, northeast and south east of Teshekpuk Lake (Kelleyhouse 2001). CAH ranges over 115,000 km^2 between the coastal plains and the foothills of the Brooks Range between the Colville and Sagavanirktok Rivers, but can extend further east (Cameron and Whitten 1980; Cameron et al. 2005). Summer ranges of the PCH are generally east of the Canning River in Alaska and northeast regions of the Yukon Territory around the Richardson Mountains; an area of approximately 72,000 km^2 (CARMA Network; www.carma.caff.is). The spatial patterns of seasonal range use for each herd vary among years in response to various factors, including forage availability, insect harassment, and areas of recent wildfire (Joly et al. 2009; 2010).

Seasonal use of ranges: Caribou of these herds generally calve during the first weeks of June (Cameron et al. 1980; Davis et al. 1980; Russell et al. 1993; Kelleyhouse 2001; Eastland & White 1990; Griffith et al. 2002). By mid-June cows and calves move to adjacent summer ranges where they spend July to August before drifting slowly towards wintering ranges. Rut occurs in generally open terrain in mid October. Usually after a heavy snowfall, cows and bulls make more directed migration to wintering grounds, south of the summer ranges (Figure 2). Previous studies demonstrated that mosquitoes in northern Alaska usually emerge around mid to late June and when mosquito activity intensifies, caribou can form large aggregations and move to insect relief areas that may be along the coast, and on ridges and hills that are exposed to high wind (White et al. 1975; Roby 1978; Dau 1986; Russell et al. 1993). Following a period of warm weather that enhances development of pupae, warble and bot flies add to the disturbance by mosquitoes by early July. By early to mid August, a few days of temperatures below freezing marks the end of the mosquito and oestrid fly season (White et al. 1975; Russell et al. 1993).

***Population trends*:** Population sizes were obtained from the CARMA website (www.carma.caff.is) and trends through the period 1975 to 2015 are shown in Figure 3. Overall the WAH with a maximum size of 490,000 (2003) and PCH with 197,000 (2013) were usually over three times greater than the TCH at 64,000 (2008) and CAH at 70,000 (2010). Between 1992 and 2011 the total population for all four herds was constant at approximately 656,000. A common trend in all four herds was a general linear increase from 1975 through the 1980s. Relative growth rates during this period were higher for the CAH (19.1%/y) and WAH (13.7 %/y), than for the TCH (7.7 %/y) and PCH (4.7 %/y).

***Data acquisition*:** We downloaded NARR data (Mesinger et al. 2006) from the NOAA-Earth System Research Laboratory website (URL: http://www.esrl.noaa.gov/psd/data/gridded/data.narr.html). We extracted a spatial subset of two variables, surface air temperature and wind speed, for the study area encompassing summer ranges of the four focal herds (Latitude: 55 to 72 N; Longitude: 170 to 130 W) and converted the data from NetCDF to binary format and the projection system to lat-long grids. We obtained shape files for summer ranges of the four herds, which were interpolated on to the NARR long-lat grid and converted into binary masks that were used to delineate grid-points within each summer range (Figure 2).

Estimation of a Mosquito Activity Index (MAI): Following Russell et al. (1993), we quantified "Mosquito Activity Index (MAI)" based on temperature and wind velocity to determine a temperature index, and a wind index (Figure 4) for each time step (8 times per day) for the duration of potential mosquito activity season, defined as 1 June to 31 August (Table 1). We assumed incidence/activity of mosquitos' increased linearly between 6° and 18° C, and that an increase in wind velocity between 0 and 6 m/s resulted in a decrease in incidence/activity of mosquitoes. No incidence of mosquitos' was assumed at temperatures less than 6°C and wind velocities greater than 6 m/s. One hundred random locations within the summer ranges were averaged for temperature; wind velocity and MAI to compute mean annual summer temperatures, wind velocity and MAI for each focal herd.

Analysis

Calculation of summer temperature, wind velocity and MAI: We calculated mean temperature, wind velocity and MAI for each year and for each herd.

Spatio-temporal analyses and development of an MAI landscape: We performed a spatial analysis based on the 31-y MAI for each grid cell of northern Alaska. NARR grid size is approximately 32 km. The MAI landscape covered three climatic zones of Alaska, primarily the Arctic with a portion of the Western zone and a part of the Interior zone.

Trends in landscape MAI over 31-y: We determined the change in MAI over 31 years based on a difference in mean MAIs for 1979 and 2009 for each grid cell.

Annual pattern in abiotic drivers and of the MAI: To discern and compare short-term trends and possible cyclical events between herds for each variable (temperature, wind, MAI), each annual variable was expressed as an anomaly of the 31-y mean for each herd. Anomalies were plotted against year and common and contrasting trends described. In addition a two-y running mean of each anomaly was computed to further describe between herd differences with respect to amplitude of each variable anomaly in the 31-y temporal pattern.

a) Temperature, wind velocity, MAI: To determine the probability that temporal patterns of abiotic drivers (temperature, wind velocity) and the resultant MAI have increased in the 31-y period, we computed two expressions of temporal trends: a) decadal means, and b) scatter plots of annual means. Scatterplots were examined to determine years of highest and lowest temperature, wind velocity and MAI. To discern and compare short-term trends and possible cyclical events between herds for each variable (temperature, wind, MAI), each annual variable was expressed as an anomaly of the 31-y mean for each herd. Anomalies were plotted against year and common and contrasting trends described. In addition a 2 or 3-y running mean of each anomaly was computed to further describe between herd differences with respect to amplitude of each variable anomaly in the 31-y temporal pattern.

b) Contribution of temperature and wind velocity to variance in MAI: We determined relative contributions made by mean annual temperature and mean annual wind velocity to the separately estimated mean annual MAI. We regressed mean MAI on mean temperature and mean wind velocity to determine separate R^2. We then determined the contribution of variable with the lowest R^2 to the unaccounted for variance of that with the highest R^2 to determine the contribution of each variable to mean annual MAI.

c) Determination of decadal and episodic changes in temperature, wind velocity and MAI: To determine the probability that temporal patterns of abiotic drivers (temperature, wind velocity) and the resultant MAI have increased in the 31-y period, we computed two expressions of temporal trends:

i) Decadal means, and

ii) Scatter plots of annual means. Scatterplots were examined to determine years of highest and lowest temperature, wind velocity and MAI.

***Seasonal patterns of MAI: determination and visualization of distributions of seasonal MAI intensity among years*:** To visualize seasonal patterns in mosquito intensity throughout the 31-y period for each summer range, we expressed MAI level (0-1) as a color scheme of purple (0), blue (0-0.2), green (0.2-0.4), light green (0.4-0.5), yellow (0.5-0.6), light orange (0.6-0.7), orange (0.7-0.8) and increasing intensity of red (0.8-1.0). Mean daily intensity for the summer range was then plotted through the 92 d season (1 June-31 August) from 1979 to 2009. Objectives of this analysis include:

a) Description of trends in duration of insect season based on first and last appearance of significant MAI (>0.2, green) each year, and

b) Identification of periods when MAI indicated severe (0.6-0.8, orange intensities) or extreme (>0.8, red intensities) MAI intensity.

Documenting long-term trends in seasonal MAI intensity: We determined landscapes that represented regional trends in MAI over the 31-y study period. For each spatial unit we calculated MAI 2009 – MAI 1979. Thus, this landscape showed regions of no change in MAI, those of decreasing trend (0 - -0.05 and -0.05 - -0.01) and those of increasing trend (0 – 0.05, 0.05 – 0.1, 0.1 – 0.15and 0.15 – 0.2).

Statistical Analyses

We calculated MAI, temperature and wind velocity as summer means, and SD, for each herd summer range and in each year between 1979 and 2009 (Microsoft Excel:mac^{2011} 14.6.1). To test for trends over the 31-y period we determined by linear and polynomial fits (Excel's built in least squares facility, de Levie 2004) to this data set. We determined degree synchrony in MAI between herds, and between the drivers of MAI (temperature and wind velocity) by regressing mean anomalies of MAI on year. We estimate anomalies in MAI, temperature and wind velocity as the difference (residual) between the observed annual mean MAI, temperature or wind velocity minus the equivalent yearly mean MAI, temperature or wind velocity. To test for relations between temperature and wind in each herd, we regressed mean summer temperature on mean wind velocity. To determine the relative contribution of temperature and wind velocity to MAI, we regressed MAI on temperature and wind velocity and determined variance accounted-for (significance of R^2) by each variable. We visually interpreted spatial distributions in MAI intensity classes across landscapes and regions. To determined trends in MAI intensity classes across northern Alaska though the 31-y study we compared intensity distributions in 1979 with 2009 by visual assessment. Likewise, we used visual assessment to interpret seasonal and annual changes in MAI intensity (color coded) on summer range for each year and for each caribou herd.

RESULTS

Annual mean temperature, wind velocity and MAI

For the period 1979 to 2009, mean (SD) seasonal temperature (°C) was 8.8 (1.5) with highest observed for WAH at 9.5 (1.2) closely followed by CAH at 9.4 (1.6), PCH at 9.1 (1.3), and was lowest was for TCH at 7.3 (1.0) (Table 2). Mean (SD) seasonal wind velocity (m/s) over all four ranges for 31 years was 3.8 (0.3) with higher for the TCH at 4.0 (0.3) and WAH at 4.0 (0.2), compared to CAH at 3.5 (0.2) and PCH at 3.6 (0.2). For the 31-year period mean (SD) MAI was similar for WAH, CAH and PCH at 0.31(0.06), 0.32 (0.08), and 0.31(0.06), respectively. In comparison the 31-y seasonal MAI for TCH was lower at 0.21 (0.05) (Table 2).

Landscape description of mean MAI

For northern Alaska, the lowest mean MAI (0-0.1) during the study period was associated with a coastal band of tundra from Pt. Hope in the west to the far eastern portion of our study area (Figure 5a). This coastal band was 2-10 km deep but extended half way to Anaktuvuk Pass, approximately 60 km south along the Sagavanirktok River drainage. Another region of low MAI (0-0.1) was located NE of Anaktuvuk Pass and consisted of upland and alpine tundra within northern foothills of the Brooks Range. This N-E region was surrounded by a major intrusion of higher MAI (0.1-0.3) that encompassed Anaktuvuk Pass and S-E through the Brooks Range. Inland from the coastal band the landscapes were a variable wide band of inland coastal tundra typified by a doubling in MAI (0.1-0.3). This band extended almost to Old Crow, Yukon in the east, but was typically a narrower band in the west from Barrow to Pt. Hope. The major MAI of the Arctic climatological region as shown in Figure 1 was for MAI of 0.3-0.4.

South of the Brooks Range in the Interior climatological region, southern foothills were composed of MAI 0.3-0.4, but otherwise MAI's were higher at 0.4-0.5. At lower elevations in the Yukon River boreal forests MAI exceeded 0.5.

Superimposing summer ranges of the herds (Figure 2) on the MAI landscape (Figure 5a), yielded variable distributions of MAI for summer ranges of each herd. MAIs of 0.3-0.4 typified 61% WAH, whereas 50% and 70% of TCH and CAH respectively were MAI of 0-0.1, and for WAH 75% of the summer range was typified by a MAI of 0.1-0.3 (Table 3). Landscapes with lowest MAI (0-0.1) made up 70% of the summer range of CAH, 50% of TCH, 20% of PCH and 5% of WAH. This landscape reflected the contribution that coastal habitats make to summer ranges of the herds.

Change in landscape MAI over 31 years

For most of the North Slope of Alaska, within the Arctic climatological region (Figure 1), we found no significant change in MAI over 31 years (see blank regions of Figure 5b). We document declining trends in MAI west of Anaktuvuk Pass to within the coastal region of Pt. Hope (Figure 5b). This landscape of declining MAI represents a major portion of the WAH summer range (Figure 2). Cooling trends further south in the Western climatological zone (Figure 1) are outside the normal WAH summer range and represent a major proportion of the winter range of this herd (Figure 2). We noted a small increasing trend in the MAI landscape west of Barrow to Kaktovik along the coastal fringe (Figure 5b). This landscape represented much of the summer range of the TCH, a major proportion of the CAH, and a very small proportion of that for the PCH (Figure 2). A major increase in MAI was apparent south of the Brooks Range in a region of the Interior climatological zone extending from south of Coldfoot, continuing N-E through the Brooks Range to Old Crow (Figure 5b). The northern part of this increasing landscape trend constituted the southern reaches of the PCH summer range (Figure 2).

Temporal trends

The highest variability in mean summer temperatures for all 31 years was for the CAH (12.9-6.1 = 6.3) with lower range for PCH (11.5-7.0 = 4.5) and WAH (12.1-7.9 = 4.2) and the least range (9.5-6.0 = 3.5) was for TCH (Figure 6a). The years 1998 and 2007 were the warmest for all four herds and 1989 for TCH, CAH and PCH. Two years were the coldest for all herds, namely1996 and 2008. Summer of 1991 was also cold for TCH, CAH and PCH summer ranges (Figure 6a) Regression of mean temperature (T ^{o}C) on date indicated no relation except for the CAH (Figure 6a, $R^2 = 0.154$, $P < 0.05$, $n = 31$), with a notable increase between 1980 and 1990. A third order polynomial fit to the data indicated that a general warming trend occurred in the 1980s, generally remaining warm in the 1990s declining in the late 1990s and early 2000s before increasing again in the mid 2000s .

There was almost no difference in the range of wind speed over 31 years (Table 2) with a ranking of highest for TCH (4.5-3.5 = 1.0) with CAH (4.0-3.1 = 0.9), PCH (4.0-3.1 = 0.9) and WAH (4.6-3.8 = 0.8). Regression of wind velocity on date indicated no linear change for the summer ranges of TCH and CAH, however wind velocity declined significantly for the WAH ($P<0.02$) and PCH ($P<0.02$) summer ranges (Figure 6b). The third order polynomial fit to the wind velocity versus date (Figure 6b) indicated no general trends. High wind velocity was indicated for 1987, while lowest velocities were indicated for 1995 for all but the PCH.

Annual patterns of MAI (Figure 6c) were virtually identical to those described for temperature showing similar decadal patterns, significant overall increase in MAI for the CAH and increasing mosquito index in the 1980s declining in the 1990s and increasing again in the 2000s. This pattern is most pronounced in the WAH (Figure 6c).

To visualize trends among herds better we calculated standardized anomalies with respect to the mean MAI, temperature (°C) and wind velocity of each herd and plotted the anomalies on a 3-year running average (Figure 7a-7c, respectively). Patterns were very similar for MAI and temperature, consistent with the analysis in Figure 6). Anomalies for MAI (Figure 7a) and temperature (Figure 7b) were increasing between years 1982 and 1992 and remained high through the 1990s, followed by an abrupt decline in the early 2000s before recovering to above normal by the mid 2000s. Although variability was noted, overall trends were similar among herds.

The 3-year running average anomaly for wind (Figure 7c) was less consistent among herds and the patterns differed dramatically from the temperature and MAI. The 1980s were characterized by generally high winds declining to a low by the mid 1990s, increasing to the early 2000s. Winds generally remained above average in the 2000s for the TCH and the CAH but declining later in the 1990s for the PCH and WAH. Although wind velocity anomalies appeared to show strong patterns, the absolute differences among herds and decades were not that great as we have seen in Figure 6b.

Although we could find no correlation between temperature and windiness, either within years or within the four summer ranges, a plot of temperature versus wind indicated that the summer range of TCH was cooler and windier than that of WAH, CAH and PCH (Figure 8).

Contribution of temperature and wind velocity to variance in MAI: MAI was more highly correlated with mean annual summer temperature (R^2, 0.88-0.95, Table 4) than was wind velocity (R^2: WAH 0.43, TCH 0.41, CAH 0.39, PCH 0.19). Thus although wind velocity accounted for 19% to 43% of the unexplained variance in MAI versus temperature (Table 4), it accounted for less than 3% of variance in

MAI (R^2, 0.02-0.23, Table 4). Contribution of wind velocity to annual MAI was highest for TCH (4.9%) and WAH (4.0%) than for CAH (2.0%) and PCH (1.5%) (Table 4).

Spatial trends

Decadal changes in temperature, wind velocity and MAI: For each herd the 1990-decade was the warmest by almost 1°C with means (±SD) at 9.4 (±1.2) compared with the 1980s at 8.4 (±1.1) and 2000s at 8.5 (±1.2). We estimated no trend in decadal wind speed (m/s) with mean (±SD) 3.87 (±0.21) in the 1980s, 3.71 (±0.23) in the 1990s and 3.82 (±0.23) in the 2000s. Decadal trends in MAI indicate highest values in the 1990s compared with the 1980s and 2000s.

Spatial dynamics of MAI intensity among years: Figure 9 shows the seasonal (x-axis in days from June 1) timing of MAI through the 31-y record (y-axis by year). Grades of MAI intensity (0-1.0) as color-coding showed seasonal progression of MAI for each year by each herd summer range (Figure 9). Thus we could identify the start and end of the MAI season and identify periods of low to absence MAI. By viewing seasonal date through year we determined longer-term changes in MAI intensity. The start and end dates of MAI gave a measure of the potential duration of the mosquito harassment season and also changes in duration over time. When a particular season is shown to express high to severe MAI over a series of years, higher intensity of yellow to red (Figure 9), we termed such a season by year interaction as a "hot spot" of seasonal MAI.

Trends in initiation and end of mosquito season: Visual examination for initiation and end of the insect season based on MAI in excess of 0.2 (green, Figure 9) indicates almost no trend through the 31-y study for WAH with initiation on approximately day 10 (10 Jun) and end of season on about day 75 (20 August) with an extension by 5 d in 2004-2006. For TCH and CAH the insect seasons were very mild between 1979 and 1986. Initiation of the insect season for both herds occurred on approximately day 20 (20 June) and became earlier until 1996 when insects could be expected on 1 June in years 1996, 2000 and 2004. End of season tended to increase from day 75 (20 August) to day 90 from 1997 to 2007. For PCH the mosquito season was initiated early (approximately day 2 in 10 of 31 years), it tended to increase in severity with time. End of the mosquito season (days 75-85) showed no major trend with year of study, but in 5 years (1979, 1989, 1993, 1998, 2006) the season ended with several days of severe to extreme insect activity as predicted from MAI (Figure 9).

Relations between population trends and MAI

All four herds experienced a population increase between 1975 and 1990. Following 1990, population trend for the PCH was negative while those for the WAH, TCH and CAH were increasing until 2001 for the WAH and about 2007-2008 for the TCH and CAH (Figure 3a,b). For all four herds the years from

1992-1996 experienced reduced productivity, characterized by 1) a reduced rate of increase (WAH; Figure 3a), 2) stabilizing to slightly declining trends (CAH and TCH; Figure 3b) and 3) continued decline (PCH; Figure 3a). After 1996 the TCH and CAH again retuned to higher growth rates, while the WAH and PCH continued to show low growth rates (WAH or continued decline (PCH). Based on these trends and, if we assume a two year lag between environmental events and herd productivity (Russell and White 2000), we compare mean MAI anomalies for: 1) 1985-1989, when all herds were increasing, 2) 1990-1994, a period of reduced productivity in all herds, 3) 1995-1999, continued reduced productivity for the PCH and WAH and higher productivity for the TCH and the CAH and 4) 2002-2006 when the WAH peaked and started to decline, rapid increase in TCH and CAH and recovery for the PCH (Figure 10).

Between 1985-1989 when herds were increasing (although the PCH was peaking), average MAI was essentially average for the 31-y data record (mean MAI anomaly for all herds = 0.0). When all herds were experiencing reduced productivity, 1990-1994, mean MAI anomaly increased to 0.58 with the PCH experiencing the highest (0.67) and WAH the lowest (0.44). For the period 1995-1999, average MAI anomaly dropped to 0.34 with the most dramatic drop for the WAH (from 0.44 to 0.03 between periods). In the 2002-2006 period all herds experienced the lowest MAI with the least change in the WAH (.03 to 0.02) and the PCH experienced the greatest drop in MAI (0.40 to -0.45).

DISCUSSION

In this paper we demonstrate that long-term meteorology data have potential applications for ecological studies. Availability of reanalysis datasets developed by atmospheric scientists provides the opportunity for researchers in other fields to fill weather and climate data gaps for studies that focus on effects on climate change. One application of these datasets is the development of spatial and temporal models of mosquito activity as driven by the abiotic drivers of mosquito abundance.

The MAI landscape of northern Alaska

The MAI landscape we developed for northern Alaska confirms that the potential abundance of mosquitoes is likely lower north and west of the Brooks Range within the Arctic and Western climate zones than the interior (Figure 5a). Highest potential MAI are restricted to the Interior climate zone. Within the Interior zone lowest MAI (0.3-0.4) were associated with higher alpine elevations that could provide caribou relief from harassment by mosquitoes. This landscape distribution depends on the formula used to estimate MAI from temperature and wind velocity. The formula (Russell et al. 1993; Table 1) has not been verified for the Alaska interior, but given that Hagemoen and Reimers (2002) and Weladji et al. (2003) have developed closely similar models that they evaluated on alpine ranges in

Norway, the model we used should be applicable to northern Alaska. The landscape analysis shows MAI was lowest (0-0.1) on coastal ranges, and could be interpreted as providing maximum relief from mosquito harassment in Arctic Alaska. The 31-y trend in landscape MAI (0.071°C per y; approx. 2°C, Figure 5b) is supported by data for the 1977-2014 period when summer temperature increased by +2.5 °C at Barrow and by a 25% increase at Prudhoe Bay over a similar time period (Raynolds et al. 2014).

Determination of mosquito abundance, abiotic drivers and harassment effects

Mosquito activity is known to be highly variable within a season as documented in the early 1970s and early 1980s for CAH caribou at Prudhoe Bay (White et al. 1975; Dau 1986) and PCH caribou in the mid-1980s in an area of north Yukon Territory adjacent to the USA-Canada border (Nixon 1990; Russell et al. 1993). Measurements of mosquito effects differed in analysis techniques from the early CAH studies (White et al. 1975) and those that followed. Mosquito effects were based on animal behavioral responses as they attempted to get a blood meal (White et al. 1975; Gaare and Skogland 1971; Thomson 1971), whereas research conducted after this time was based on mosquito abundance as assessed by using a sweep net (Dau 1986; Russell et al. 1993) and animal responses based on abiotic conditions that favored mosquito abundance. Well documented responses of reindeer (Skjenneberg and Slagsvold 1968; Baskin 1970) and caribou (Kelsall 1968) to mosquitoes can be quantified through measurement of activity budgets that document time spent in energy costly activities such as standing, walking and running compared with lying (Gaare et al. 1975; Thomson 1971; Gaare & Skogland 1975; White et al. 1975; Russell et al. 1993). Activity scaling was allocated to none, mild and severe levels of insect harassment by White et al. (1975) and these quantitative measures were similar for reindeer in alpine tundra (Gaare et al. 1975) and caribou in coastal tundra ranges (White et al. 1975). Although for these and other studies (Bergerud et al. 2008) mosquito abundance was assessed by landings per 30 s on an observers' arm, only the observations of Bergerud et al. (2008) quantified mosquito activity. Russell et al. (1993) deduce good agreement between abundance from sweep net measurement and activity budgets for the PCH in the mid-1980s. For the "severe" scaling reported by White et al. (1975), both mosquito and warble flies presented the combined harassment effects, similar to that reported by Gaare et al. (1975), Russell et al. (1993), Hagemoen and Reimers (2002), and Bergerud et al. (2008).

The formula used to derive MAI (Table 1; Russell et al. 1993) was based on short-term and instantaneous observations of the effects of temperature and wind velocity. We assume the same relations for predictions made from grid cells of abiotic data obtained by extrapolations of weather data (Russell et al. 2013). The NARR dataset uses very high resolution "NCEP Eta Model" together with the Regional Data Assimilation System, which significantly improves assimilation of precipitation and other variables. It is significantly superior to previous global re-analyses, mainly due to additional and updated input data, incorporation of the regional model, and advances in modeling and data assimilation techniques since 1995 (Mesinger et al. 2004). Because the observed data are not available at equal distance, points on an equi-distance grid are systematically interpolated using statistical functions in the process of reanalysis. Thus, the interpolation procedure results in less certainty in regions of less data. For instance, in data-poor regions such as the arctic, reanalysis data are more dependent upon the model structure, assumptions, and data assimilation methods than in data-rich regions (Lindsay et al. 2014). Different climate datasets have different spatial resolutions ranging from few kilometers to few hundred kilometers. NARR is relatively a high-resolution dataset with approx. 32 km spatial grid size. However this 32-km resolution does not resolve complex Alaskan topography. It is possible to further downscale the models and get a further refined spatial representation of climate, but we are not aware of downscaled datasets with hourly temporal- and a 2-3 kilometer horizontal resolution. With this limitation recognized, we proceeded with the grid analysis assuming predictions of temperature will be better than wind.

Abiotic drivers of MAI

Limitation on our analyses due to estimates of wind velocity are not only due to assessment of wind velocity based on limited monitoring weather stations and projection algorithms, but also on the nature of wind patterns. Wind velocity is highly variable throughout the day (Figure 4). By using daily mean wind velocity (Table 2) we could not detect the effect of high velocity (> 6 m/s) that restricts mosquito flight during the day. Therefore, such daily patterns will not be detected and the effect of high wind in eliminating mosquito abundance as a contribution to MAI is underestimated. For instance, in no year in this 31-y analysis did the mean annual wind velocity exceed 4.6 m/s (Table 2). The mean annual MAI was based on seasonal patterns of MAI intensity (Figure 10). Thus, although the analysis of contribution of wind accounts for less than 4% of the variance in MAI based on an analysis of mean annual data sets (Table 4), the velocity used for seasonal analysis could be greater as it is based on daily means. The mean annual MAI shown in Table 2 is based on summation of daily MAI intensity and reflects the daily mean temperature and wind velocity. When mean annual MAI is calculated from the mean annual temperatures and wind velocities reported in Table 2, we underestimated mean annual MAIs reported in Table 2 by approximately 40%.

Temporal trends in abiotic drivers and MAI

Annual mean temperature for Alaska region has increased by approximately 1.9°C over last half century (Wendler et al. 2010). This trend could continue in Alaska because future global climate scenarios point towards a continued summer warming in the arctic region (ACIA 2005). However, Shulski and Wendler (2007) report that this increase has not been linear and the net change as well as range of variability in temperature is smallest for summer among all seasons.

Analysis of linear trends in annual temperatures of summer ranges indicated that only the CAH increased significantly ($P < 0.05$) over 31 years (Figure 6a). Our findings for the CAH summer range of an increase in temperature between 1979 and 2009 ($0.071°C.y^{-1}$, Figure 6a) is in agreement with a 26% increase in the Summer Warmth Index (SWI, annual sum of monthly mean temperatures above freezing) for the local Prudhoe Bay and Deadhorse weather stations reported by Raynolds et al. (2014). In addition, extreme high SWI reported by Raynolds et al. (2014) for 1989 and 1998, are confirmed for the CAH annual data (Table 2, Figure 6a) and in a plot of anomalies in annual temperature (Figure 7b).

Large-scale atmospheric patterns are an important driver of both temperature and wind and therefore summer ranges of arctic Alaska. Alexeev et al. (2015) show a possible association with pressure systems over the Beaufort and Chukchi Seas that can result in temperature differentials over land. They report that a low-pressure system in 1996 resulted in low temperatures. In agreement, mean annual temperatures (Table 2), plots of temperatures (Figure 6a) and temperature anomalies (Figure 7b) for summer ranges of all four herds were low in 1996; the most extreme anomaly was noted for the WAH (Figure 6a). This event occurred during a period of decrease in wind anomalies and the most extreme reduction was for TCH. Thus, for 1996 mean annual MAIs for summer ranges of from less than 0.2 for TCH to less than 0.25 for the other herd ranges suggest that mosquitoes may have been of low abundance under these low-pressure conditions. In spatial plots of seasonal MAI phenology (Figure 9), daily MAIs were almost consistently <0.7 in 1996 with only the summer range of the PCH experienced daily MAIs in excess of 0.7 and then on two brief periods starting on days 35 and 45.

In contrasting pressure differences, hot and dry conditions result when a high-pressure system dominates circulation differences in large-scale patterns (Alexeev et al. 2015). Summer of 2007 was hot and dry and tundra fire resulted from a lightning strike in the upland tundra south of the Brooks Range (Jones et al. 2009; Alexeev et al. 2015). Although the fire was in the summer range of the CAH, all four herds registered an increase in annual summer temperature in 2007 with WAH, CAH and PCH temperatures in excess of 11°C while that for the TCH was almost unaffected at 7.9°C (Table 2). Although predicted annual MAI exceeded 0.4 for the WAH, CAH and PCH (Table 2), low precipitation likely resulted in drought conditions. The seasonal MAI phenology plots (Figure 9) indicated that 2007 was characterized by "hot spots" of MAI in excess of 0.7 as early as 1 June, at the start of the calving period, for the WAH, CAH and PCH. Although daily MAI was generally lower at this time for the TCH, it was unusually high at 0.4-0.6 until 20 June in 2007. Daily MAI indices indicate levels of activity and harassment by mosquitoes might have occurred during the calving period. This is an extremely rare event and to our knowledge not previously reported for arctic Alaska. Although warmer weather results in increased mosquito abundance, if it is accompanied by a lack of precipitation a drought condition may result and mosquito abundance may be low to completely absent. Drought conditions lower mosquito abundance after the spring flush due to water loss from wet sedge meadows, ponds and other habitats that are suitable for mosquito breeding. In one example experienced by co-author RGW for the summer range of the WAH in 1975, mosquito abundance was zero following the spring flush around Atqasuk, approximately100km south of Barrow (Haugen and Brown 1980; White and Trudell 1980). Although mosquitoes were absent for most of that summer, high temperatures and dry tundra substrate were ideal for warble fly pupation. Thus, a shortcoming of our study is that we have not modeled the effects of drought for these four summer ranges, and this limits our full assessment of the effects of both mosquito and warble fly abundance.

As opposed to temperature projections, wind velocity versus time series have been subjected to far fewer trend analyses and projections (Breslow and Sailor 2002, review by Pryor and Barthelmie 2010). Some available models predict reduction in wind speeds for the conterminous United States in response to global climate change, but these models exclude the Alaska region (Breslow and Sailor 2002, Logan et al. 2003). In our summer range analyses of wind (Figure 6b) we document a significant (7.5%) reduction in velocity for the WAH ($P<0.02$) and PCH ($P<0.02$) over 31 years.

Climate change and MAI

Climate projections indicate a small increase in spring temperature and precipitation and to an earlier spring snowmelt-off and earlier onset of the growing season (ACIA 2005). Such an effect is reported for the calving grounds and early summer of the PCH (Eastland and White 1990; Gunn and Skogland 1997; Griffith et al. 2002). Warmer temperatures in spring also may provide for early mosquito hatching habitats. Our mosquito phenology analysis allows us to determine if there is evidence of an earlier onset of the mosquito season (Figure 9). Using the intensity of MAI of 0.6-0.9 as indicative of initiation, no conditions existed until 1996, but in years 1999, 2004 and 2007, the potential mosquito MAI was recorded as early as June 1 for the WAH, CAH and PCH. These dates have significance because mosquitoes could possibly have been present at calving. In these years early initial MAI were associated with high mean annual MAI (Table 2) and high mean annual temperatures in 1999 and 2007, but not for 2004 (Table 2; Figure 6a).

The same criteria (daily MAI > 0.6) used to estimate end of the mosquito season indicates considerable between year differences. However, 1979, 1989, 1993, 1997, 2005 2006, 2007 and 2009 appear to be years when the index exceeded 0.6 after day 70 (9 August) for all herds. This suggests that the period of freezing days that kill mosquitoes has become later with time. The general trend to later warming and seasonally longer MAI is shown by the right hand dotted white line in Figure 9. Visually "hot spots" were increasing in about day 40 (10 July) before 1990 expanding to days 60-70 (1-9 August) by 2009. An exception was for PCH when end of season "hot spots" developed from the mid-1980s (Figure 9). In intervening years initiation of mosquito abundance was highly variable. In accordance with the TCH being exposed to lower temperatures and higher wind velocity on its summer ranges, the TCH received almost no mosquito harassment in 13 of 31-y if we assume a mean annual MAI needs to exceed 0.2 (Table 2). For 12 of the 18 years that annual MAI exceeded 0.2, we observed distributed "hot spots" (daily MAI > 0.6) during those years (Figure 9).

The frequency of high MAI intensity making up the "hot spots" in Figure 9 should correspond with the annual MAI (Table 2). For the WAH, four years were associated with annual MAI greater than 0.35 (1979, 1993, 1997, 2005). For the CAH five years were likewise associated (1979, 1989, 1993, 1997, 2006), but for the PCH only three years (1979, 1989, 1993) were associated with an annual mean MAI >0.35. For the TCH, although average annual MAI was low (Table 2; Figure 6), those years when MAI was >0.25 were associated with high late season daily MAIs (1979, 1989 and 1993). In only 1979, 1989 and 1993 were late season high MAI associated with high annual MAI (> 0.35) for the CAH and PCH (Table 2; Figure 6).

Vulnerability of herds to mosquito harassment

We anticipated that vulnerability of a herd to potential harassment by mosquitoes could be assessed from the distribution of MAI intensities by overlaying summer range shape file on the MAI landscape. However, assessment of potential vulnerability was more complex than what could be deduced from spatial dynamics alone. Summer ranges of WAH and PCH occupy larger areas than the TCH and CAH, and therefore the distribution of MAI intensity is wider (Table 3). Although this is an advantage for herds of high population size, such as the WAH and PCH (Figure 2), by allowing access to highly varied landscapes (see Russell et al. 1993; Griffith et al. 2002) the MAI landscape suggests that only 7% of the WAH landscape is of MAI less than 0.2. In contrast, the two smaller herds (TCH and CAH) have a lower potential vulnerability to mosquitoes because 50-75% of summer ranges are composed of zones of very low MAI (<0.2). Thus, a ranking of the vulnerability to mosquito harassment would be TCH and CAH low, PCH medium-high and WAH very high. Verification of the efficacy of basing vulnerability on the MAI landscape should be subjected to temporal trends based on landscape change in MAI (Figure 5b) and be supported by the 31-year mean and MAI (Table 2), the temporal analysis (Figure 6c) and the seasonal MAI phenological trends (Figure 9). For only the WAH was summer range MAI decreasing (0 to – 0.1), while those for the TCH and CAH showed moderate increase (MAI 0 to +0.1) and the PCH summer range exhibited highly variable change (MAI 0 to +0.2) depending on location (Figure 5b). These landscape-based trends suggest that mosquito harassment conditions on WAH summer range should be improving, while that for the TCH should be increasing. Thus, combining the landscape analyses minimizes the strength of vulnerability rankings between the herds. Analysis of the mean and MAI supports the landscape assessment that TCH is least vulnerable (mean MAI 0.2, MAI 6.4), however there is no clear ranking for CAH, WAH and PCH (mean MAI 0.3, MAI 9.5-10). Temporal trends in annual mean MAI of summer ranges indicates a significant linear increase ($P < 0.05$) for CAH, whereas the expected decrease for the WAH was not supported by the annual trend analysis (Figure 6c). A visual assessment of vulnerability based on seasonal phenology of MAI (Figure 9) can be made from the preponderance of "hot spots" (WAH = CAH > PCH > TCH) and blue to purple indications of low MAI (TCH > PCH = CAH = WAH). Summing these assessments generally supports the landscape vulnerability of WAH > PCH > CAH = TCH compared with WAH > PCH = CAH > TCH based on temporal analyses. But in what way do rankings in vulnerability based on the landscape and temporal analyses relate to population changes?

Linking level of mosquito harassment to animal and population responses

Based on the increase in energy expenditure as determined from behavioral responses and activity budgets (White et al. 1975; Fancy 1986; Russell et al. 1993) and movement from preferred feeding sites to sites of lower mosquito abundance that are often of lower nutrient quality (White et al. 1975; Russell et al. 1993; Witter et al. 2012) simulation of caribou productivity indicate a decline due to negative energy and protein balance (Fancy 1986; Russell et al. 1993) associated with mosquito harassment. Helle and Tavanainen (1984) attribute yearly trends in low calf body weight to the abundance of insects, including mosquitoes. Some effects of mosquitoes have been attributed to a decrease in distance between individuals of a group that disturbs grazing behavior (Helle and Aspi 1983) as animals aggregate in response to mosquito abundance (Roby 1978) and animals minimize mosquito attack by moving to the center of a group (Nixon 1990). Such observations are interpreted as increasing competition for forage as well as taking time from foraging (Roby 1978; Helle and Aspi 1983; Russell et al. 1993). Thus, we suggest the possibility that a series of years of high mosquito abundance could have an effect on individual productivity, which when integrated could affect herd productivity. When combined with other drivers of herd productivity such as abundance of biting flies, parasite infestation (Gunn and Irvine 2003; Cuyler et al. 2012; Kutz et al. 2013), range nutritional condition (Griffith et al. 2002), winter conditions that cause changes in maternal body condition entering spring (Adams and Dale 1998; Chen et al. 2012) and predation, harassment becomes an additive component of cumulative effects that drive population change (Orians et al. 2003; Gunn et al. 2011; 2013; White et al. 2015).

As discussed in the introduction, many factors contribute in a complex and interacting way to drive population trends in caribou herds; we have only examined one of those factors, mosquito activity index. However we note that although mosquito abundance is a single factor, drivers of population change are not independent of each other. One clear association to mosquito index is summer temperature, which when combined with precipitation rather than wind, is a measure of drought. Summer drought in turn has significant impacts of the timing, abundance and quality of forage. Thus in interpreting the results of our analysis of MAI anomalies with respect to population productivity (Figure10), we need to consider the possibility that bad insect years are also associated with bad drought years for those years with reduced precipitation. Further, populations go through periods of abundance and scarcity with a periodicity of 40-60 years (Gunn 2003) and thus environmental factors, although playing a key role in population dynamics, through buffering mechanisms, do not necessarily track the highly variable environmental indicators (Caughley and Gunn 1993). Even considering those cautions, our analysis indicates that there appeared to be an association between the herd productivity and average MAI anomaly. All herds were increasing in the late 1980s, associated with low to average mosquito abundance; all herds underwent a reduced productivity in the early 1990s when mosquito abundance peaked (among the four time periods we analyzed). After the early 1990s mosquito abundance dropped off and both the CAH and TCH returned to high productivity. However the PCH continued to decline (the drop in abundance was modest) while even though the drop was more dramatic in the CAH they continues to level off in the late 1990s eventually peaking in 2001. In the early 2000s mosquito abundance dropped off dramatically in all herds but the WAH. For the PCH this period marked the beginning of a recovery phase in their cycle of abundance. For the WAH mosquito abundance did not change from the late 1990s and the herd began to decline throughout the 2000s. By the mid 2000s both the CAH and TCH finally peaked and initiated a decline phase even as mosquito abundance declined.

Griffith et al. (2002) suggest that for the PCH factors that affect adult female recruitment are more likely drivers of the 1989 to 2001 population decline. They suggest that increasing freeze-thaw events in late autumn-early winter and again in spring are associated with the population decline. However, mosquito activity cannot be eliminated as a contributory factor. In addition to direct effects of debilitating effects of harassment on milk production, late July is also associated with a time that some cows of the Porcupine caribou herd are reported to wean calves when maternal body protein regain is low (Russell et al. 2000). When maternal body weight regain is low it can result in low milk production and consequent lower offspring growth (White 1992).

To illustrate this point, we related calf growth rate to summer annual MAI for the years 1992-1994, a period when Griffith et al. (2002) report between-year differences in calf growth rates in the 0-3 and 4-6 week post-calving periods (Figure 11). We determined mean MAI over the 0-3 and 4-6 wk periods following calving assuming peak calving occurs on 4 June. We determined mean MAI for each period and each year from the MAI phenology progression in Figure 10 (Table 5) and related them to the growth rates reported by Griffith et al. (2002). Calf growth rate (CGR, kg/d) was negatively related to 3-wk mean mosquito abundance (MAI):

$$CGR = 0.634 - 0.6021 * MAI \qquad R^2 = 0.854, P < 0.01, n = 6$$

Although the lower growth rates in this data set are attributed to increased MAI, especially in mid to late July, we cannot discount an alternate hypothesis that the effect is due to the increase in summer range temperature that could influenced forage nutritional content and biomass that in turn influences milk production (White 1983; 1992; Griffith et al. 2002).

Potential applications for caribou herd management

An understanding of the abundance and distribution of caribou is critical to managing this important resource to subsistence users, sport hunters, and viewers of wildlife and arctic landscapes. In our analysis we have shown associations between our measure of mosquito abundance and caribou productivity. However we stress that factors dictating the productivity of these herds are complex. We recognize that our contribution to spatial landscape ecology considers only one factor; however a similar analysis for other factors such as regional snow patterns, green-up patterns, and summer drought could all contribute to a better understanding of caribou populations. Thus a retrospective analysis of population trends and seasonal distributions can be used to make predictions on what the future might hold, especially when the components of the system become better understood. To maximize the use of this retrospective analysis of MAI and its drivers, we need to overlay this information on seasonal distribution patterns of these caribou herds in specific years. As a management tool we need to predict how caribou herds respond, and potentially, adapt to climate change. Communities that depend on these caribou herds have a vested interest in such predictions as they share their observations to management boards and managing agencies.

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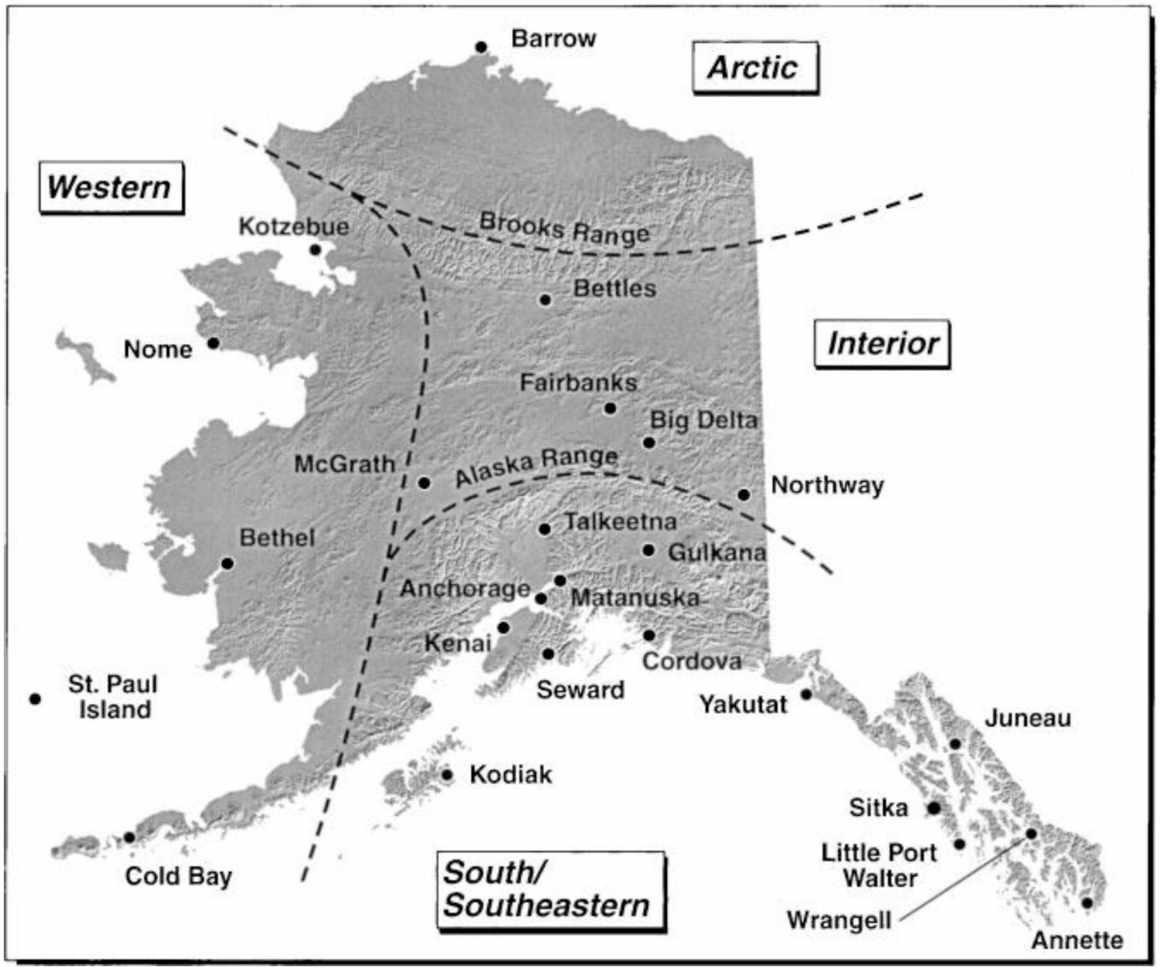


Figure 1. Regional climate zones of Alaska.

Zones used to describe climate change within Alaska as proposed by Shulski and Wendler 2007.

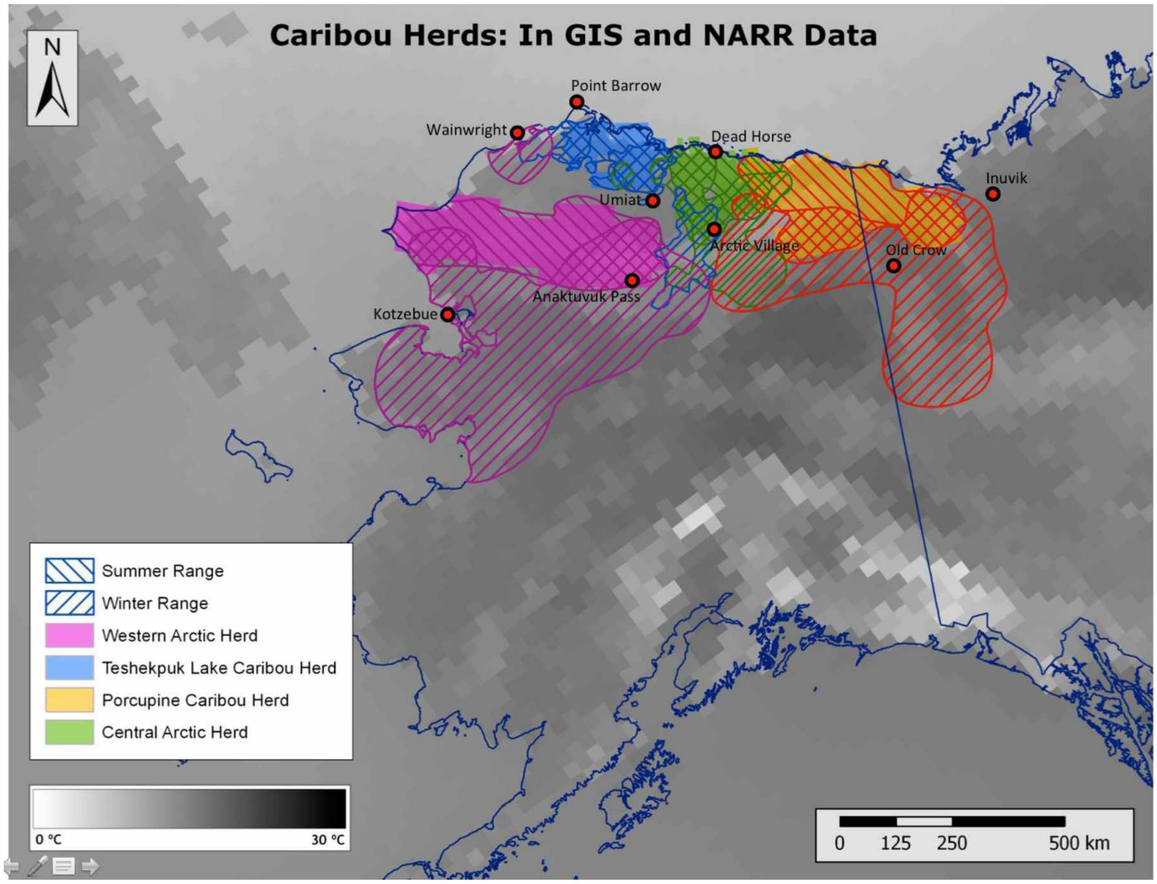


Figure 2: Summer ranges of Arctic caribou herds as detailed from shape files.

The spatial extent of data extracted from NARR, along with the summer and winter distributional ranges of the four caribou herds – Western Arctic Herd (WAH, pink color polygon), Teshekpuk Caribou Herd (TCH, blue color polygon), Central Arctic Herd (CAH, green color polygon) and Porcupine Caribou Herd (PCH, yellow color polygon). NARR data represents mean summer seasonal temperature for the period 1979-2009 on a gray scale background. GIS data on caribou ranges was provided by the CircumArctic *Rangifer* Monitoring and Monitoring (CARMA) Network.

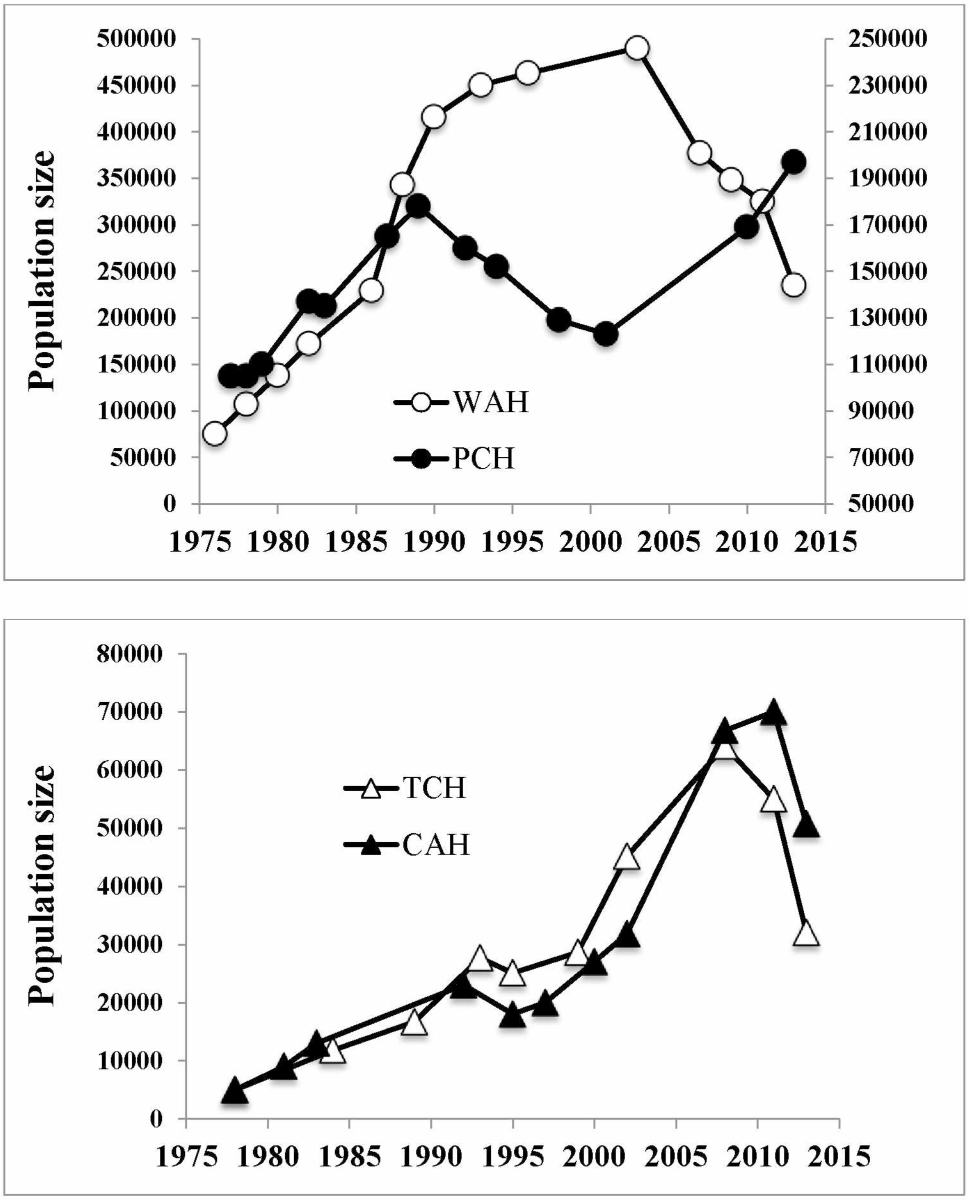


Figure 3: Population sizes and trends in caribou of arctic Alaska.

a) Size of the Western Arctic Herd (WAH), left axis, and the Porcupine Caribou Herd (PCH), right axis.

b) Size of the Teshekpuk Caribou Herd (TCH) and the Central Arctic Herd (CAH).

Estimates were obtained for the CARMA website for data contributed by the Alaska Department of Fish and Game.

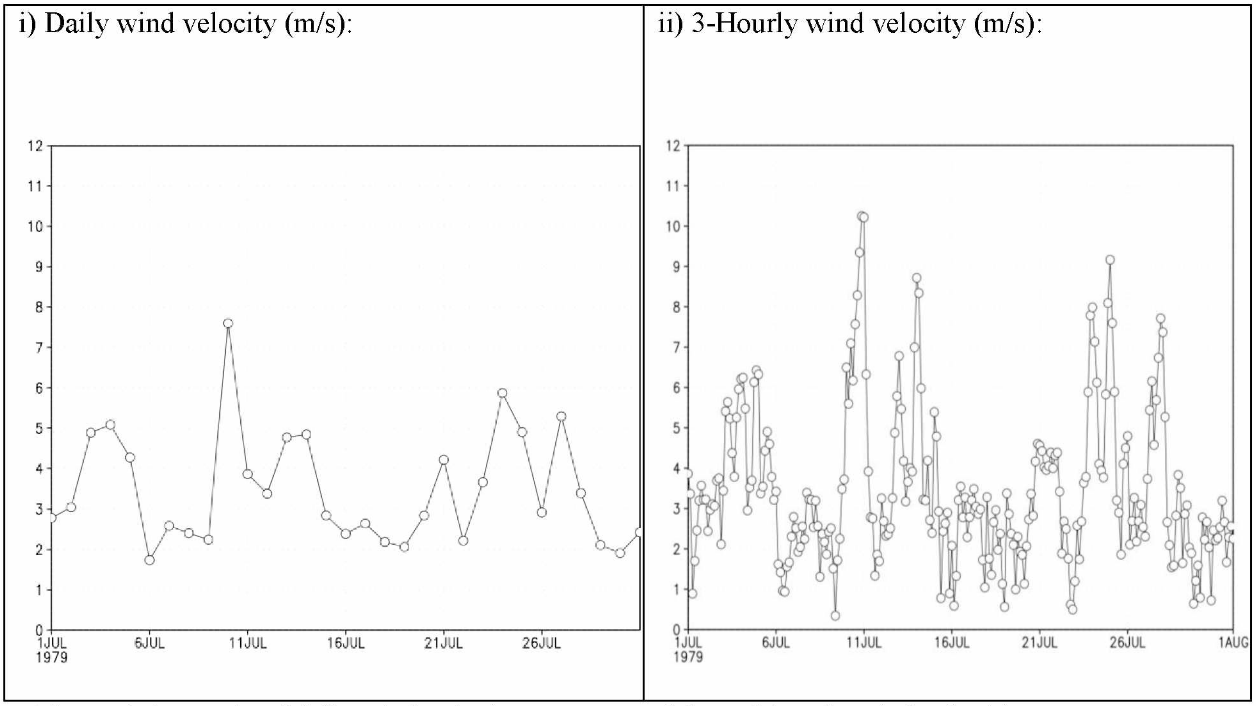
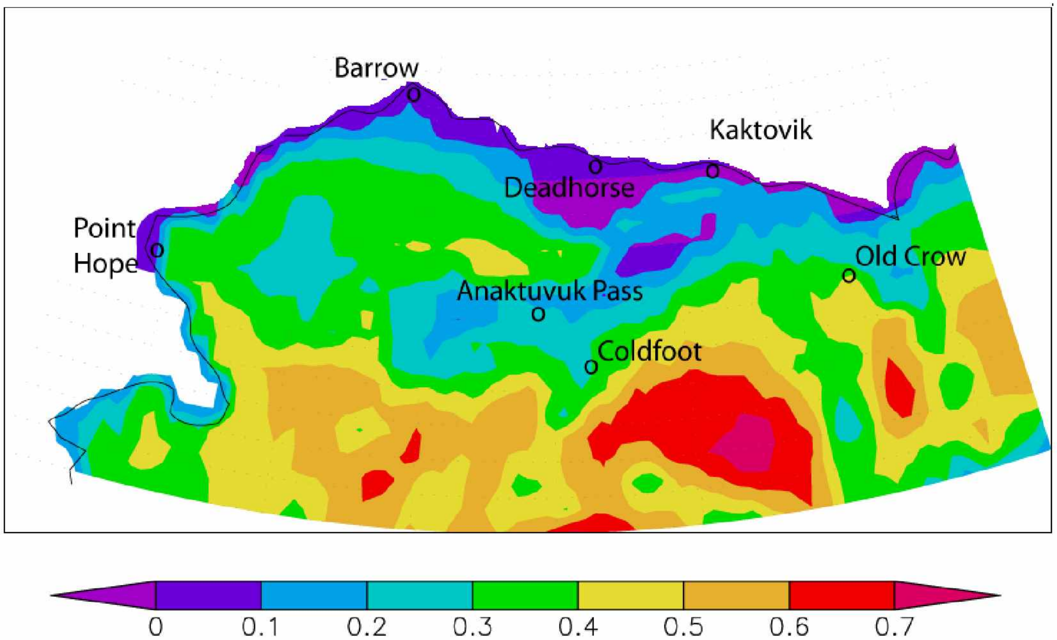


Figure 4: Example of daily wind velocity as computed from 3-hourly wind velocities.

a)



b)

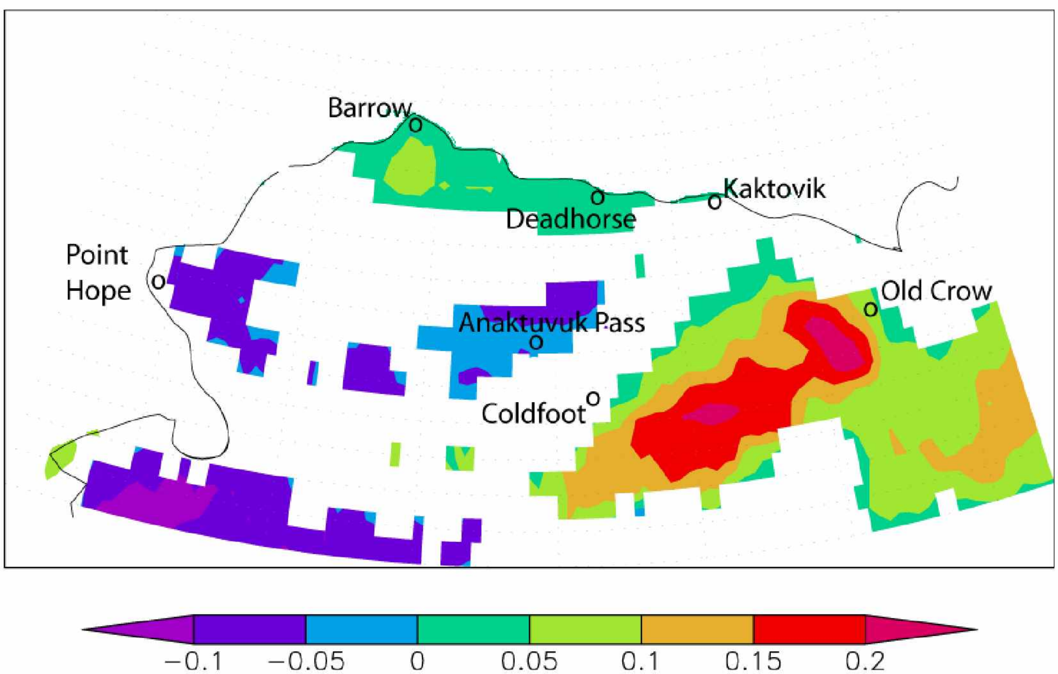


Figure 5: Landscape of mosquito activity index (MAI) for northern Alaska and change in MAI between 1979 and 2009. Gradations in the 31-y MAI (0 – 1) represented by low (0 – 0.2) purple to dark blue, moderate (0.2 – 0.4) by light blue to green, severe (0.4 – 0.6) by yellow to light brown and very severe (>0.6) by intensity of red). Change in cumulative MAI estimated in 1979 and 2009. No change is depicted as no color on landscape, a decrease (0 - -0.1) as shades of purple, a moderate increase (0 - +0.1) as grades of green, and a high increase (+0.1 – +0.2) as yellow and red.

a)

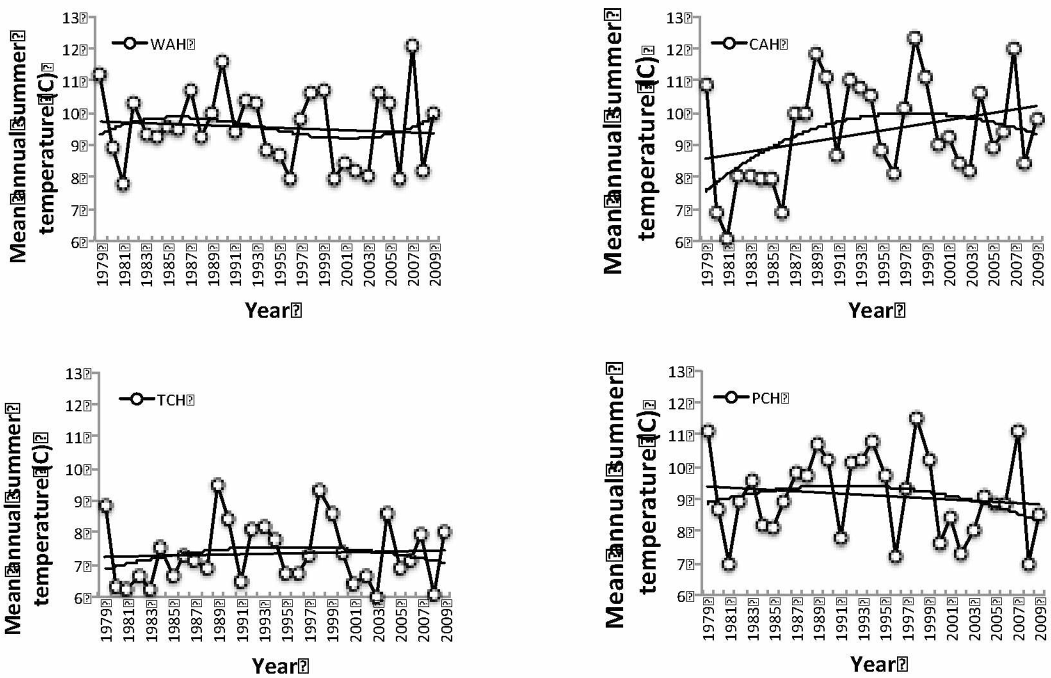


Figure 6: Mean annual change in summer (June 1-August 31) temperature (6a), wind velocity (6b) and mosquito activity index (MAI) (6c) in the Western Arctic Herd (WAH), Teshekpuk Caribou Herd (TCH), the Central Arctic Herd (CAH) and Porcupine Caribou Herd (PCH).

Shown are linear and polynomial trends in the 31-y records.

b)

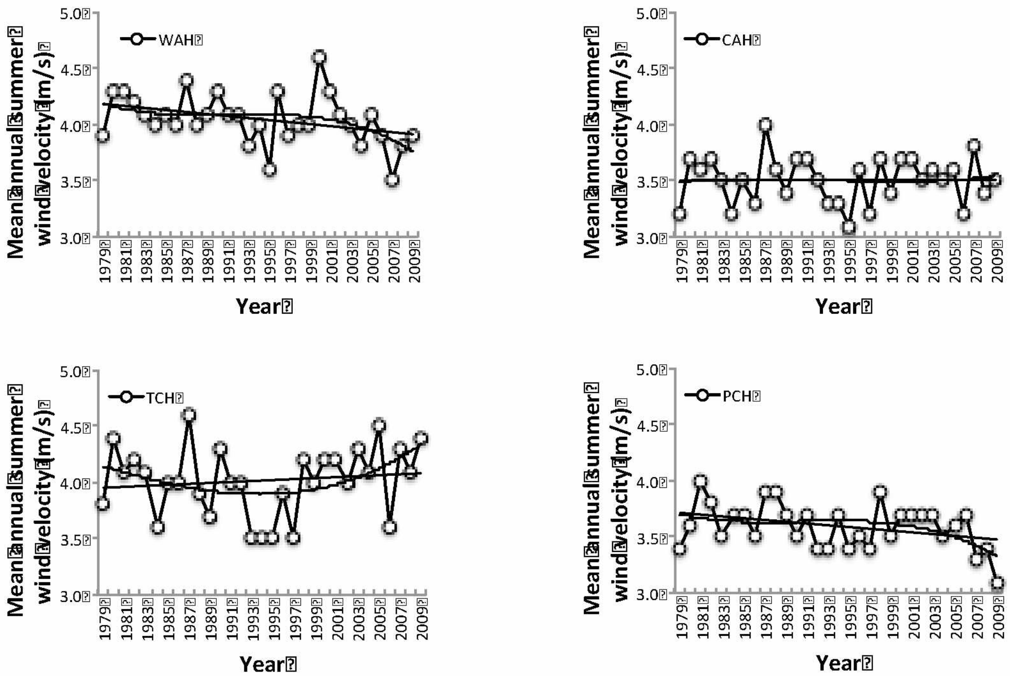
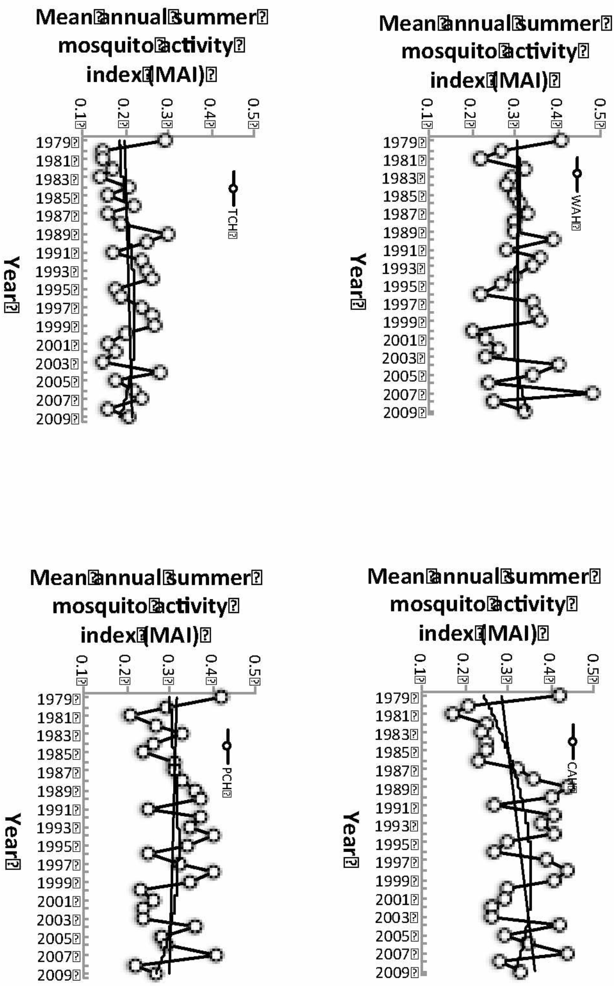


Figure 6 cont.

Figure 6 cont.

c)



Mean annual summer mosquito activity index (MAI)
Year
TCH
WAH
PCH
CAH

a)

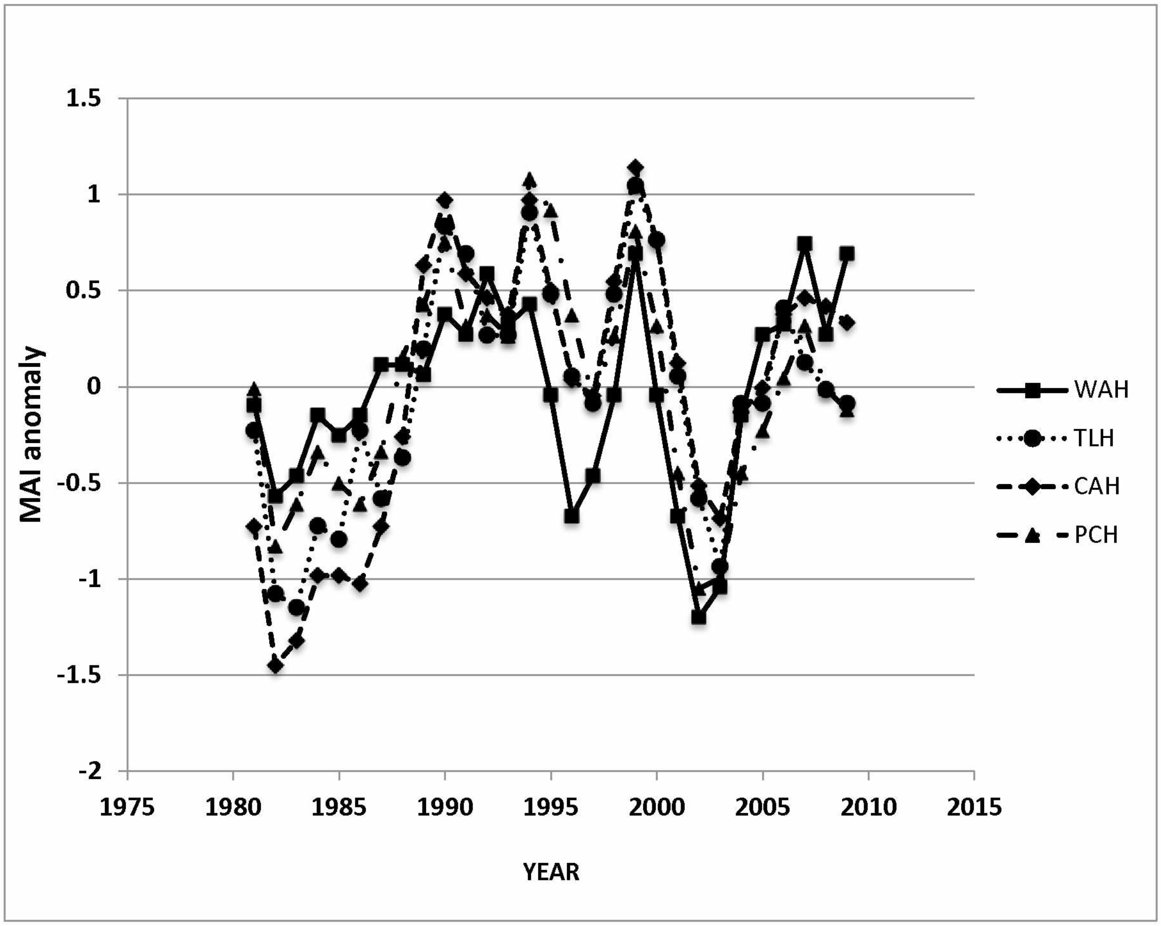


Figure 7. Comparison of among-herd and between-year patterns of 3-year running annual mean anomalies in summer (June 1-August 31) mosquito activity index (MAI, 7a), temperature (7b) and wind velocity (7c).

Separate 3-y running means are shown tor the Western Arctic Herd (WAH), Teshekpuk Caribou Herd (TCH), Central Arctic Herd (CAH) and Porcupine Caribou Herd (PCH).

b)

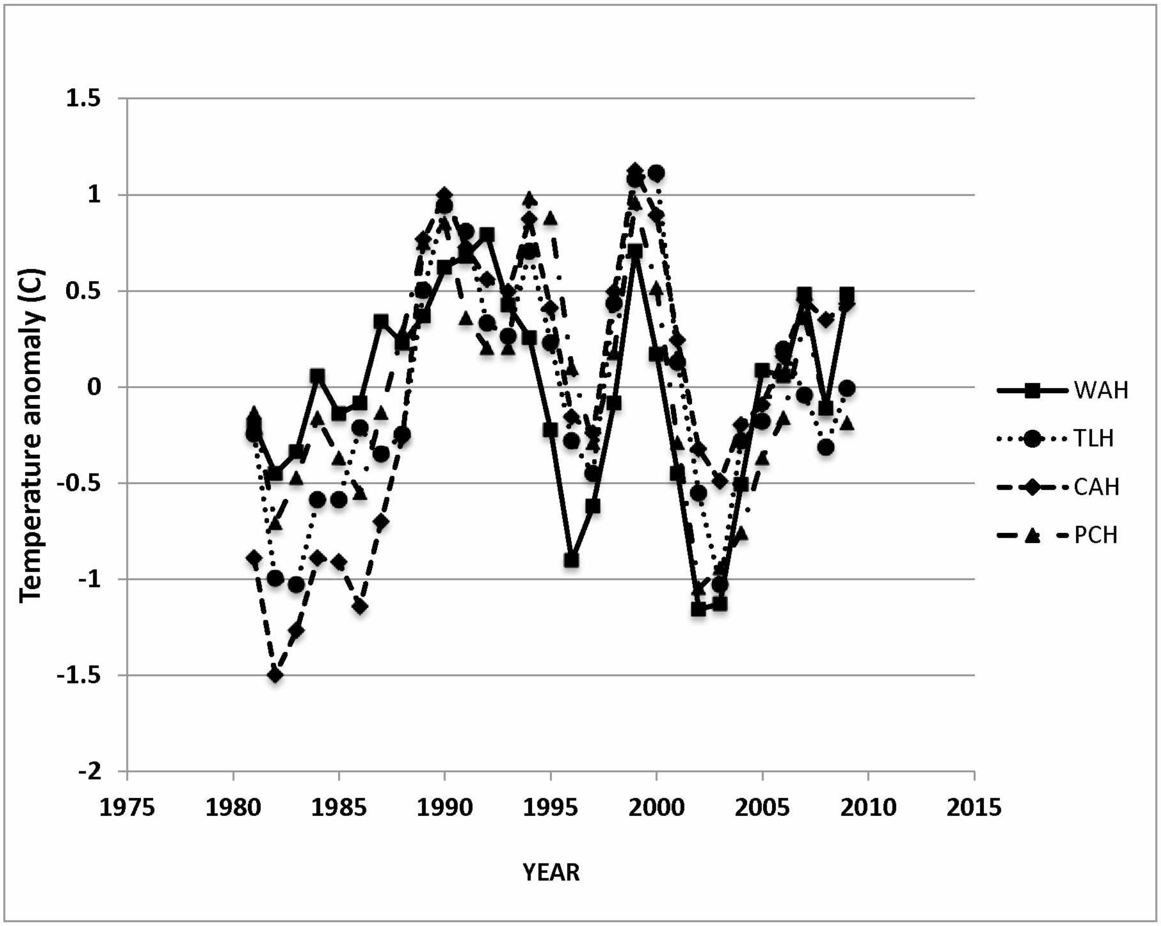


Figure 7 cont.

c)

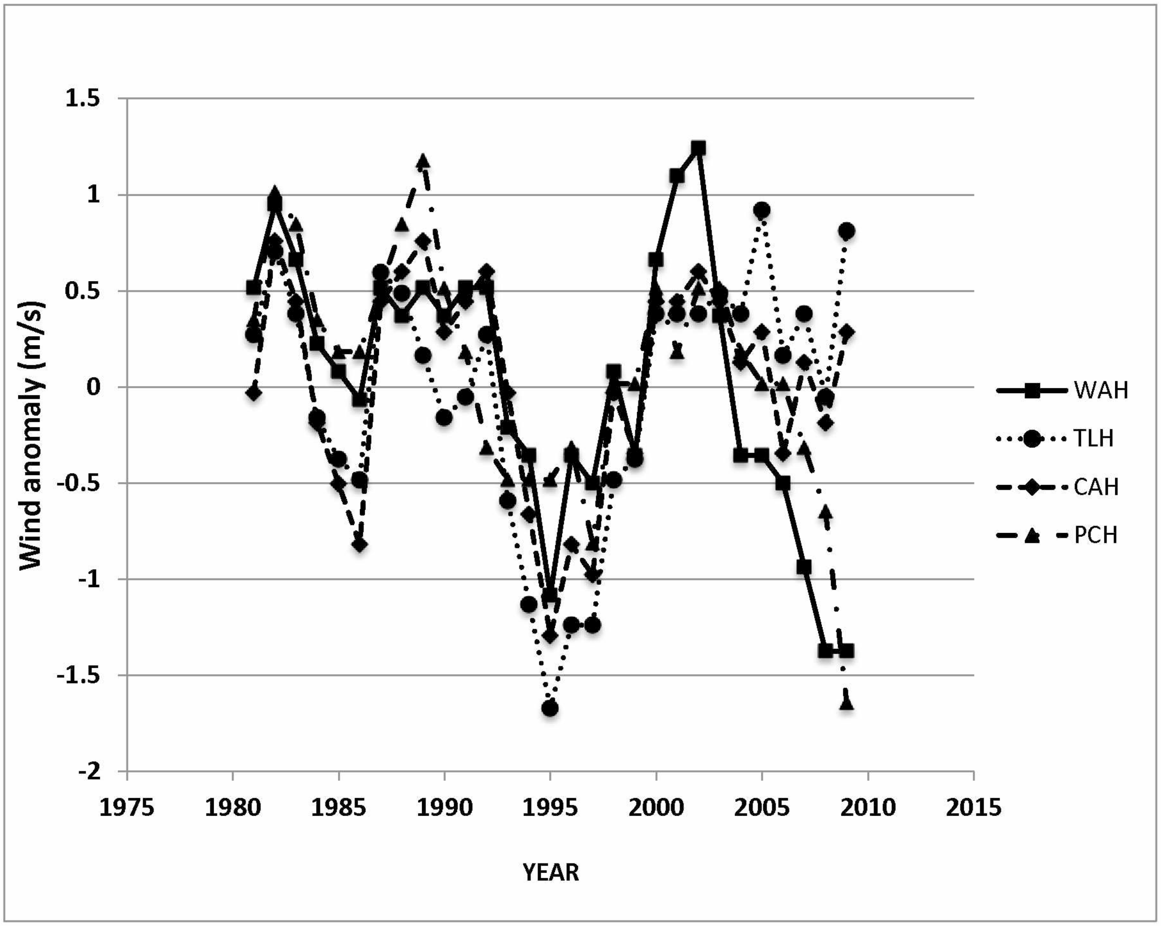


Figure 7 cont.

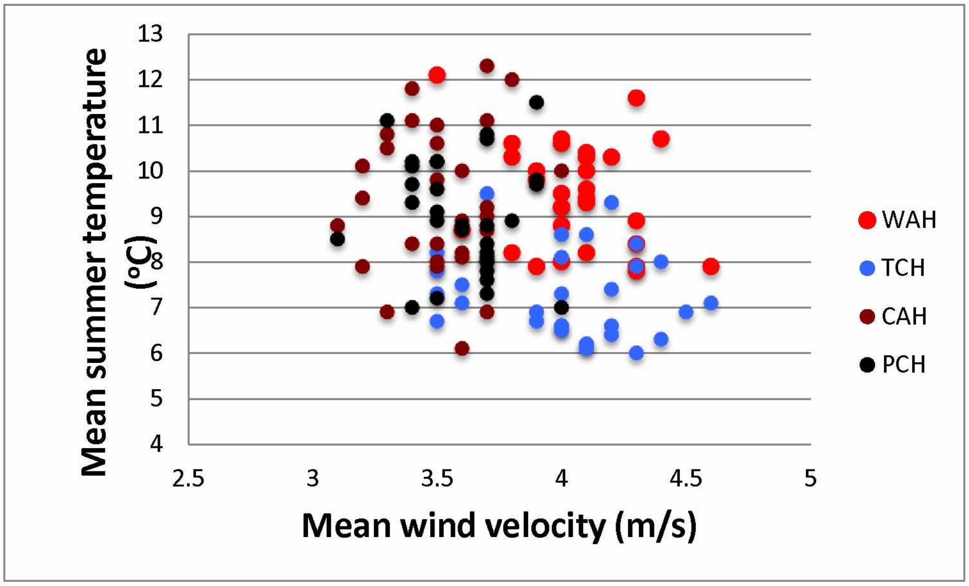


Figure 8. Scatter plot of mean summer (June 1-August 31) temperature and wind velocity for the Western Arctic Herd (WAH), Teshekpuk Caribou Herd (TCH), Central Arctic Herd (CAH) and Porcupine Caribou Herd (PCH).

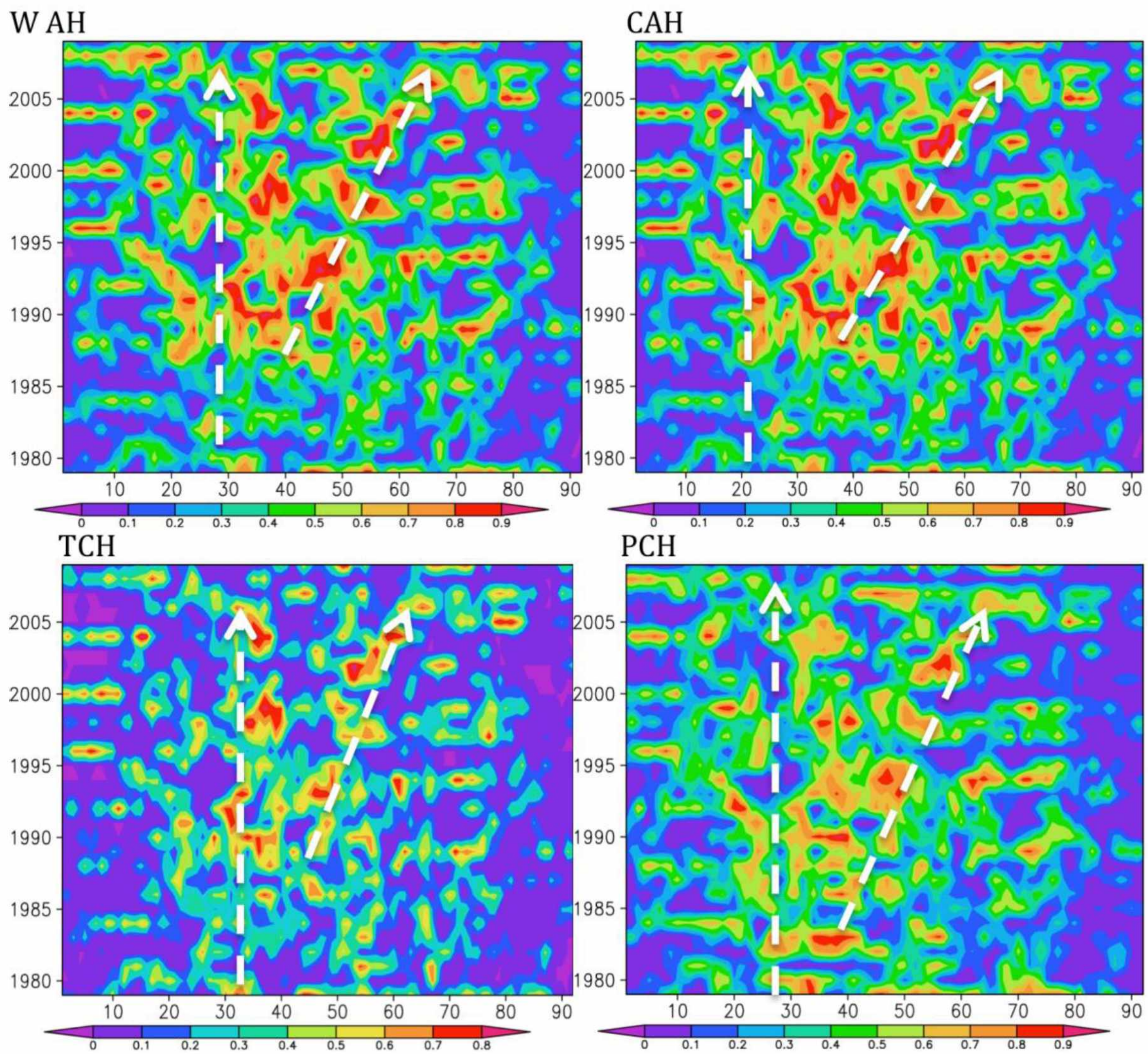


Figure 9. Mosquito phenology landscape: Distribution of daily mosquito activity index (MAI) for the summer season (June 1-August 31) in relation to year for Western Arctic Herd (WAH), Teshekpuk Caribou Herd (TCH), Central Arctic Herd (CAH) and Porcupine Caribou Herd (PCH).

Intensity of MAI (0 – 1) is given for low (0 – 0.2) purple to dark blue, moderate (0.2 – 0.4) by light blue to light green, severe (0.4 – 0.6) by dark green to light green and very severe (>0.6) by yellow, orange and red. Where MAI exceeds 0.6 at a set of dates through a number of years, the contiguous colors are defined to form a "hot spot." Dotted lines suggest trends in "hot spots" through time.

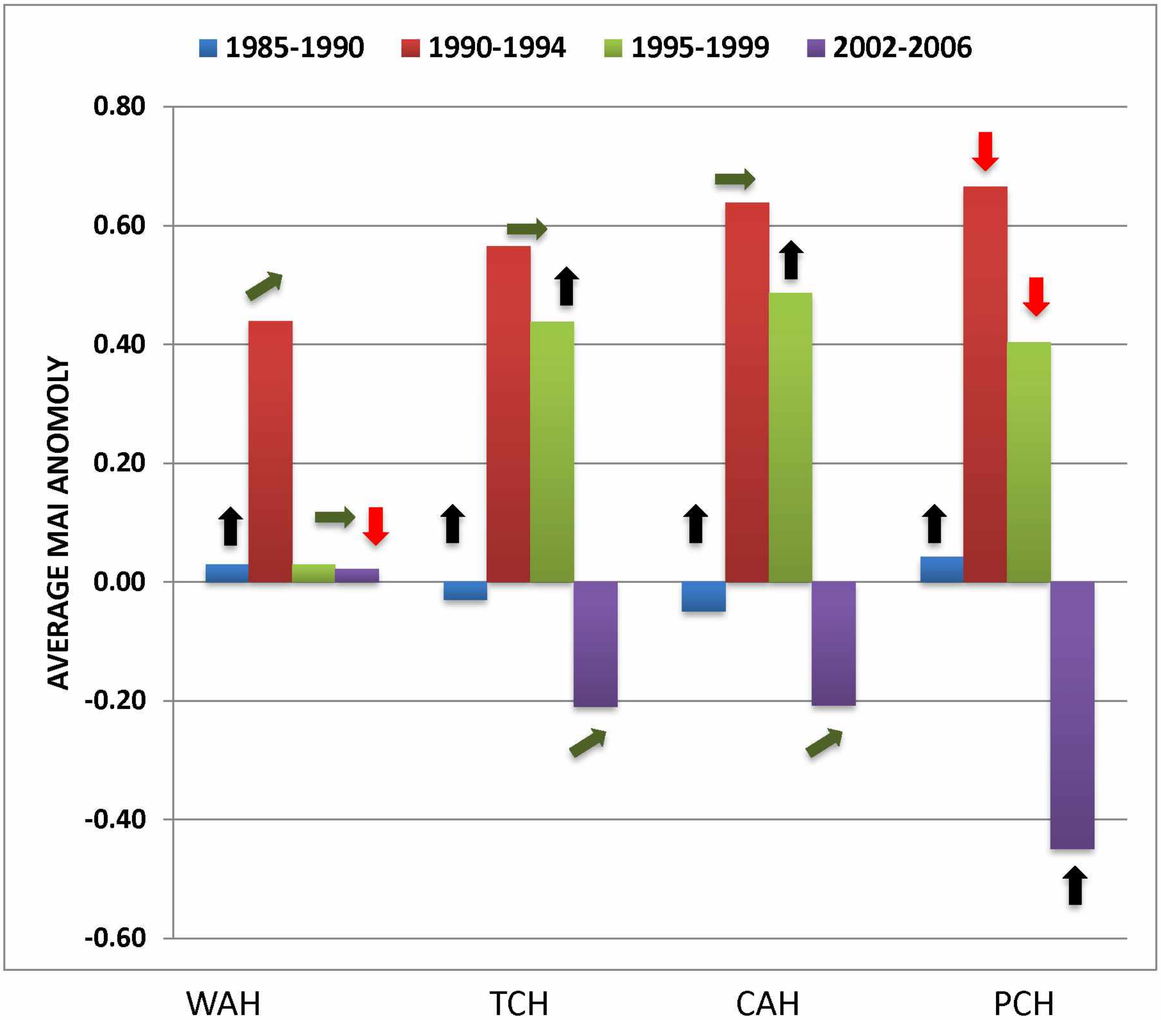


Figure 10. Comparison of average anomalies in mosquito activity index (MAI) with 4-y trends in population size represented by arrows with black as increasing, red as decreasing and green as variably changing for the Western Arctic Herd (WAH), the Teshekpuk Caribou Herd (TLH), the Central Arctic Herd (CAH) and the Porcupine Caribou Herd (PCH).

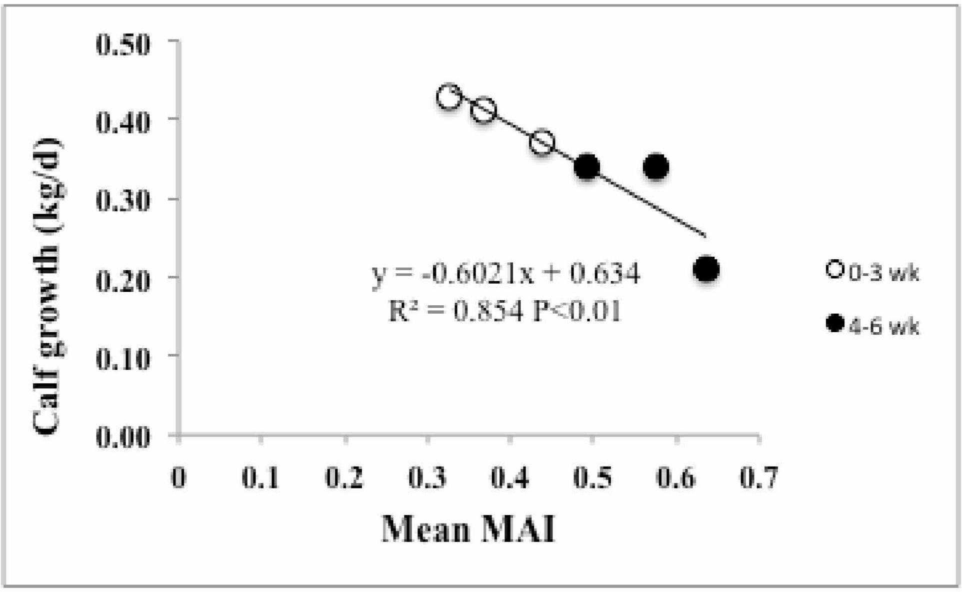


Figure 11. Relation between calf growth rate in weeks 0-3 and 4-6 post-calving and the mosquito activity index (MAI) for the same time periods assuming calving occurs 1 June.

Growth rates are for calves of the Porcupine caribou herd in 1992, 1993 and 1994 (Griffith et al. 2002) and mean daily MAIs for the three-week periods in each year as extracted from Figure 9.

Table 1. Equations for calculating Mosquito Activity Index (MAI) using surface air temperature and wind speed data (Russell et al. 1993).

If temperature $T > 18°$ C	→ Temperature Index TI = 1
If $T < 6°$ C	→ TI = 0
If $6°$ C $\geq T > 18°$ C	→ $TI = 1 – ((18-T)/ 13)$
If wind speed $W > 6$ m/s	→ Wind Index WI = 0
If $W \leq 6$ m/s	→ $WI = 1 - (6-W)/6$
Mosquito Activity Index $MAI = TI \times WI$	

Table 2. Annual means (average for the period June-July-August each year) of Mosquito Activity Index (MAI), temperature (°C) and wind velocity (m/s) for the period 1979-2009 for summer ranges of the Western Arctic (WAH), Teshekpuk (TCH), Central Arctic (CAH) and Porcupine (PCH) caribou herds.

HERD	WAH			TCH			CAH			PCH		
YEAR	MAI	Temp.	Wind	MAI	Temp.	Wind	MAI	Temp.	Wind	MAI	Temp.	Wind
1979	0.41	11.2	3.9	0.29	8.8	3.8	0.42	10.9	3.2	0.42	11.1	3.4
1980	0.27	8.9	4.3	0.15	6.3	4.4	0.21	6.9	3.7	0.29	8.7	3.6
1981	0.22	7.8	4.3	0.15	6.2	4.1	0.17	6.1	3.6	0.21	7.0	4.0
1982	0.32	10.3	4.2	0.17	6.6	4.2	0.25	8.0	3.7	0.27	8.9	3.8
1983	0.29	9.3	4.1	0.14	6.2	4.1	0.24	8.0	3.5	0.33	9.6	3.5
1984	0.28	9.2	4.0	0.21	7.5	3.6	0.25	7.9	3.2	0.26	8.2	3.7
1985	0.30	9.6	4.1	0.16	6.6	4.0	0.25	7.9	3.5	0.24	8.1	3.7
1986	0.31	9.5	4.0	0.22	7.3	4.0	0.23	6.9	3.3	0.31	8.9	3.5
1987	0.33	10.7	4.4	0.16	7.1	4.6	0.32	10.0	4.0	0.31	9.8	3.9
1988	0.30	9.2	4.0	0.19	6.9	3.9	0.36	10.0	3.6	0.33	9.7	3.9
1989	0.30	10.0	4.1	0.30	9.5	3.7	0.44	11.8	3.4	0.36	10.7	3.7
1990	0.39	11.6	4.3	0.25	8.4	4.3	0.40	11.1	3.7	0.37	10.2	3.5
1991	0.28	9.4	4.1	0.17	6.5	4.0	0.27	8.7	3.7	0.25	7.8	3.7
1992	0.36	10.4	4.1	0.24	8.1	4.0	0.41	11.0	3.5	0.37	10.1	3.4
1993	0.34	10.3	3.8	0.25	8.2	3.5	0.38	10.8	3.3	0.35	10.2	3.4
1994	0.30	8.8	4.0	0.26	7.8	3.5	0.41	10.5	3.3	0.40	10.8	3.7
1995	0.27	8.7	3.6	0.18	6.7	3.5	0.30	8.8	3.1	0.34	9.7	3.4
1996	0.22	7.9	4.3	0.19	6.7	3.9	0.27	8.1	3.6	0.25	7.2	3.5
1997	0.34	9.8	3.9	0.24	7.3	3.5	0.39	10.1	3.2	0.32	9.3	3.4
1998	0.35	10.6	4.0	0.26	9.3	4.2	0.44	12.3	3.7	0.40	11.5	3.9
1999	0.36	10.7	4.0	0.27	8.6	4.0	0.41	11.1	3.4	0.35	10.2	3.5
2000	0.20	7.9	4.6	0.20	7.4	4.2	0.30	9.0	3.7	0.23	7.6	3.7
2001	0.23	8.4	4.3	0.16	6.4	4.2	0.29	9.2	3.7	0.26	8.4	3.7
2002	0.26	8.2	4.1	0.18	6.6	4.0	0.26	8.4	3.5	0.24	7.3	3.7

Table 2 cont.

2003	0.23	8.0	4.0	0.15	6.0	4.3	0.26	8.2	3.6	0.24	8.0	3.7
2004	0.40	10.6	3.8	0.28	8.6	4.1	0.42	10.6	3.5	0.36	9.1	3.5
2005	0.34	10.3	4.1	0.18	6.9	4.5	0.29	8.9	3.6	0.28	8.8	3.6
2006	0.24	7.9	3.9	0.22	7.1	3.6	0.35	9.4	3.2	0.29	8.8	3.7
2007	0.48	12.1	3.5	0.24	7.9	4.3	0.44	12.0	3.8	0.41	11.1	3.3
2008	0.25	8.2	3.8	0.16	6.1	4.1	0.28	8.4	3.4	0.22	7.0	3.4
2009	0.32	10.0	3.9	0.21	8.0	4.4	0.33	9.8	3.5	0.27	8.5	3.1
31 Year Mean	0.31	9.53	4.05	0.21	7.34	4.02	0.32	9.38	3.51	0.31	9.11	3.60
31 Year SD	0.06	1.18	0.23	0.05	0.98	0.31	0.08	1.59	0.21	0.06	1.28	0.20
31 Year Sum	9.49			6.43			10.04			9.53		

Table 3. Fractional distribution of 31-year MAI (1979-2009) across summer ranges (June 1 – August 31) of the Western Arctic (WAH), Teshekpuk (TCH), Central Arctic (CAH) and Porcupine (PCH) caribou herds within Alaska.

Range of MAI	WAH	TCH	CAH	PCH
0.0 - 0.1	0.05	0.50	0.70	0.20
0.1 - 0.2	0.02	0.25	0.20	0.40
0.2 - 0.3	0.22	0.25	0.10	0.35
0.3 - 0.4	0.61	0.00	0.00	0.05
0.4 - 0.5	0.10	0.00	0.00	0.00
0.5 - 0.6	0.00	0.00	0.00	0.00
0.6- 1.0	0.00	0.00	0.00	0.00
Sum	1.00	1.00	1.00	1.00

Table 4. Contribution of temperature and wind velocity to the Mosquito Activity Index (MAI).

Dependent	Independent	Variance accounted for in estimated MAI			
		WAH	TCH	CAH	PCH
MAI	Temperature	90.6	87.8	94.8	91.7
MAI	Wind*	4.0	4.9	2.0	1.5
	Combined**	94.6	92.8	96.8	93.2
Residual (MAI v T)	Wind***	42.7	40.5	39.3	18.6

Table 5. Association of mean calf growth rates with mean mosquito activity index (MAI) during two three-week periods post-calving for years 1992-1994 for the Porcupine caribou herd.

Time period (weeks)	Year	Mean growth rate[1] (kg/d)	Mean MAI[2]
0 - 3	1992	0.37	0.44
	1993	0.43	0.33
	1994	0.41	0.37
4 - 6	1992	0.34	0.49
	1993	0.21	0.64
	1994	0.34	0.57

[1] From Griffith et al. (2002)

[2] Estimated from daily MAI in Figure 10 assuming calving occurs on 4 July

Chapter 2

Voices of the Caribou People: A Participatory Videography Method to Document and Share Local Knowledge from the North American Human-*Rangifer* Systems[1]

ABSTRACT

"Voices of the Caribou People" is a participatory videography project for documenting and sharing the local knowledge of caribou-user communities about social-ecological changes. The project was conducted in partnership with indigenous people who share a long and close relationship with caribou and self-identify as the "Caribou People." The Caribou People desired to share their knowledge, experiences, challenges, and coping strategies with other indigenous communities and with scientists and wildlife managers. Six communities in the North American Arctic participated in the project, with 99 people interviewed about the ecological, cultural, spiritual, and nutritional aspects of their relationship with caribou. The Caribou People wished to tell their stories with their own voices, without the filter of a researcher's interpretations of their messages. The communities defined three project goals, i.e., documentation, communication, and sharing of knowledge, and we identified methodological challenges associated with these goals. Through videography, we sought to overcome these challenges and accomplish community goals, which formed the basis for our project's evaluation. Participants reported changes and concerns ranging from impacts of oil and gas exploration, mining activities, nonlocal hunting, and high energy costs to impacts of climate-related conditions. All interviews were made available in the public domain via the Internet for sharing. In the view of the communities, videography preserved their legacy and served as a repository of traditional knowledge in changing times; visual images were seen as a powerful medium to communicate with policy makers and the public at large and were seen as a preferred informal, unstructured approach. We have (1) described the approach of the Voices of the Caribou People project as a collaborative video methodology and (2) discussed the effectiveness of this method in meeting the goals of participatory research. General insights into the process of using videography as a participatory research tool to study social- ecological systems in partnership with indigenous communities have been provided.

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INTRODUCTION

The International Polar Year (IPY) of 2007-2008 was a breakthrough for large-scale Arctic scientific studies because indigenous people of the Arctic were specifically engaged in learning and studying about changes affecting their social- ecological systems (Krupnik 2009). Collaborative approaches between indigenous people and researchers are increasingly seen as critical for both (1) the effective documentation of traditional knowledge that provides a long-term baseline information about the past and contemporary social and ecological conditions (Berkes et al. 2000), and (2) the integration of indigenous local knowledge (LK) and scientific research that can address the challenges of rapid environmental and social changes in the Arctic (Moller et al. 2004). Integration of LK with Western scientific methods and findings, however, presents a suite of epistemological, ontological, and practical problems (Berkes 2012).

Some of the barriers in incorporating LK with scientific research and assessments are rooted in the difficulties of accessing such knowledge (Huntington 2000). For example, traditional ecological knowledge (TEK), a component of LK, is passed on as an oral tradition in stories attached to people and events over generations, and contemporary LK is usually shared as stories describing personal experiences. Too often, scientific interpretations of LK are decontextualized, rendering that knowledge as devalued (Cruikshank 1998). Local observations and experiences are embedded in specific contexts, times, and spaces. We regard that context as a critical component of LK in maintaining local community member perspectives, i.e., what is changing, what the effects are, and what people's concerns are, because the knowledge holders are an integral part of the system undergoing change. Consequently, Huntington (2000) urged that LK be documented as a project on its own prior to incorporation into a scientific enterprise; otherwise, the local context and breadth of knowledge would be lost.

We set out to document the context and breadth of the social- ecological system encompassing Arctic people and caribou through the Voices of the Caribou People project, hereafter referred to as the "Voices Project," i.e., a picture of the changing Arctic through the eyes of the people of the Arctic (Bali and Kofinas 2008). Human-*Rangifer* Systems are the coupled systems of indigenous communities in Alaska and Northern Canada and their traditional subsistence resource, the barren-ground caribou (*Rangifer tarandus*). The caribou is the most numerous large terrestrial mammal in the Arctic. Many native communities maintain strong nutritional, cultural, and spiritual ties with caribou and identify themselves as the "Caribou People." Although these human-caribou systems have persisted for thousands of years, the living conditions in the present are undergoing rapid change. Over the past 50 years, all major caribou herds in North America have been exposed to industrialization and developmental activities (NRC 2003). In addition to these direct human activities, the North is also faced with rapidly changing climatic conditions (ACIA 2004) and a suite of other social, economic, and political changes, which have resulted in a high cost of living, changes in the ways caribou are hunted and used, and incidental loss of traditional knowledge.

The Voices Project is a video-based documentation of the indigenous knowledge, observations, and perspectives of the Caribou People, focusing on social-ecological changes as perceived during the IPY. The IPY program is an international initiative at a grand scale both geographically and also in the scope of research themes and diversity. Within such an international program, often there is a risk of local voices getting passed over or lost in the process of knowledge production and broad-scale knowledge synthesis. The Voices Project was an attempt to bring forward the local views and the expression of LK in a multidimensional way and contribute to a circum-Arctic–scale research program. This project was supported by the Circum-Arctic *Rangifer* Monitoring and Assessment (CARMA) network as part of their IPY research program. CARMA is a network of researchers, managers, and community people who monitor and share information about the population and status of caribou and how they are affected by global changes (http://www.caff.is/ carma).

The applied objective of our project was to document the local people's experiences of change, perceptions of impacts, and responses to those changes in six communities across the North American Arctic. We also sought to create a living web-based information source of the Caribou People's voices for ongoing contributions and as a lasting legacy of the IPY. We describe the process of carrying out such a large-scale participatory project in a way that is culturally appropriate and sensitive to the spatiotemporal context of the knowledge. From a research perspective, our primary goal was to evaluate if participatory videography was an effective tool for accomplishing both community and science goals and needs. Further, we discuss how we overcame the methodological challenges of accomplishing three specific goals set by the communities for this project: documentation, communication, and the sharing of their perspectives and concerns.

METHODS

The art and science of documenting local knowledge with videos

In the early 1950s, English anthropologists Gregory Bateson and Margaret Mead (1952) comprehensively demonstrated the utility of film as a research tool with their documentary *Trance and Dance in Bali* (Lipset 1982). Since then, the popularity and use of film and video as ethnographic tools have grown along with the increasing availability and transportability of equipment (Rosenstein 2002, Lunch and Lunch 2006, Chalfen 2011). Videography has been used for qualitative research, awareness, and advocacy on a wide array of issues including historical documentation (Hartman 1994), human health (Lynagh 2010), language preservation, education and engagement with youth (Gearheard 2005), environmental assessment (Usher 2000), wildlife monitoring and natural resource management (Moller et al. 2004, Branch 2011), and climate change (Cruikshank 2001, Kunuk and Mauro 2010).

Although film has only been recognized as an ethnographic research tool since the 1950s, its use in documenting indigenous cultures has continued since films were first made (Barbash and Taylor 1997). In the Arctic, Flaherty's (1922) *Nanook of the North* began a trend that has continued to the present, where film has found increasing appeal for both engaging indigenous people in shared projects and bringing forth images, albeit contrived in some cases, of the remote indigenous cultures to the mainstream public. Recently, there has been a proliferation of the use of videography to document and communicate indigenous knowledge, especially in the Arctic, so much so that now there are film enterprises owned and operated by several indigenous First Nations. For instance, the Vuntut Gwitchin First Nation from the Yukon Territory, Canada, has been producing documentaries on various oral histories, cultural practices, and cultural geography projects, such as *Drymeat Making* (Moses 2001), *Our History That Binds Us* (Kassi 2001), and *Imprints of Our Ancestors* (Moses and Kassi 2003). The Inuit-owned film production house and TV channel Isuma Productions in Nunavut, Canada, has successfully produced several critically acclaimed films depicting Inuit culture and perspectives, such as *Atanarjuat the Fast Runner* (Kunuk 2001) and *Inuit Knowledge and Climate Change* (Kunuk and Mauro 2010).

Moving visual images and sounds bring people and cultures alive onscreen, capturing the living testimony of conditions in a way neither written words nor still photography can. Through contemporary information distribution systems, video also offers the possibility of reaching a far wider audience than academic publications, providing opportunities for engagement with lay as well as scientific audiences (Barbash and Taylor 1997). For these reasons, videos offer ideal opportunities for the more complete archiving of language, culture, and the context in which people lived.

Most importantly, ethnographic video allows subjects of films to judge the ethnographer's representation of them, i.e., the culture, people's experiences, and their personal stories, in relation to specific questions and context. Hence, the process of video ethnography is a very challenging undertaking and also a two-way learning experience. This is perhaps even more important in a collaborative project, where participants are actively engaged partners, as opposed to being seen just as the "subject" of research.

Capturing "Voices of the Caribou People"

During the 2007 annual gathering of CARMA network members in Vancouver, British Columbia, Canada, indigenous participants expressed a desire to be more involved in CARMA research. In particular, they asked that their perspectives concerning the broader social-ecological context be included in the existing biophysical research program on caribou. In response to this request, we proposed a project to document the perspectives of the indigenous Caribou People of North America using videography. The indigenous participants received this suggestion with enthusiasm, and the Voices Project was initiated.

We used participatory videography, also referred to as collaborative or engaged filmmaking, a process in which the filmmaker engages "subjects" in deciding what story will be told, how, and to whom (Stiegman and Pictou 2010). More simply, participatory videography is a method to make a video with, not just about, people. The level of participant engagement in this type of effort may take on a spectrum of options; on one end, subjects may work with a director to create films about themselves, or on the other end, subjects may make their own films. In the Voices Project, we took on the role of facilitator/filmmaker and worked in consultation with the community members to film what they felt were the important aspects of their lives to be shared. Several intermediate and final products were mutually agreed on for accomplishing participants' expectations, including products for the communities as well as products for wider distribution.

Framework for a post-hoc review of the Voices Project's participatory videography approach

Participants' performance measures: A prerequisite for meaningful partnership between the researcher and the participants is the need to recognize and include participants' goals in the project, i.e., the type of knowledge produced and its relevance to the participants (Wallerstein and Duran 2003). Through shared goals, tangible outcomes of such collaboration can be identified, agreed on, and achieved through establishing trust, assuring participation, and the sharing of power with communities and participants (Israel et al. 1998). However, establishing and maintaining trust and respect, creating a shared purpose, and maintaining engagement and participation have also been identified as the main challenges of participatory research at the same time (Wallerstein and Duran 2003, Cargo and Mercer 2008).

Voices Project objectives were based on needs expressed by the indigenous participants. The participants wanted their knowledge and observations to be included in CARMA's IPY research project and their perspectives to be highlighted. In these times of rapid and dramatic social-ecological change, they wanted their traditional knowledge to be documented to preserve it for future generations. They recognized that other Arctic communities are faced with similar challenges, so they expressed interest in learning from each other, i.e., sharing with other communities about their conditions and challenges and how they are responding to those conditions. Thus, the project objectives (Table 1) served as a primary set of measures to assess how well our process performed in meeting with the project's goals, forming successful partnerships, and producing the outcomes desired by the participants.

Overcoming methodological challenges: We had set out to document and communicate LK using videography as a tool; therefore, overcoming the practical and philosophical challenges articulated in the literature on methods of participatory videography and documenting LK became our secondary goal (Table 1). Concerns pertaining to appropriate use of videography in social science research include issues of data ownership and availability (Albrecht 1985), as well as interpretation and representativeness (Prosser 1998). All these challenges collectively apply to participatory videography, which is frequently critiqued as a problematic method because of inadequately addressing these challenges (Rodriguez 2001). However, there are few explicit guidelines of what constitutes "good practice" in the use of videography in a cross-cultural context (Chalfen 2011). Similar challenges are also inherent in the documentation and application of indigenous knowledge systems and are again related to access, interpretation, and dissemination of the knowledge (Cruikshank 1998, Huntington 2000, Rosenstein 2002, Berkes 2012). Collectively, these participant- defined and literature-based criteria allowed us to conduct the post hoc assessment of the Voices Project's performance.

The process of the Voices Project

Introduction: From conceptualization to execution, the Voices Project took more than 4 years. The project was conceptualized in 2007, formally initiated in 2008, and now functions as a fully developed, ongoing process (Fig. 1, Table 2). We started the project by inviting a large suite of about 50 organizations of indigenous communities that traditionally subsist on caribou to participate in the North American effort. This included all the communities with pre- existing relationships with the CARMA network, to represent the Caribou People throughout the range of the North American Human-*Rangifer* System. Information flyers with the project's intention were disseminated via regional caribou comanagement boards, indigenous organizations, biologists and researchers, and environment and natural resource agencies in Alaska and Canada. Six indigenous communities, 1 in the United States and 5 in Canada, consented to collaborate: Anaktuvuk Pass, Alaska, USA; Old

Crow, Yukon Territory, Canada; Wekweeti and LutselK'e, Northwest Territories, Canada; Arviat, Nunavut, Canada; and Kawawachikamach, Quebec, Canada (Fig. 2, Table 3).

All communities were north of 55 degrees latitude, with Anaktuvuk Pass and Old Crow located above the Arctic Circle. None has road access, so primary access to urban centers and their services is by air, although some communities have seasonal boat/snowmobile access. Kawawachikamach has limited rail connections to a few cities. All communities have been seasonally nomadic in the past but settled at different points in history. Old Crow has the oldest history of settlement in its current location since the 1870s, whereas the Kawawachikamach settlement was established only recently in 1981. All community settlements were strategically located around caribou ranges or migration routes of one or more herds. Once participating communities were identified, we started a dialogue to understand community expectations of the project and planning logistics and "how-to."

Seeking and forming partnerships: To conduct this project, we needed research permits and community approvals at various levels. For instance, in the United States, an institutional review board (IRB) committee is responsible for approving, monitoring, and reviewing all research involving human participants. In Canada, instead of a centralized agency, we needed to work with each First Nation tribal government as well as respective academic research license granting institutions. In addition to the Human Subjects Review Board at our institution, the University of Alaska Fairbanks, a total of 10 permits were required, involving communications from the territorial to the local level. We ensured throughout the process that project goals and the active participation of the communities were compatible with the ethical requirements of IRBs. We sought informed consent from the participants in every case, making them fully aware of the project's goals and outcomes, and of public dissemination of all the material without any modification from our side, unless the community or the participant desired otherwise.

After necessary permissions were obtained, we identified one local organization in each community that would become the project's point of contact and collaborator and take primary responsibility for guiding and coordinating the Voices Project in the community. Our project's organizational collaborators included Anaktuvuk Pass Simon Paneak Museum, Old Crow Vuntut Gwitchin First Nations organization, Community Government of Wekweeti, LutselK'e Dene Band, Arviat Hunter- Trappers Organization, and Naskapi Hunter-Trappers Organization. CARMA provided each collaborator funds, a maximum of US$5000.00 per community, to cover direct costs and honorarium for participants, based on local institutional norms. In each community, we entered into a "memorandum of understanding" with the collaborating agencies, thus creating a mutual agreement of what would be done and how. We agreed a priori that all videos would be made available in the public domain without critique or modification from our side, and neither CARMA nor any other organization would profit financially from the project.

The filming: Fieldwork was conducted from May to August 2008. Field visits in each community were for approximately 15 days. We video recorded people's knowledge and observations of changes taking place on their homelands and in their communities' ways of life, and how these changes are affecting their traditional culture. Our partner community organizations identified prospective interviewees broadly classified as follows: (1) elders, i.e., community residents who were considered LK holders, experienced in traditional activities, and long-term residents in the community; (2) leaders, i.e., elected representatives such chief, member of the legislative assembly, mayor, or village council member; (3) active hunters, i.e., those who actively engaged in caribou subsistence hunting activities; and (4) youth, i.e., young members and children, who were included wherever possible. We sought to include women representatives in all categories to bring out a comprehensive understanding of community perspectives.

Archana Bali conducted all interviews and filming, with the assistance of at least one local representative in each community. The local assistants were assigned by the collaborating organizations to help meet the communities' criteria of their knowledge documentation. The methods of interviews ranged from semi-structured with open-ended questions to spontaneous conversations where the respondents talked about issues that they felt were important to share. The participants were aware that the project was focused around their knowledge and issues related to caribou and people, but they were given freedom to talk about any issues of interest and concern to them. This approach provided flexibility and freedom to the participants to express their own stories, in the way they felt they should be told (Huntington 1998). For non-English-speaking participants, translators were provided. The interviews were recorded as either one-on-one conversations with the researcher-filmmaker or as conversations between two or more people.

We interviewed 20-24 residents in each community. Videos included traditional subsistence-related activities, such as hunting, fishing, and gathering, processing of native foods, and arts and crafts making; and recreation activities, such as storytelling, dancing and drumming, and potlucks. Knowledge on traditional activities such as native foods preparation, processing of meat for long-term storage, and processing caribou hides was documented. Individuals' stories, legends, and songs were also recorded.

The outcomes of the Voices Project

Postfilming and end products: A total of 99 interviews resulting in more than 120 hours of video data were collected. The postproduction process included three phases: (1) technical work, i.e., converting raw data into finished products; (2) products for communities, i.e., sharing the products with the communities; and (3) living voices, i.e., making the products available to a wider audience via the Internet.

Phase 1 included digitization of all video material, editing raw footage to create movie files for each interview. We used the program FinalCutPro for editing and producing movie files of each interview. Additionally, interviews in native languages were translated and transcribed in English. The task of translation and transcription was most time intensive and one of the greatest challenges of the project. Our arrangement with communities was to provide an unabridged version of their interviews; in other words, nothing was to be modified or left out. Hence, our primary role as editors was to render the interviews into a consistent and finished form. The first phase proved to be the most time- consuming and technically intensive part of the project.

In phase 2, we sent all the documented information back to the individual participants from each community to accomplish the Voices Project's first objective. These interviews, finished as easy- to-view movie files, were sent to each participant in the form of a DVD. Each of the participating communities received the entire set of videos filmed in its village, as a repository of its LK recorded during IPY 2007-2008. To meet the second objective, to generate interest about the project and spread awareness about the lives of the Caribou People, we created short thematic films. Several versions of the video documentary *Voices of the Caribou People* have been produced since 2008. These short films were intended for distribution to communities, libraries, schools, museums, and cultural centers. They have also been presented at IPY meetings and other scientific conferences as a form of outreach to the scientific community. Versions of this film have also been screened at several film festivals in United States, Canada, and other countries and have won two awards, including the International IPY Student Video Contest (2008).

To accomplish the third objective, phase 3 was focused on wider outreach using the Internet as a medium. An interactive web archive, containing the entire set of videos gathered, is publicly available on the website http://voicesproject.caff.is/ and is easily accessible to the communities, Arctic researchers, and a wider audience via the Internet and linked through the CARMA website. Since 2008, more communities in Alaska, Canada, Greenland, and Russia that depend on caribou and wild reindeer have expressed an interest in being included in the Voices Project. We are working toward making the website an ongoing project, where in the future community members can create their own videos and post their voices to the project's website. Because LK is dynamic in nature over space and time (Berkes 2012), this website would be a true legacy of the IPY program, a snapshot of conditions during 2007-2008, and serve as baseline information for future comparisons. Phases 1 and 2 are complete, and phase 3 will continue on as "living voices," to provide a continuing and locally based record of important issues concerning the human- caribou systems.

A synopsis of the Voices Project

In all communities, participants talked about cultural, spiritual, and nutritional dependence on caribou, observations of changes, and concerns about sustaining caribou in the future. The elders spoke about long-term changes in lifestyles, caribou hunting and usage, and changing climatic conditions as they experienced during their lifetime. Elders explained the traditional methods of hunting caribou and living off the land and contrasted what they viewed as their traditional, more resilient lifestyle with the modern one where their ability to hunt caribou depends on economic factors. Hunters spoke about their needs for caribou and current conditions on the land, as well as the difficulties they face while harvesting caribou. Hunters also shared their knowledge on how caribou movements, body condition, and numbers have fluctuated over time in their regions, and how the animals might be affected by climate-related or anthropogenic disturbance such as roads and mines. Leaders talked about the major political challenges their communities face and their strategies to respond to those challenges. They also talked about the communities' needs for information and assistance from scientists and agencies to adapt to the changes. The youth spoke about the importance of caribou in their life and their future aspirations. They talked about their experience on land and involvement in traditional activities, such as hunting, fishing, arts and crafts making, and consumption of native foods.

We found several commonalities between these communities in the nature of the challenges they are facing. These challenges include the ubiquitous problem of the high cost of living in remote Arctic areas, which is largely attributed to high energy costs; greater extractive development activities in homelands; and social challenges of integration with modern society and problems of engaging youth in traditional pursuits. Voices Project participants also talked about the effects of climate change, although the concern about climate change varied in importance as compared with social and economic issues.

Summary of challenges faced by the six communities

Caribou are very important to the last remaining Nunamiut of Anaktuvuk Pass, but there is a very high rate of unemployment and very limited economic opportunities in this isolated community.

As a result, the community was torn about whether to support oil and gas exploration activities in their region, which they were concerned would affect their caribou herds' movements but also create job opportunities for the community members. In addition, the community voiced concern about the effects of low- flying aircraft around caribou and competition from nonlocal hunters.

The Vuntut Gwitchin of Old Crow were very concerned about the future of the Porcupine caribou herd and noted the link between caribou and their own future. The main threat to the Porcupine caribou was thought to be from potential oil and gas development in the Arctic National Wildlife Refuge, and for past two decades, without failure their representatives have been participating in the lobbying efforts in Washington, D.C., to avoid development within the refuge. In addition, they have systematically observed dramatic changes in environmental conditions over the past few years, which they attribute to the significant impacts on caribou movement patterns.

The Tlicho of Wekweeti subsist mainly on the Bathurst caribou herd. Right in the middle of a narrow section of the migration path of the Bathurst herd, there are four diamond mines. The people of Wekweeti suspect several adverse impacts of the mining and related activities on their caribou's food, health, and movement.

The LutselK'e people share similar concerns as Wekweeti members because they also subsist on the Bathurst herd. They also face competition from outfitters and nonlocal hunters when seeking to meet their subsistence requirements. The community is engaged in land-claim agreements and voiced needs for more information and support from agencies and researchers to make decisions regarding their resources.

Arviat, located in the newest Canadian territory of Nunavut, where only 30,000 people live in 2 million km² of wilderness, are faced with a lack of adequate infrastructure and employment options. The community faces the dilemma of trade-offs between strict protection for their land and resources, i.e., calving grounds and migration paths of the Qamanariaq caribou herd, versus support for proposed uranium and other mining industries, similar to the dilemma faced in Anaktuvuk Pass with oil development.

The Ungava region in northern Quebec where Kawawachikamach is located has a long history of mining and exploration. The Naskapi people voiced their concerns about climate change effects and the disturbance on land from mining operations affecting the availability and accessibility of the George caribou herd to their people. They talked about seasonal changes resulting in early springs and rapid river breakups with negative effects on hunting and fishing. They had to hire airplanes to go hunting, which was both expensive and did not provide enough traditional food.

DISCUSSION

A post-hoc assessment of the Voices Project

In the literature, videography is touted as an extremely powerful tool for enabling community members to document their way of life through a relatively unfiltered method. Such videos provide the participants with a way to not only educate their own future generations but also inform outsiders about their knowledge, culture, and way of life (Barbash and Taylor 1997, Gearheard 2005, Cullen 2010, Branch 2011, Chalfen 2011). Our experience confirmed this finding. During the filming, several opportunities or challenges were articulated by community participants specifically related to using video as a tool for documenting and accessing their LK. In considering the effectiveness of this project, we discuss the project's performance at accomplishing the participants' objectives and addressing the methodological barriers (Table 4).

Documentation and preservation of the community's TEK: As for other researchers, we confirmed that the use of video is a useful and easy method to preserve and access community knowledge because the audiovisual medium aligns with how indigenous people teach and learn, by watching, listening, speaking, and following (Gearheard 2005, Branch 2011). This finding was reflected in the experience of Voices Project participants as well. Our process was consistent with the idea of an engaged videography (Chalfen 2011) that involved a collaborative process to formulate the right questions, appropriate themes, and content to document. In their comprehensive review, Cargo and Mercer (2008) highlighted self-determination, the capacity of individuals and groups to chart their own courses, as an important prerequisite for the appropriate participation. The decisions were made in a collaborative process and evolved as the partners deemed appropriate. For instance, who should participate and how they should participate were left to community organizations to decide. As participatory videographers interested in an ethnographic account, we recognized the need to develop mutual trust and understanding with the participants and the importance of their discretion in deciding what parts of their lives they wanted to share and how (Stiegman and Pictou 2010).

The participants also acknowledged the important role that this methodology serves in archival of LK in a community's own words; videotaped information will serve their communities as a repository of traditional ways, in the changing times. They also recognized that videos effectively engaged the young members of the communities. Distinct from other methods that often focus on a researcher's own specific interests, this format includes a wide swath of information that may serve the communities and other researchers into the future.

A major prerequisite in making this partnership successful was the active and engaged participation by community members. All fieldwork took place during the summer months. As a result, the timing of our project presented conflicts with other activities such as hunting, fishing, and so forth. Despite their interest in the project, community members were at times unavailable to participate. In one case (Wekweeti), despite all prior communications, arrangements, and engagements with the collaborating community organization, 90 percent of the community members were unavailable during the scheduled fieldwork. To make the best use of time and resources, we documented interviews of the available members and moved on to the next community.

A few participants expressed research fatigue or "burnout" (Cullen 2010). Since the advent of the current IPY, there has been an increase in the intensity of Arctic research and interest in TEK integration with science. With the majority of fieldwork concentrated in the summer months, in each one of the six participating communities, participants commented on the overall increase in community visitations by researchers. Participants in some communities expressed annoyance over being treated as "subjects of research" where information was gathered and results and findings were not reported back. In some cases, different universities or agencies were carrying out similar research projects simultaneously. The Voices Project's use of videography was perceived by participants as a relatively refreshing mode of interviewing, over conventional methods, with some participants expressing enjoyment in "being on-screen." Our written commitment to send all materials back to the communities and each participant also seemed to alleviate issues of "take-it-and-leave" research approaches and research fatigue. We have received supportive inquiries from the participants since starting the project, expressing their curiosity about the project's progress, which is another indicator of successful engagement with the participants.

Communication of the communities' LK and outreach: Achieving successful stewardship of social-ecological systems has been linked to documenting, integrating, and using LK in monitoring, research, and policy making (Berkes and Folke 1998, Folke 2004, Chapin et al. 2009). These linkages have been found in many cases to contribute to the adaptive capacity of systems (Armitage et al. 2007). Although theoretically elegant as an idea, realizing this goal in practice is a significant challenge. In part, this challenge is related to the historical conflict in management and governance of Human-*Rangifer* Systems attributable to the dominance of the science-based epistemological perspective over indigenous systems and the limited trust of indigenous people in the government agencies directing resource management (Freeman 1989, Urquhart 1989, Klein 1991). Although the settlement of land claims and the establishment of comanagement arrangements have opened the door for greater interactions between parties, operationalizing the ideas of integration remains problematic

(Kofinas 2005). The Voices Project sought to provide a platform for indigenous perspectives within the context of CARMA without fragmentation and interpretation of results by third parties. The full collection of videos from individual interviews and the composite short features exposed nonindigenous perspectives to aspects of the Caribou People's lives, ranging from understandings on caribou ecology to community challenges related to the intergenerational transfer of traditional knowledge. This approach, therefore, served as a test to explore how creating such a space would complement the greater CARMA effort and interests among communities of the Caribou People.

Videos provide a powerful means of communication and form of outreach to other communities. As Branch (2011) found, participatory videography is empowering to the community members because the visual component puts emphasis on them, i.e., the one who is telling the story. Video presents points of view/ opinions and beliefs as a form of bearing witness and making a testimony. This process transforms the presentation of experiences to a wider public as a form of political action (Rodriguez 2001). Participants in these isolated communities looked at the Voices Project as an opportunity to connect with other indigenous communities and a gateway for social and political exchanges among them. The leaders in all six participating communities recorded extensive interviews and identified their statements combined with visual images to be a powerful message to reach out to policy makers and the greater public. In this respect, the project was successful in giving the Caribou People another voice in today's multidimensional social- political milieu.

Traditional knowledge is the intellectual property of the knowledge holder and the community; often there is a tension about what and how much can be shared with outsiders and who should have access to it (Huntington 2000). Northern Canadian communities that are in the process of land-claim settlements and have information pertaining to traditional hunting areas have concerns about what information is available publicly and how that information could affect settlement procedures. These communities with limited power and capacity are dealing with significant political maneuvering and challenges. For them, the decision to participate in the Voices Project and how much information to disclose publicly was beyond the IPY agenda. We were cognizant of this issue, and wherever necessary, the videotaped content was reviewed by the community leaders before it was included in the project's information base.

There is also an epistemological dilemma pertaining to the appropriateness of interpreting knowledge and the translation of LK without consideration of its source and location. In doing so, there is a danger that the researcher or interpreter might construct, deconstruct, and reconstruct another's knowledge (Rosenstein 2002). This problem is especially pertinent to video data because video as a medium can be more intrusive and more open to abuse than other research methods; there is a risk of the information being manipulated through editing or being taken out of context and presented, which can change its entire meaning. An important characteristic of the Voices Project was to tell the stories of people with their own voices and without any modifications or abbreviations. Although reviewing the project's objectives and methods with participants a priori, the Caribou People described this aspect of the project as important and expressed satisfaction in not being treated as subjects of research but rather having their voices presented without alteration.

Sharing of the Voices Project by making the videos freely accessible in the public domain: The issue of data ownership is complex in all research, and even more so with the data collected through the participatory process or videotaped intellectual property (Albrecht 1985, Rosenstein 2002). Do the videotaped data belong to the subject of the video or to the researcher? The participants or the researcher may want to use the video for documentation, publicity, fund-raising, or other purposes. Where should the resultant video product be shown? Can the researcher show it at will to colleagues at conferences or to students during lectures? In the Voices Project, these questions were addressed a priori, and an agreement was reached with participants on how and where the data would be used and distributed. A basic understanding to which all agreed was that all information would be made freely available to the public via the Internet.

Additional methodological and philosophical challenges

The technical challenges of filmmaking: Filmmaking is a time- and effort-intensive process; filmmaking in collaboration with communities makes it even more so (Barbash and Taylor 1997, Stiegman and Pictou 2010). If the process is too slow, there may be a loss of interest and trust from collaborating organizations; if the process is too fast, there can be questions of trust from community representatives. Time and funding constraints of researchers limit the engagement with participants. Language differences required translators in some communities, which were sometimes difficult to find. Cargo and Mercer (2008) also highlighted time and funding limitations as an important source of challenges in doing participatory research that include establishing and maintaining trust and respect, ensuring sufficient time to develop a partnership, and providing adequate time and resources to the collaboration.

Relevance of research products and outcomes for the participants: Evans and Foster (2009) note that despite the popularity of videography in community-participatory research, there has been a lack of creation and distribution of research products that are relevant, inclusive, and accessible to the communities. In the Voices Project, we created video-based resources and products that the community members found useful and made efforts to bring the products back to the communities.

The Voices Project was successful in overcoming this problem of relevance. We produced short films and websites, performed screenings at various national and international venues including film festivals and scientific conferences, and have been distributing the material widely to other Arctic communities and outreach centers free of cost.

The limitations of participants' involvement in every step: In the case of video-based research, it is challenging to maintain participation across all phases of the production process. Depending on the project objectives or participants' skills, it may neither be necessary nor desirable to involve participants at all levels. In the Voices Project, participation did not extend to the editing phase, in part because of the geographic spread of communities and the budgetary limitations of being inclusive in this phase. Editing can be challenging because of technical complexities and logistical difficulties. Involvement in this phase would also have diverted participants from their other priorities, e.g., subsistence activities. Community members, especially youth who expressed interest in learning, were included in the videography process and were provided the opportunity and some training to use the camera.

Integration of the Voices Project into the wider CARMA research agenda

Our primary objective was to facilitate intercommunity communication and to extend this communication to non-community members, e.g., researchers and agency personnel. Communities wanted to learn from each other, so we started a process of documentation and sharing between communities. The communication with researchers was largely an indirect benefit. These direct and indirect effects of the Voices Project for the CARMA network are significant in the long-term because of the development of new trust and communication relationships between indigenous communities and CARMA researchers. Indigenous people took the leading role in this process, allowing for local voices to be represented along with science in a more holistic manner. In other words, this project provided a broad stage on which the Caribou People's perspectives were articulated, documented, presented, and archived for the future. The Voices Project was one of the main research initiatives of CARMA, and in that way elevated the legitimacy of the CARMA network for both caribou researchers and the Caribou People.

CONCLUSION

We have described the methodology of the Voices Project. We successfully accomplished the three goals set by the participating communities through the application of our participatory videography, which overcame the primary challenges we had identified in documentation and sharing of traditional knowledge (Table 1).

To date, the project has documented the perspectives of the Caribou People from six different communities of North America and facilitated communication and sharing of this information with other communities, scientists, and the general public. As a partnership with communities, the project portrayed the Caribou People and their changing world through their own experiences and stories. The information gathered through interactions in each community provides insights on the range of issues being faced by people in different villages and will contribute to the discussion about the effects of environmental and social changes on caribou as well as people who subsist on caribou. The project continues as an ongoing effort through use of the Internet. We envision this project as becoming an ongoing legacy, where more communities join in and share their voices and experiences by creating and posting their own videos.

The participants of the Voices Project found video to be a useful tool for several reasons. The elders in most communities said that stories captured on videos would be their legacy for the communities after they pass on. These videos would serve their people as a repository of traditional ways in changing times. The videos were acknowledged to be an effective outreach and educational tool by the elders and leaders. These communities looked at the Voices Project as a potential way of connecting with other indigenous communities and a gateway for social and political exchanges among them. From a methodological perspective, we found that only through active participation of the community members were the most notable challenges overcome. Nevertheless, several issues we raise still require care and commitment to this type of work, as is the case with any culturally sensitive ethnography.

The outcome of this project is a web interface, which is in progress through which all the interviews will be shared in the public domain. The Voices Project is also important in its international scope. On the one hand, barren-ground caribou may be transboundary in nature, and on the other hand, the issues facing the Caribou People are shared, irrespective of political boundaries. The Voices Project was one mechanism to overcome transboundary issues.

The approach and findings of this project may inform scientists and wildlife managers seeking to develop stewardship strategies and foster community resilience in times of rapid change. By incorporating LK and perspectives in scientific research, and in cooperation with the caribou users, scientists and wildlife managers are better able to support community efforts toward adaptation and sustainability. Local voices enhance local adaptive capacity through helping to document and share the invaluable knowledge and experiences of the communities among the Caribou People and the greater world. The outcomes of this project and the model of using videography that it provides have contributed to a holistic understanding of change and therefore to promoting the adaptive capacity of these northern communities.

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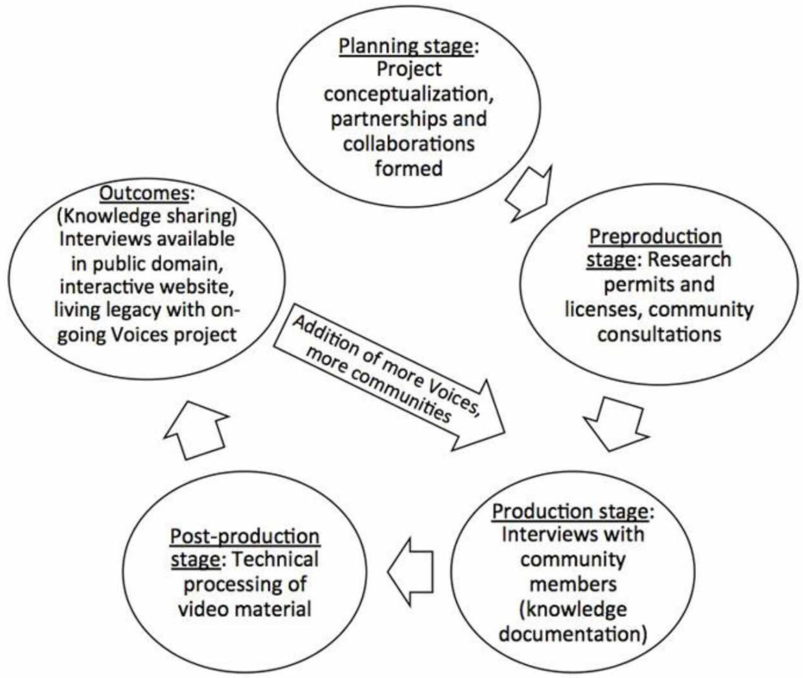

Figure 1. Process flow diagram for the Voices Project. Details of activities involved at each stage are provided in Table 2.

Figure 2. Map showing the six participating communities of the Voices of the Caribou People project along with the ranges of North American caribou herds (Adapted from Gunn et al. 2011).

Table 1. Participant-defined goals and literature-based challenges for accomplishing those goals. Our criteria for evaluation of Voices of the Caribou People Project were how successfully we (1) overcame the challenges and (2) accomplished community goals.

Objectives of Voices of the Caribou People project based on the indigenous participants' goals:	Methodological and philosophical challenges identified in documenting and communicating local knowledge through participatory videography:
Document the Caribou People's local knowledge and observations about the changes taking place in their Human-*Rangifer* Systems to create a repository of knowledge for the communities and their future generations.	Participatory research: research fatigue, respondent burn out (Cullen 2010, Moerlein and Carothers 2012).
Communicate the Caribou People's stories and perspectives with the outside world to inform the policy makers, northern researchers, and public at large about conditions in these Human-*Rangifer* Systems during the current International Polar Year (IPY).	TEK-related research: Deconstruction and/or fragmentation of knowledge, and danger of imposing nonlocal construct (Cruikshank 1998, Huntington 1998, 2000).
Facilitate sharing of the Caribou People's local knowledge and concerns to other northern communities faced with similar conditions and challenges to create a platform to share the strategies for coping with changes between communities.	Videography method: Technical and logistical challenges.

Table 2. The main steps in the process and important tasks of each step, as identified by the Voices Project.

PLANNING STAGE:

Conceptualize the project strategy: Initiate the project by contacting the communities of caribou-users in Alaska and Northern Canada, to invite them to participate in the project.

OBTAINING COMMUNITY APPROVALS & RESEARCH LICENSES:

Coordinate process of application for obtaining required permissions and research licenses from all applicable agencies: Institutional Review Board (IRB) at the University; various provincial institutions in Canada and consultations with each of the participating communities and project approvals from respective First Nation Tribal Governments.

FIELD WORK:

Work with the participating community residents (or collaborating local agencies?) to video-document interviews of community members. This included coordinating the logistics and carrying out the fieldwork: contacting interviewees, conducting and video-recording interviews, providing for translators wherever required, transcription of translated. The interviewees included elders, active hunters, community leaders, women, and children and they talked about the importance of caribou for them and the changes as observed by them.

LAB WORK:

Digitize footage. This means transferring all footage from the tapes on to hard drives in a digital format. This is used for creating and editing videos.

INFORMATION DISSIMINETAION:

To archive the video interviews on the Internet, making them freely available in the public domain. To send all the video material back to each of the participating communities and copies of video to respective participants.

FUTURE:

To create one consolidated documentary on summary of the North American perspectives. To extend the project to include indigenous communities from Greenland, Russia, and others interested.

Table 3. Profile information on the six participating communities representing heterogeneous social-ecological conditions.

Community name	Anaktuvuk Pass, (Alaska)[†]	Old Crow (Yukon Territory)[‡]	Wekweeti (Northwest Territory)[§, |]	Lutsel' Ke (Northwest Territory)[¶]	Arviat (Nunavut)[#]	Kawawachi-kamach (Quebec)[††]
Tribe	Nunamiut Eskimo (inland Eskimos)	Vuntut Gwitch'in (people of the lakes)	Tlicho (Dogrib, Dene)	Chipewyan, Dogrib	Inuit (Eskimo)	Naskapi (Iyiyiw)
Language	Inupiat	Gwitch'in Athapaskan	Tlicho 96% population speak the aboriginal languages	Chipewyan 77% population speak the native language	Inuktitut 93% population speak the native language	Naskapi Vast majority of community members speak Naskapi.
Population size	324 (2010), 84 households	267 (2008), 118 households	145 (2011), 35 households	310 (2011), 90 households	2060 (2006), 450 households	643 (2010), 134 households
Settlement size	12.7 Km²	14.15 km²	14.66 km²	43.01 km²	132 km²	41.44 km²
Geography	Lat: 68°08' N, Elevation: 670 m. Located in the Brooks range in Alaska's north Slope.	Lat: 67°34' N, Elevation: 250m. Northern most community in YT, situated by the Porcupine River.	Lat: 64°11' N, Elevation: 368 m. Located on the north shore of Great Slave Lake, 195 km north of Yellowknife, the capital of NWT.	Lat: 62°24' N, Elevation: 168m. Located on the East Arm of Great Slave Lake, 201 km east of Yellowknife.	Lat: 61°06' N, Elevation 10 m. Located on the western shore of Hudson Bay.	Lat: 54°52' N, Elevation: 580 m. Located 16 km northeast of Schefferville, on the Quebec-Labrador border.
History of establishment	The nomadic Nunamiut moved to the current location in 1949. In 1951, a post office was established and the former settlement was incorporated in 1959.	1870.	Wekweeti was an outpost hunting camp until 1962. The community was founded when the Tlicho elder and former chief Alexis Arrowmaker brought several families from Behchoko who wanted a more traditional lifestyle.	Lutsel' Ke was set up as the Hudson Bay Company Post in 1925. In 1954, homes were moved to the current site and in 1960 a school was built.	The Hudson Bay Company established a trading post at Arviat in the 1920s. The area had previously been used by the Inuit to hunt for seals, walrus, and whales. In 1957 because of starvation, other inland Inuit bands were relocated to Arviat by the Royal Canadian Mounted Police.	Formally settled in Kawawachikamach in 1981. Originally from northern Quebec, the Naskapi were subjected to several relocations before moving to recently founded iron-ore mining community of Schefferville in 1956. In 1978 they acquired the 41 km² of land from Quebec government and built the village of Kawawachikamach.
Economy	Subsistence hunting and trapping for food and clothing. Fur sale, sale of traditional caribou skin masks. Some, limited, outside seasonal employments.	Main source of livelihood is hunting trapping and fishing.	Subsistence hunting, trapping, fishing. Produce art and craft, jobs in the diamond mines and seasonal jobs outside town.	Subsistence hunting, trapping, fishing. Jobs in the diamond mines, outfitting for hunting and sport fishing, arts and crafts	Hunting and fishing. Well known for art and craft, and music talent	Hunting, fishing, trapping, arts and crafts, tourism, outfitting, and construction work.

Table 3 cont.

Income	Mean annual per capita income $15,200 (2007), 4.4% of population below poverty line.	Mean annual household income $28,244 (2006)	-- Information Not Available	Mean annual household income $58,611 (2009)	Median annual household income $45,184 (2006)	Median annual household income $45,312 (2005)

†Anaktuvuk Pass: Alaska 2010 - Summary Population and Housing Characteristics. 2010 Census of Population and Housing. United States Census Bureau. [online] URL: http://www.census.gov/prod/cen2010/cph-1-3.pdf

‡Old Crow: http://www.oldcrow.ca/

§Wekweeti: http://www.tlicho.ca/communities/wekweeti

|Wekweeti statistical profile. NWT Bureau of Statistics, GNWT report 2009 (survey did not include children under 15 years). http://www.statsnwt.ca/ community-data/Profile%20PDF/Wekweeti.pdf

¶Lutsel'Ke statistical profile. NWT Bureau of Statistics, GNWT report 2009 (survey did not include children under 15 years). http://www.statsnwt.ca/ community-data/Profile%20PDF/Lutselke.pdf

#Arviat: Statistics Canada. 2007. *Arviat, Nunavut (Code6205015). 2006 Community Profiles*. 2006 Census. Statistics Canada Catalogue no. 92-591-XWE. Ottawa, Ontario, Canada. Released March 13, 2007. http://www12.statcan.ca/census-recensement/2006/dp-pd/prof/92-591/index.cfm?Lang=E

††Kawawachikamach: http://www.naskapi.ca/en/Overview-1

Table 4. A performance evaluation of the Voices of the Caribou People project. TEK = traditional ecological knowledge.

Objectives	Opportunities	Challenges
Documentation and preservation of the community's TEK	Videos provide a useful and easy medium to document local knowledge. Videos align with how indigenous people teach and learn, by watching, listening, speaking, and following. The Voices Project was able to engage men and women of all three generations alike to share their knowledge and experiences. Each community received a set of DVDs containing all the material contributed by their members.	Lack of willingness to participate due to time conflict with subsistence or other activities. Hesitation in participation due to research fatigue and respondent burnout. Likely to face difficulties in gaining trust due to "lack of reporting the research findings back to the communities" from previous research projects that were conducted in the communities.
Communication of the communities TEK and outreach	Participatory videography is empowering to the communities because the process puts emphasis on the participants. The video content presents participants' point of view, opinion, and belief as a form of bearing witness and making a testimony. While communicating indigenous knowledge systems, there is a danger of deconstructing and misinterpreting an information piece when it is presented out of context. The unabbreviated videos in Voices Project help preserve the relevant context.	Challenges related to sensitivity of indigenous knowledge and stories to misinterpretation, and issues pertaining to access and dissemination of the indigenous intellectual property highlighted in literature. In certain cases, there was hesitation in sharing certain stories and observations because of the communities' ongoing land claims negotiations with the government agencies.

Table 4 cont.

Sharing of the Voices by making the videos freely accessible in the public domain	The internet provides a great platform for facilitating the information sharing. Resolves the issues of data ownership and access.	Issues of data ownership needed to be addressed and resolved a priori. Multiple technical challenges related to filmmaking and making large video datasets available through the Internet.

Chapter 3

Voices of the Caribou People: The Film[1]

ABSTRACT

A summary film, "Voices of Caribou People" interviews was produced.[1] The edition of the film in this dissertation was presented at the 2014 North America Caribou Workshop in Whitehorse, Canada. That film is archived with this dissertation. A summary of the Voices of Caribou People Project and all individual interviews with Caribou People are archived on the Arctic Council's Circumpolar Arctic Flora and Fauna (CAFF) web site: http://voicesproject.caff.is (Last accessed April 10, 2016).

[1] Bali, Archana and Gary Kofinas. 2014. *Voices of Caribou People*, HD video. Posted at Circumpolar Arctic Flora and Fauna (CAFF). http://voicesproject.caff.is

Chapter 4

In the Words of Caribou People: Local Perspectives on Changing Human-Caribou Systems of North America[1]

ABSTRACT

Many Indigenous communities of the North American Arctic maintain strong nutritional, cultural and spiritual ties with barren-ground caribou (*Rangifer tarandus*), identifying themselves as the "Caribou People." We drew on our work with the Voices of Caribou People Project examining how the Caribou People described on-going social-ecological changes in relation to caribou and their ability to lead a productive and healthy life. The Voices of the Caribou People Project (voicesproject.caff.is) encompassed video interviews of 99 individuals in six different communities of the North American Arctic, documenting current living conditions, local observations of change, and residents' concerns about social, ecological, cultural, economic, spiritual, and nutritional aspects of their changing relationship with caribou and environment (Bali and Kofinas 2014). Analyzing a sample of 34 interviews, we explored the questions: i) How do Caribou People describe changes in their system, ii) How have they responded to those changes, iii) What are the challenges they face in today's world, and iv) what do they feel they needed to meet challenges.

Caribou People reported that while aspects of traditional cultures persist, such as the nutritional needs for caribou meat and the practice of food sharing among kinship groups and elders, other practices have transformed to embrace modern life-ways, such as the use of new technologies for harvesting and uses of caribou products. Community residents described impacts of change to food security, ranging from more passive adaptations (e.g. needing to go beyond traditional hunting areas to find caribou) to transformations in hunting organization (e.g., hiring local hunters to procure caribou for an entire community). While scientists are highly focused on vulnerabilities from ecosystem changes resulting from climate change, Caribou People reported that they are more concerned with changes in social, cultural, and economic conditions, such as assimilation into modern society, threats from industrial developmental activities in homelands, the loss of traditional knowledge, and lack of economic opportunities. Respondents voiced a need for more information and resources to increase their capacity to

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[1] Prepared for publication in *Polar Research*, authored by Bali, Archana and Gary P. Kofinas.

respond to these challenges and greater authority in decision-making in matters that affect their livelihood.

INTRODUCTION

Barren-ground caribou (*Rangifer tarandus*) is the most important terrestrial subsistence resource for arctic Indigenous People of North America, providing both a source of substance and cultural identify (Kofinas and Russell 2004, Kofinas et al. 2007). Rapid social-ecological change raise concerns about the state of these systems and the future of traditional relationships of northern people and wildlife (Huntington et al. 2005, Klein et al. 2005). Understanding the nature of these changes and the challenges they bring to local residents is, however, problematic, with efforts confounded by imposed research agendas and constructs, highly structured research methods, power differentials, and limited opportunities for northern Indigenous People to express their perspectives in unfiltered ways (Smith 1999, Kovach 2010, Aikenhead and Michell 2011, Chilisa 2011)

This analysis drew on interviews of the "Voices of Caribou People Project" (herein referred to as the "Voices Project") to present local perspectives on human-caribou relations as reported by northern Indigenous Peoples during the second International Polar Year (2007-2009). Following a participatory videography method (Bali and Kofinas 2014), we interviewed 99 northern Indigenous People of rural communities in Alaska, Yukon, Northwest Territories, Nunavut, and Quebec who self-identified as "Caribou People" in an unstructured and self-directed platform for describing their relationship with the animal. The narratives of Caribou People from interviews encompassed a wide range of topics including traditional ecological knowledge of caribou, the human role in caribou systems, how human-caribou systems are changing, and what challenges Caribou People face in seeking to sustain their communities, how people are responding to changes, and what they feel they need to adapt. The Voices Project was undertaken as an activity of the Circum-Arctic *Rangifer* Monitoring and Assessment (CARMA) Network as part of its contributions to the International Polar Year.

BACKGROUND

From 2007-2009 the second International Polar Year brought together the most ambitious Arctic research program ever undertaken, involving more than 50,000 scientists from 60 countries, initiating over 170 scientific investigations and spending approximately US $1.2 billion (Krupnik and Hik 2011). Although the IPY program explicitly aimed to strengthen connections between science and Indigenous Peoples through cooperation in climate change studies, only 3% of all IPY funds (about $35 million) were spent on research to study "The Human Dimension" (Krupnik, personal communication, 2013). The majority of funding focused on human systems was awarded to non-Indigenous scholars who served as principal investigators of research projects, several of whom partnered with northern residents.

Despite the recently heightened interest in research on the human dimension of climate change (ACIA 2005, Hovelsrud and Smit 2010, Lovecraft and Eicken 2011), research documenting Indigenous perspectives on this topic and Indigenous needs with respect to adaptation are still relatively limited (Cochran et al. 2013). Much of the published literature focuses on what scientists have learned from local communities (e.g. Knapp et al. 2014, Brinkman et al. 2014, Jones et al. 2015), or what scientists believe Indigenous People and their knowledge can contribute to science (e.g., Huntington 2000). While these efforts are laudable, they typically generate products that *represent* local and traditional knowledge. They also raise questions about the quality of Indigenous knowledge documented by these project, the ways indigenous views of change are portrayed, and the extent to which Indigenous views can be "integrated" with (i.e. use for) more formal western traditions of knowledge projection (i.e. science). Miller et al. (2009) explored the power dynamics of knowledge production, and argued that integration of knowledge systems is limited, and the best approach is therefore "epistemological pluralism." We followed this thinking, with the findings of this analysis standing in parallel to other models of research.

Krupnik (2009) noted that in the first IPY venture (1882–1883) "Arctic Indigenous Peoples had hardly any documented voice, except by serving as 'subjects' for museum collecting or while working as dog-drivers, guides, and unskilled assistants to research expeditions". However, while the voice of Indigenous Peoples in the second IPY was far stronger and better integrated into the academic discourse, the strong interest in climate change framed much of the activities and research and thus, the ways Indigenous People were engaged in IPY activities.

In a review of 117 peer-reviewed publications from research on human dimensions of climate change in eastern Canadian Arctic, Ford et al. (2012) pointed out that a large majority of social science research in the Arctic explicitly focused on climate change impacts, adaptation and vulnerability studies. While traditional knowledge was utilized to document social-ecological change in these efforts, he noted there was still a pressing "need for critical reflection on methodology to incorporate TK" (Ford et al. 2012). We suggest that the singular focus of the climate change research agenda directs and biases the documentation of local perspectives, while not providing insights into the broader set of perspectives and concerns as held by the traditional knowledge holders.

We suggest that the strong academic focus on climate change largely reflects the current academic, economic, and political zeitgeist. Smith (1999) and other Indigenous scholars argued that past methods of science engaging Indigenous People in research was a form of western colonialism. Chapin et al. (2016) argued that community-initiated and directed research is more likely to contribute to community adaptation and well-being. Literature related to the effects of climate change on northern communities escalated in the 1990s and early 2000s (Larsen et al. 2010). These efforts raise the question of the extent to which the climate change agenda is of importance to those living in the North, as compared to other issues.

The IPY CARMA Network: The Voices Project received finding as part of the CARMA Network (Circum-Arctic *Rangifer* Monitoring and Assessment Network http://carma.caff.is/), an IPY program funded primarily by the Canadian Government IPY program and some support through an NSF project. Much of the scientific research of CARMA was focused on assessing the status of herds, amassing and comparing biophysical data, and developing much-needed standardized protocols for monitoring and assessing caribou populations and caribou health (Russell et al. 2000). Like the greater IPY focus, climate change was a central focus of CARMA activities and research, with limited studies examining the ecological implications land use change (e.g., industrial development) on ecological and social systems. CARMA Network gatherings occurred annually, and were largely composed of caribou biologists and agency managers, with some participation of Indigenous People.

The idea of the Voices Project emerged when Indigenous participants of CARMA expressed a need for their knowledge systems to be included in what had become a mostly scientific enterprise. The idea of capturing the changing social-ecological conditions in communities across North America, as perceived and reported by local users of caribou, quickly gained strong support among Indigenous and non-indigenous CARMA Network members. The Voices Project's participatory approach in engaging residents as well as its potential value in serving as legacy "data" for future generations were embraced and funded (Bali and Kofinas 2014).

RESEARCH QUESTIONS

While research on vulnerabilities and adaptation relating to climate change is clearly important, the Voices Project sought to document the universe of issues and concerns about human-caribou systems as expressed by Indigenous People. In doing so, we indirectly explored the question of whether the bias in funding and scientific activity on climate change is leading the scientific community to miss the mark in what is viewed as important to and for Arctic communities.

To maintain a broad perspective on local perceptions of change, we took a relatively unique approach to the documentation of Traditional Ecological Knowledge (TEK) and local observations. Most researchers enter a community and collect TEK with the desire to understand a particular research question. (See Ford et al. 2012 for review). Our research turned the tables and focused on identifying what the questions would be for the Indigenous community – and how those questions correspond to the scientific agenda and focus, and thus how Arctic people perceived 'climate change' among numerous factors affecting the sustainability of arctic Indigenous communities. Thus, the Voices Project documented the perspectives of Indigenous Peoples, asking:

- What do Caribou People perceive as changes in their human-caribou systems?
- How are Caribou People responding to changing conditions?
- What do they view as the critical challenges facing communities?
- What are their needs to meet those challenges?

METHODS

The objectives of the Voices Project from a methodological perspective were to:

1. Interview representative members of Indigenous communities that subsist on caribou and have a strong cultural relation with the animal;
2. Document their observations and perspectives about a variety of topics in an undirected and unbiased manner;
3. Identify and compile key topics and issues expressed by subjects;
4. Discuss Caribou People's perspectives in context of current science activities and academic literature.

To do this, the Voices Project used participatory videography in six indigenous Arctic communities across North American (Figure 1, Table 1) to document individual community members' observations of change and their concerns about social, ecological, cultural, economic, spiritual, and nutritional aspects of their changing relationship with caribou and environment. Archana Bali did all filming and conducted all the interviews. All interviews were edited for sound quality and are archived as a part of a permanent IPY collection of CAFF (voicesproject.caff.is).

Ford et al. (2012) pointed out there is an over representation select 'small, traditional settlements', in northern case study research, whereas a large number of other communities have no research engagement at all. Ford et al. (2012) called for broader inclusion of communities to allow comparative analysis leading to well supported generalizations. The six communities included in the Voices project represent a range of conditions in small northern communities inhabited primarily by Indigenous People, with the common denominator of having long-standing and intimate relationships with caribou. In the Voices Project we interviewed 99 community members across the six communities, including caribou hunters, elders, community leaders, women, and youth (Figure 1, Table 1, and Table 2). All interviews occurred in June and July 2008. We used an open format of interviewing that promoted self-expression, self-directed perspectives. We worked with local organizations (i.e., councils) to select Caribou People in their community to be interviewed and to the extent possible, included broad representative types of community members, as noted above. No bias toward English versus non-English language speakers was made. As needed, language interpreters were provided for those having a non-English preference. When interviewing, we did not include an explicit focus on any particular topic, such as climate change, and instead told subjects of our interest in human-caribou relationships, asked that they comment in whatever way they desired, and encouraged participants to express themselves as freely as they wished on all topics of their interest.

After the Voices Project interviews were completed, we asked our partner organizations in each of the participating communities to identify six people previously interviewed from their community who have knowledge of social, ecological, cultural, economic, spiritual and nutritional aspects of their changing relationship with caribou, and their environment. The community of Wekweeti had a total of only four interviews and all were included in the analysis. 34 interviews out of the total 99 were selected (see Table 2). The 34 selected interviews were transcribed using a grounded theory approach (Glaser and Strauss 1967, Strauss 1987), open coding was completed and code with the software Atlas ti version 7.0 (ATLAS ti 2013)., with codes and sub-codes identified and tabulated. Coding was partially completed by A. Bali, and completed by research assistant, E. Padilla. G. Kofinas organized codes into thematic areas.

The results from coding are reported bellow with limited reference to frequency. We limit quantification to be consistent with the oral traditions of Caribou People, reflecting the extent to which they referenced numbers in the narratives they shared. What emerges is a portrait of the observations, concerns, challenges and needs, expressed by North American Caribou People.

RESULTS

Demographics of Caribou People included in this analysis

Of the 34 selected Caribou People, 29 reported their age, with the sample ranging from 30 years old to Elders greater than 65 (see Table 3). Thirty-eight percent of respondents self-identified as Elders, 72 percent as caribou hunters, and 17 percent as formal or informal community leaders. Fifty-five percent were male and 45 percent were female. Table 2 reports the number of respondents by community included in this analysis and the total number of Voices Project interviews from each community.

Themes (results of open coding)

It is beyond the scope of this paper to report on all thematic areas identified. Instead, we highlight the construction of Caribou People's perspectives on i) the past, ii) change, iii) responses to change, iv) challenges Caribou People face in today's world, and v) what they feel is needed to meet their challenges. Open-ended interviewed generated discussions about a wide range of topics, with open coding yielding 20 general thematic areas (Table 4).

Remembering the Past: References to the past, both as stories from deceased Elders and personal experiences, were a common theme in interviews. Whether the discussion was about the times when there were no caribou, the resultant starvation of people, the way people followed traditional practices in past hunting, the role of leaders in organizing hunts and achieving community consensus, or colonialism by southern-based governments. The past was reported as a kind of baseline for understanding change and reference point for describing current conditions, possible futures, and ways of meeting challenges. People also reflected how their long association with place and caribou, and stories about the past through oral traditions serve them in responding to change. Several Elders talked about their own experiences at boarding schools and the lasting negative impacts that has had on them personally and for community well-being as a whole.

Discussions of traditional ecological knowledge (TEK) occurred when talking both about the past and the present. Caribou people described their traditional knowledge as being slow to accumulate, and how knowledge was passed from generation to generation. The content of caribou traditional knowledge included understanding the timing of caribou movements, the role of caribou leaders in directing caribou movements, the awareness of various caribou migration routes and river crossings, the collective action of community hunters working together to stalk and kill caribou, the skills of properly butchering caribou, the importance of respecting and not wasting, and the knowledge of what parts to eat and how to prepare them. The obligation to share caribou harvests with others was also noted as a central tenant of caribou traditional knowledge and Indigenous worldview. Elders spoke of former days when people lived without electricity in sod houses, used dog teams, hunted by foot, stored food in underground ice cellars, and the extent to which hunters would go to avoid waste. The role of Elders was described as a key part of Caribou People's history, and in imparting TEK and traditional practices with others.

Perceptions of Change: Caribou People's views on change were expansive, describing a wide range of topics, from descriptions of changes in caribou, caribou health, and general biophysical changes, to the many dimensions of change in culture, the socio-economic arena, and systems of governance. See Table 5.

People's discussions were typically offered as holistic assessments that did not parse the ecological from the social, but instead constructed change as sets of social-ecological dynamics. Attribution of causality was often referenced with personal observations. Changes in caribou were reported in considerable detail - changes in insect harassment and erratic caribou migrations due to climate change; changes in caribou numbers, health, and migration due to displacement and disturbance from diamond mines; in increase in skin parasites for particular herds. Of all the changes in caribou reported, changes in migration were most frequently mentioned. These changes were described as multidimensional - modifications of traditionally used caribou migration routes, a decrease in the density of caribou groups migrating, and changes in the timing of migrations.

Caribou people also reported changes in other species, such as the number of predators, birds, muskoxen, insects, geese, and walrus, (including those related to caribou, and in some cases were viewed as the consequence of disrespectful hunting, disturbance to the land, and the loss of traditional knowledge and practices (as discussed below).

Changes in land use were mostly described in the context of industrial development and resource extraction (i.e., mining and oil and gas). Oil and gas development impacts were highlighted where herds have had exposure to industrial activities, such as Alaska, with comments made both about how such exposure has had health effects on animals as well as on people. Caribou people also addressed changes in level of noise, resulting from an increase in the number of aircraft and number of roads and vehicles on roads. People in both Canada and Alaska talked about calving grounds as the most critical habitat for caribou, with a few Elders reminiscing about the use of young calves for clothing in a former time. Only a few people commented that development activities have not had an impact on caribou, with some indicating that a lag effect is likely and impacts likely to be observed at a later time.

The occurrence and effects of climate change were mentioned by about a third of the interviewees. Climate impacts were referenced by their consequences – increases in insects; reduced insect relief areas; a drying of the tundra; difficulties in processing caribou because of warm temperatures when butchering and drying meat; fewer winter storms; increases of fire frequency affecting caribou habitat, changes in seasonality (i.e., later fall weather and earlier arrival of spring) affecting migration; hotter summers being hard on caribou; the invasion of new species like white-tail deer; changes in snow conditions; more wind and rain; the erosion of landscapes.

Social and economic changes were described in great detail and more frequency than biophysical changes. These included changes in traditional practices, reduced human well-being, near disappearance of trapping as a livelihood, loss of food security, increased cash needed for hunting and overall participation in the subsistence economy, the greater presence in government assistance, the growth of government and its role in people's lives, increase in the cost of fuel, and cultural changes as in shifts in values and beliefs.

Changes in caribou hunting opportunities were referenced as the consequence of climate, ecological, social, cultural and economic conditions. Highlighted by many were the effects of changes in migration patterns, as noted above. Hunters talked about caribou now being further away and in fewer numbers, making harvesting success more difficult. Changes in landscapes from climate were said to affect access conditions, including trails and use of waterways. Changes in waterways included unsafe ice, changes in timing of freeze up and break up, and water levels and riverbed conditions (e.g., sand and gravel bars) in the summer months. In the latter case, Caribou People talked about changes in rivers damaging motors and making some previously used river channels inaccessible. Increases in forest fires were also mentioned as negatively affecting access to caribou hunting grounds. The shooting of caribou leaders (i.e., key caribou that direct herd movements) were also described as contributing to the changes in hunting. Some talked about an overall decrease in harvesting caribou by their community.

Often associated with changes in hunting opportunities were changes in Caribou People's traditional ecological knowledge (TEK) and in traditional practices for caribou hunting. The "loss" of TEK was mentioned by elders when talking about younger generations of hunters who no long follow traditional ways or have the knowledge to know when, where, and how to harvest. Loss of language was a part of many of these narratives. Faster or "quick hunts" were also seen by some as negative and disrespectful, while others felt that the change accommodated jobs and family life.

Caribou people also discussed changes that are associated with now living in permanent settlements, the benefits it has brought, as well as the negative aspects, such as a greater dependence on modern technology and need for money.

People talked about an overall decrease in the role of Elders as in guiding decision making and as teachers. They also referred the consequences of substance abuse (i.e. alcohol and some drug use), limited opportunities for jobs, the social problems of youth, their confused sense of identity, and the loss of people's "roots". Many articulated an overall transformation of community social cohesion, referencing the tight-knit community that existed in the past. Some also mentioned issues of out-migration of some community residents to urban centers, and the problems they face.

All changes were not reported as negative, with people describing the benefits of modern life, the opportunities that come with jobs through mining and other industry, the on-going interest by many in hunting and subsistence, and the efforts made at schools to preserve language and culture. Many people referenced change as part of a great transition of culture, community, and livelihood.

As noted above, coding of people's narratives on change revealed that social, cultural, and economic change were referenced with more detail and greater frequency than biophysical changes, with climate change being only a small proportion of those mentioned.

Caribou Peoples' Responses to Change: Reported responses to change fell into two categories – those that have occurred and those that are desired. Many of the comments regarding occurred responses to changes were in reference to actions to insure successful harvesting of caribou to meet community needs, such as employing hunters to harvest caribou for community members, working more with wildlife management agencies to address wastage by non-local caribou hunters, successful lobbying impose regulations on land use or non-local hunting, the establishment of formalize programs in which Elders teach youth TEK and youth participate in hunter education programs, and efforts to teach Indigenous language in school. Some people also spoke of new efforts to collaborate with scientists to conduct studies. At the individual level, one hunter spoke of using his woodstove more to reduce the cost of fuel. Some, however, suggested that the best response to changing conditions would be to return to a traditional way of life, return to the days of using dog teams, and give up modern conveniences of village life, like electricity.

Challenges of the Day: "Challenges" coded from interviews are listed in Table 6. Topics reported fell into several areas, including hunting, impacts on and disturbance to caribou, community-level challenges, and those related to governance. These areas touched in issues of threatened food security, the cost of subsistence, conflicts with non-locals, balancing traditional values and practices with interest in economic development, adapting to rapid change, managing community life, engaging governments, and finding solutions to difficult problems. About a third of these challenges fall in the area of being respectful of caribou and meeting community caribou needs. Social problems and "development" (i.e. oil and gas and mining) were commonly highlighted. Climate change was clearly part of the subtext of many narratives, but not explicitly referenced as a challenge.

Needs for Meeting Challenges: Caribou people told about things they need to meet their challenges. Needs fell into four categories - improved communication; more and better information and studies; maintaining community; and a stronger role in governance. See Table 7.

The focus on improved communication and cooperation were common themes found in Caribou People's narratives. These needs suggest a belief that through mutual understanding, challenges can be confronted and resolved. The need for more information and better research again, reflect the concern about industrial development, but also included needs for information about climate change. Many people commented that more studies needed to include the full participation of Caribou People and a role for their traditional knowledge. The need for greater unity, community cohesion, and planning were referenced where people acknowledged change occurring at rapid rate, and collective action is needed to maintain non-material values that are important to well being. Many people talked at length about the need for effective governance, including the need for communities to have a stronger say in decisions affecting their livelihoods and well being. Many of these comments referenced the quality and quantity of local engagement in resource management decision-making at the regional and federal levels.

DISCUSSION

Caribou People participating in the Voices Project used self-directed interviews to provide narratives about their relationship with caribou, how that relationship is changing, their efforts at responding to changes, the on-going challenges they face, and what they need to meet those challenges. They described their system in holistic terms in what sustainability scientists would call, "a dynamic, complex and integrated social-ecological system", in which humans are a key component. The wide range of topics and the similarities in observations, challenges, and needs among the six communities are striking.

The most consistent observation about caribou concerned changes in caribou migration, which was reported as affecting communities' ability to meet their food needs and thus, negatively impacting their overall food security. These reports are no surprise given the detailed traditional knowledge Caribou People have regarding the distribution and movements of caribou herds (Padilla and Kofinas 2014). Findings of the interviews attributed the changes in migration to ecological and social factors including changes in seasonality, disrespect by hunters, and disturbance from development activities.

Caribou people did talk about the effects of climate change and demonstrated they are acutely aware of how climate change effects are cascading throughout the system, but the more commonly cited concern and challenge was in the area of community economics. Participants noted the lack of jobs and economic opportunities, high cost of fuel and the overall high cost of modern lifestyle in relation to economic challenges. The most commonly cited societal challenges were loss of language, the loss of TEK in younger generations, and the loss of subsistence culture. The loss of TEK was in many cases attributed to loss of language, the transition to cash economy, and lack of time spent on the land engaging in traditional activities due to schools and jobs. In relation to this latter challenge regarding school and employment commitments, interviewees had concerns about hunters' tendency to perform "quick hunts," which were reported as contributing to the wastage of meat and viewed by all Elders as disrespectful behavior towards caribou. Interviewees in all communities noted that the reduction in caribou availability was due to changes in caribou distribution, population size, and timing of migration. This means caribou are fewer and dispersed further away from the traditional hunting areas. Interviewees note that in some cases, communities responded to changes in availability by designating or hiring experienced hunters to go further and perform collective hunts on behalf of the community. In some cases, communities hired bush plane pilots to locate herds and transport the appointed hunters. This strategy increased the cost of hunting, with interviewees emphasizing the close connections with economic concerns. When organizing hunts for a community in this way, the meat's reported use is mainly for the elderly and needy, then shared among other community members. Thus, new technologies and new forms of social organization for subsistence emerged while traditional values and practices persisted. The lack of caribou availability was, however, perceived as changing people's diets, which in turn reportedly had negative consequences for human health. Many elders noted that modern life was too easy and therefore unsatisfying, and there is a need to return to the old ways.

The use of modern technology is relatively recent for most of these Indigenous arctic communities (since 1970s), but it has quickly intensified in its application in all facets of their lives. As evident through many examples, people reported they were successfully adapting to dynamic conditions of life by employing modern technology to the fullest. A commonly reported adaptive response was the use of radio-collar information to determine a caribou herd's location, and employing this information for efficient subsistence hunting. Hunters agreed that radio-collar information improved caribou hunting, although some elders said that the use of radio collar information was a disrespectful behavior towards the animal.

Caribou people also talked about making use of modern technology to replace the loss of TEK about the knowledge of landscape. The use of caribou collars noted above is one example. Another is the use of GPS units for navigation, thus aiding in maximizing hunting opportunities. Older Caribou People mentioned how in the 70s under-ground caribou caches stored caribou meat and how today every household has chest freezers for long-term meat storage.

While technological advances have facilitated adaptation, interviewees noted they have also significantly altered traditional human-environment interactions. Since the 1950s, hunting methods changed from collective hunts to mostly individual, with occasional community hunts organized in times of limited caribou availability. While use of technology optimizes subsistence opportunities and enhances food security for some, it also reportedly brought a reduction in meat sharing for elderly and needy community members, hence compromised food security for others. As many respondents note, hunting has become very expensive activity, only those with jobs and cash income can afford to hunt regularly. Table 8 summarizes knowledge and perceptions of implications to communities, as described by Caribou People. Interviews revealed that certain aspects of the traditional culture persist, such as nutritional needs for caribou meat and food sharing within family groups or with elders.

Caribou People's narratives also highlighted dilemmas and their difficulties assessing trade-offs, such as the decision to support resource extractive industries and the jobs they bring verses the risk that caribou may be harmed from land use change. These dilemmas were described by some local leaders as illustrative of the inner struggles experienced by northern Indigenous communities and reflect difficult decisions they face.

The need for more information and better research expressed by the Caribou People contrasts with the singular focus of much of today's arctic science which is more exclusively focused on climate change. The need to be centrally involved in arctic research also contrasts with the role Caribou People currently hold in the northern science enterprise. These findings suggest that if science is to be of service to residents of the North and contribute to the sustainability of their ways of life, there is a need by the research community, including funding agencies, to reflect carefully on its areas of study, its view of acceptable research methods, the allocation of resources, and methods of communication about science in ways that allow for meaningful two-way dialogue and collaboration (Chapin et al. 2016).

It is also clear from the interviews that Caribou People are highly resilience to the changes they have faced, and continue to think carefully and deeply about their futures. The evidence from the Voices Project show how Indigenous people of the North have sought innovative solutions to novel challenges, greater authority in systems of governance, and working towards proactive ways to maintain their sense community, achieve human development, and maintain Indigenous values.

CONCLUSION

Caribou People interviewed in the Voices Project shared an in depth and multi-faceted understanding of the human-caribou systems of which they are part. Their knowledge went far beyond observations of change, to include a sophisticated understanding of causality, a linking of ecological process and human need, and a worldview that integrates spirituality, values, and sustainability.

A key finding of our research is that while ecosystem changes as a result of climate change are often considered by scientists as primary driver of social and ecological vulnerability in the Arctic, Caribou People interviewed here had less of a concern about the direct impacts of climate change and were much more concerned with social and economic challenges and changes. The interviews of this analysis support the conclusion that the challenging economic and social conditions of Indigenous communities that rely caribou are of far greater local salience than the impacts of climate change. These include the challenges of assimilation into modern society, threats from industrial development activities in homelands, incidental loss of traditional knowledge and indigenous languages, and lack of economic opportunities. With respect to adaptation to change, those interviewed voiced a need for more and better communicated information from researchers, managers, and politicians for increasing their response capacity. They also expressed a need for more studies in which they have a central role as partners.

Methodologically, the findings of this study illustrate the utility of documenting people's perspectives through an open-interview/videography approach that focuses on a broad set of social-ecological issues, and not through presumed and imposed questions generated by outsiders. Attention to community needs and challenges through appropriate research is critical if the science-policy interface is to successfully address how communities can shape their futures in a rapidly changing world.

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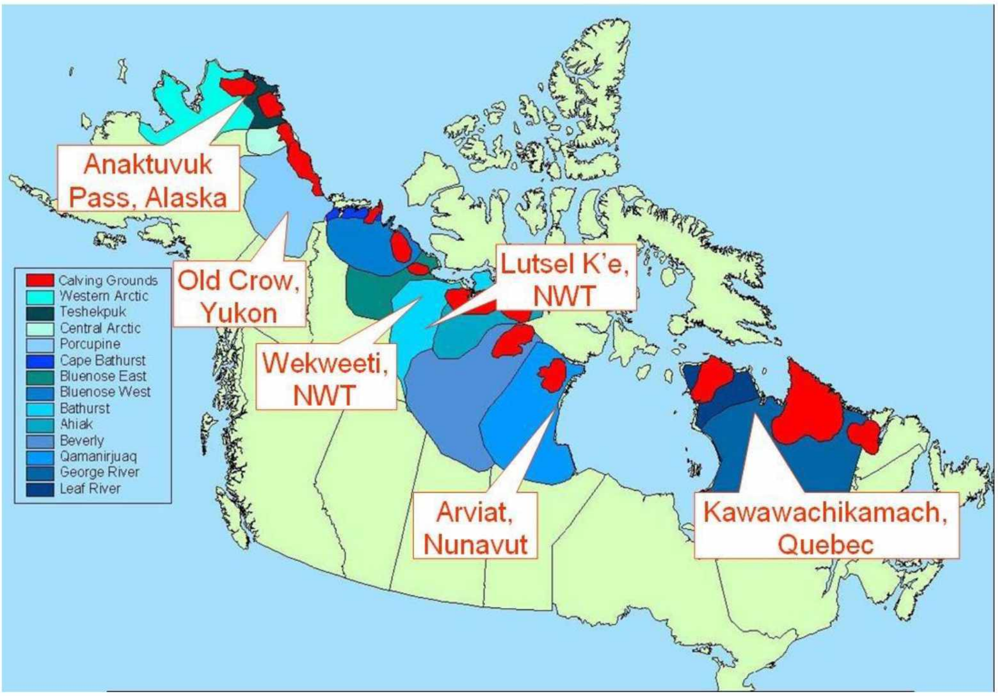

Figure 1. Study Communities of Voices Project and caribou herd ranges with calving grounds (red)

Table 1. Voices communities, population, herd harvested.

Community	Human Population	Herds harvested
Anaktuvuk Pass	249 (2007), 84 households[†]	PCH, CAH, TCH, WAH
Old Crow	267 (2008), 118 households[±]	PCH
Wekweeti	145 (2011), 35 households[§]	BCH, QCH
Lutsel K'e	310 (2011), 90 households[¶]	BCH,
Arviat	2060 (2006), 450 households[¶]	QCH
Kawawachikamach	643 (2010), 134 households[††]	GRH, LRH

[†]Anaktuvuk Pass: Alaska Native Village Statistical Areas
http://www.census.gov/geo/www/ezstate/anvsapov.pdf

[±]Old Crow: http://www.oldcrow.ca/ (accessed January 8, 2012).

[§]Wekweeti: http://www.tlicho.ca/communities/wekweeti (accessed January 8, 2012).

[|]Wekweeti statistical profile. NWT Bureau of Statistics, GNWT report 2009.
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[¶]Arviat: Statistics Canada. 2007. *Arviat, Nunavut (Code6205015)* (table). *2006 Community Profiles*. 2006 Census. Statistics Canada Catalogue no. 92-591-XWE. Ottawa.
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[††]Kawawachikamach: http://www.naskapi.ca/en/Overview-1 (accessed January 8, 2012)

Table 2. Interviews with Caribou People selected from the Voices Project.

Community Name	*Regional jurisdiction*	*culture groups*	*Number of interviews included (total interviews conducted)*
United States:			
Anaktuvuk Pass	Alaska	Nunamiut Inupiat	6 (of total 21)
Canada:			
Old Crow	Yukon Territory	Vuntut Gwich'in	6 (of total 19)
Wekweeti	Northwest Territories	Tlicho, Dene, Dogrib	4 (of total 4)
Lutsel K'e	Northwest Territories	Chipewyan, Dogrib	6 (of total 23)
Arviat	Nunavut	Inuit	6 (of total 13)
Kawawachikamach	Quebec	Naskapi	6 (of total 20)

Table 3. Age of interviewees.

Age (Years)	n= 34
30	4
38	1
41	5
44	3
50	2
≥50	2
62	1
≥65	11
No answer	5

Table 4. General topics discussed

The Past
Caribou Hunting
Traditional Practices
Traditional Ecological Knowledge
Changes in Caribou
Changes in Well-Being
Changes in Wildlife
Land Use Change
Climate Change
Impacts from Mining and Oil and Gas Development
Changes in Hunting
Opportunities
Social Change
Language Loss
Loss of Traditional Ecological Knowledge
Challenges
Social-Political Conditions
Political Engagement
Responses
Solutions
Needs

Table 5. Major topics of change, as described by the Caribou People.

Changes in Caribou
Changes in Well-Being and Health
Changes in Wildlife
Land-Use Change
Climate Change
Impacts from Mining and Oil and Gas Development
Changes in Hunting Opportunities
Social Change
Language Loss
Loss of Traditional Ecological Knowledge
Changes in Governance Systems

Table 6. Today's challenges, as expressed by the Caribou People

Hunting	• Knowing when and where to hunt with unpredictable migration routes
	• Disrespectful hunting by outfitters and sport hunters
	• Disrespectful hunting methods affecting caribou availability
	• Disrespectful hunting methods by young indigenous hunters
	• Meat wastage
Disturbance	• Displacement of caribou because of habitat loss
	• Disturbance by aircraft
	• Conflicts with sport hunters
	• Managing development with indigenous values and traditions
	• Balancing the modern economy and the traditional economy
Community	• Use of radio collar data for locating caribou and planning hunts
	• High cost of hunting
	• Adequate jobs
	• Alcohol and drug abuse
	• Teaching youth
	• People not being united in thinking and in efforts to resolve problems
	• Managing community in a state of transition
Governance	• Dealing with disagreement between Caribou People and government agencies about caribou numbers
	• Lack of support and subsidy from government for communities
	• Consequences of development bringing an influx of outsiders
	• Finding workable solutions to problems
	• The rapid increase in world population

Table 7. The Caribou People's stated needs for coping with the future.

Improved communication	• Universities and researchers • Other indigenous groups • Hunters • Developers • Scientists (with respect to caribou diseases)
More and better information and studies	• Impacts of climate change on people, caribou, and environment • Impacts of industrial development on caribou • For making decisions about caribou, the Caribou People, and industrial activities • Methods for maintaining healthy caribou population levels • Better monitoring of impacts of environmental changes on caribou herds • Better (smaller/lighter) devices for tracking caribou.
Building and maintaining community	• More unity among community members • Long-term planning for the community to measure impacts of industrial development • Education of younger generations on how to respect caribou • Ways of reducing meat wastage • Jobs
Effective governance	• Greater involvement and engagement in decision making to protect caribou • Authority to stop some human activities (e.g., uranium mining) and create no-fly zones • Creative solutions to problems

Table 8. Summary of Caribou People's knowledge of change and their perceptions of the implications to community life ways.

Type of change	Direct Effects	Time Scale	Indirect Effects	Implications
Ecological	Climate Change: Variability in weather patterns, timing of river freeze up/ break up; snow; variability in intensity and seasonality of winter/ summer; drying up of lakes, wetlands	Short to long-term	Unsuitable conditions during caribou spring migration, dangerous traveling for hunters on land and water. Warmer weather makes meat storage difficult.	Food security and personal safety
	Changes in Vegetation: plant phenology, plant diversity, abundance, northward expansion of shrubs	Long-term	May cause changes in habitat for caribou, other wildlife	Food security
	Changes in Caribou: health, population, distribution, habitat quality, migration routes, new parasites	Short to long-term	Changes in access to and availability of caribou	Food security
	Changes in other wildlife: migration timing of waterfowl, fish, beaver, arrival of new species (northward expansion of ranges)	Short to long-term	Changes in availability of alternate subsistence resources	Food security
Land-use change	Roads and infrastructure development	Long-term	Disturbance and stress to caribou, changes in migration route, disturbance to other wildlife. Invasive species. Easy access to wildlife resources	Food security. *Enhanced subsistence opportunities. Increase in non-local hunters, and disrespectful hunting methods*
	Industrial development: oil and gas, mining and exploration	Long-term	Disturbance to caribou and other wildlife, pollution, contamination. Creation of job opportunities.	Food security and social well being
	Sport hunting/ out-fitting	Long-term	Competition with local hunters	
Economic change	Transition to cash-based economy.	Long-term, intensified in recent years	Increased dependence on jobs to maintain ability for subsistence hunting and gathering	Food security and social well being
			Increased cost of living. Reduced opportunities to engage in traditional activities and life-style	
Socio-Cultural change	Exposure to western/ modern culture	Long-term	Issues with assimilation in modern society: school, alienation, exposure to drugs and alcohol	Reduced social well being, native-identity issues, reduced health.

Table 8 cont.

	Engagement of youth in traditional activities	Long-term, increased in recent years	Loss of language, reduction in inter-generational transfer of traditional ecological knowledge. Changes in ways of caribou hunting, butchering and meat storage. Wastage of meat.	Food security. Social well being. Loss of culture.
	Changes in diet, availability, procurement, storage and consumption of traditional foods	Long-term, increased in recent years	Increased dependence on non-native foods; Access to non-traditional foods causing health problems.	Food security, health and social well being
Socio-Political change	Land Claims			Need information for decision making
	Research Engagement	Recent years		Access to information
	Engagement with oil and gas industry	Recent		
Technological advancements	Access to modern housing, heat and electricity	Over decades	Higher cost of living, very high cost of energy in remote communities.	Increased dependence on jobs and cash-economy
	Access to modern communication technology	Over decades, but intensified in recent years	Access to radio-collar information enhances access to caribou and hunting success. Use of radio and GPS enhances safety on land.	Optimizes subsistence opportunities and enhances food security. Changes in human-environment interactions
	Changes in modes of transportation on land and hunting methods	Over decades	Changes in hunting methods: from collective to individual; from dog-teams to ATV and snow-machines. Easier access to subsistence resources. Increased cost of subsistence hunting and food procurement.	Implications for food security, and social well-being. Changes in human-environment interactions.

Epilogue

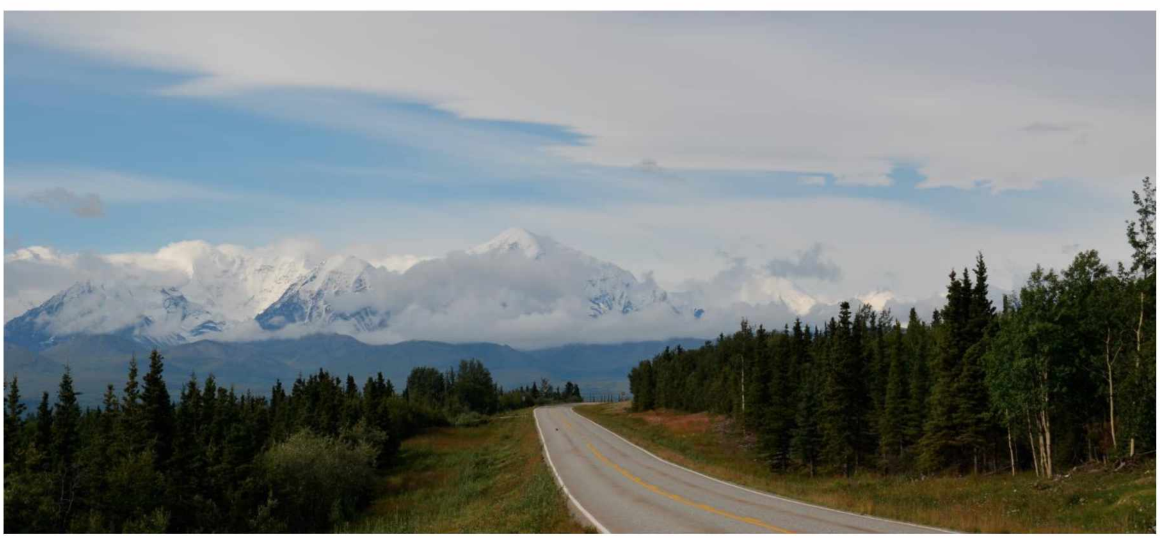
REMEMBERING

Eulogies by Archana Bali; originally written for Yusuf Mamu; October 27, 2012.

We have had a loss of a dear friend. Our hearts ache and nothing seems to cure it. But let us think of what we can do for others in their names, those who have left us... whether here or far away.

Whatever happened is the only thing that could have happened.

Nothing, absolutely nothing of that which we experienced could have been any other way. Not even in the least important detail. There is no "If only I had done that differently... then it would have been different..."



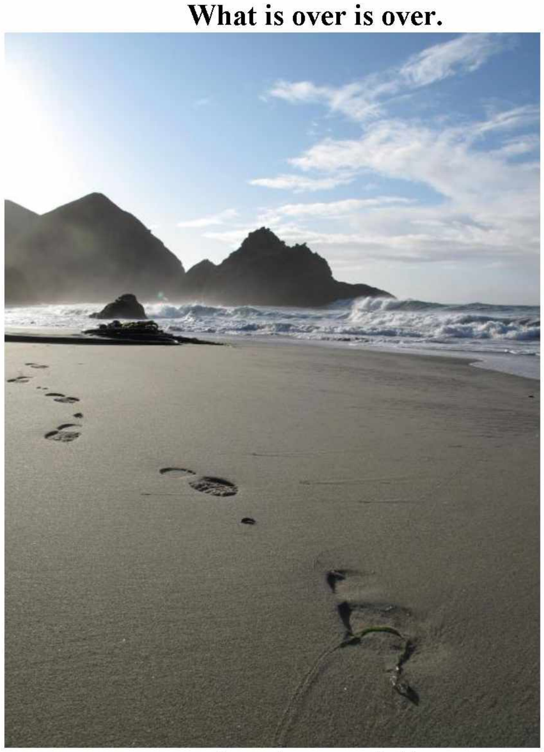
Whomsoever you encounter is the right one.

No one comes into our life by chance. Everyone who is around us, anyone with whom we interact, represents something, whether to teach us something or to help us improve a current situation.

Each moment in which something begins is the right moment.

Everything begins at exactly the right moment, neither earlier nor later. When we are ready for it, for that something new in our life, it is there, ready to begin.

What is over is over.



It is that simple!!

When something in our life ends, it helps our evolution. That is why, enriched by the recent experience, it is better to let go and move on.