

Alaska Park Science

National Park Service
U.S. Department of Interior
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Anchorage, Alaska



Connections to Natural and Cultural Resource Studies in Alaska's National Parks

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Gulf of Alaska

Cover Photo.
NPS photograph by K. Joly

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Backcover Photo. The 2006 excavation crew: (from left to right) Mike Hammons, William Hunt, Anne Pollnow, Amanda Davey, John Gapp, Israel Ginn, Mikile Fager, Anne Vawser, Josh Meabon, and Ricky Goodall.

Article on page 42.

Scars on the Tundra ►
Article on page 16.

A stockpile of small arms cartridges, presumably originating from Canadian forces. Such small artifacts are at risk from looting by unsupervised visitors.

Photograph by Dirk H.R. Spennemann

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Phil Brease, 1950-2010

Phil Brease died May 12, 2010, in the field, sharing his knowledge of park geology with students. Teaching was a role he loved, whether the students were youngsters on a field trip or colleagues in the NPS.

Phil started his career as a professional musician, but was quickly sidetracked by his love of geology. He graduated from Central Washington University and worked for multiple agencies before coming to Denali in 1986 to work on mining evaluation. Phil's work with mining in the park transitioned over time from the

contentious job of evaluating mining plans and claims, to the significant challenges of restoring mined lands. Phil excelled at developing cooperative research relationships and throughout his career facilitated research with a wide network of educators, geologists, and paleontologists.

Phil's contributions to park geology and paleontology were many. His efforts to improve understanding of park geology and his fostering of the park's newly recognized paleontological resources were especially important. His exceptional wit and excitement was

infectious as he communicated colorful geologic stories to countless and diverse audiences.

Phil exemplified the goals of this publication: developing science in the parks and communicating that science to a broad range of the public. Phil's name will live on in the minds of many researchers, park staff, visitors and school children, as well as in the Devonian *brachiopod* named in Phil's honor, the *Myriospirifer breasei*.

Meg Hahr, 1967-2009

Meg Hahr and her husband, Sidney Shaw, left Alaska in March 2009 when Meg accepted the Chief of Science and Natural Resources position at Pictured Rocks National Lakeshore in Michigan. She loved her work and had a bright future ahead of her with the National Park Service. Meg died suddenly on June 21, 2009, after a mountain bike accident near her new home.

Meg started her NPS career studying lynx, fisher and wolverine in Glacier National Park during the late 1990s. While there, she completed her Master's degree with the University of Montana. In 2002, Meg arrived in Alaska as the Natural Resource Program Manager at Klondike Gold Rush National Historical Park in Skagway.

She molded the park's fledgling Natural Resources program, inviting others to share her enthusiasm for the unique natural resources of the park. In the Taiya River Valley, in the heart of historic Dyea, staff are treated to her most visible accomplishment – each

summer a muddy pond, trampled by horses, transforms into a beautiful field of irises surrounding a small clear running stream. The Nelson Slough restoration showcased the park's mission of resource protection in a way that many projects could not.

She also began a process that led to the inventorying of the park's lichen community and the discovery of several hundred never before identified species. One new species was named *Coccotrema hahriae* in her honor. Less visible was her influence on seasonal staff whom she mentored with great care, and her coaching of the founders of Taiya Inlet Watershed Council who recently restored Pullen Pond and Creek. She was well-loved in the small community of Skagway.

Meg transferred to Kenai Fjords National Park as the park's Ecologist in 2006. She was instrumental in the backcountry campsite monitoring project reported in this issue. Meg cared deeply about the park's resources

and worked tirelessly to understand and protect them. She conducted seabird colony counts, coordinated bear management activities and worked with the Southwest Alaska Inventory and Monitoring Program marine nearshore sampling program. She worked hard, but also had fun at her job. Her dedication, love of the park and quiet sense of humor made working with her a pleasure.

Meg was an intelligent, energetic, and articulate advocate for natural resources. At Kenai Fjords her legacy continues. We will be conducting new projects on peregrine falcons and additional seabird research in the next few years as a result of Meg's vision and excellent proposal writing skills.

She will always be remembered for her unfailing kindness, her generosity of spirit, and her genuine humbleness. With Meg's untimely death at 41 years old, the National Park Service lost a rising star, and she is deeply missed.

The Rewards and Risks of Working in Alaska's National Parks

By Robert Winfree

As we were working to prepare this issue of Alaska Park Science, the NPS science and resources community received sad news that several close friends and colleagues had passed away. Meg Hahr and Phil Brease were active participants in two studies published in this issue. Four others, Mason McLeod, brothers Neal and Seth Spradlin, and pilot Marco Alletto were lost in a tragic accident when their plane went down while returning from fieldwork in Katmai National Park and Preserve.

Losing a close friend and coworker is hard, regardless of the cause. The shock of learning that it occurred unexpectedly through a severe accident or other medical emergency compounds our sense of loss. For those of us who share a love of the natural world, and who value a sense of adventure and self-reliance, the time we spend in parks often feels like our dream come true.

Our love of the outdoors may seem reason enough to spend time in parks, but we have learned from experience that successful fieldwork results from preparation. We train for our job; plan for severe weather, wildlife hazards and challenging travel; and try to anticipate other contingencies. We carry emergency gear and extra supplies, but teamwork and good judgment are the most important tools we bring to difficult situations.

Sometimes, after successfully working through a difficult situation, we realize that luck was with us. Other times however, our own resources may not be enough, and we have to seek help from others. These situations give each of us cause to reflect on the time we spend in remote and hard-to-reach locations, where help is often far away. Have we done everything we can to ensure that we, and the people around us, are prepared to deal with unexpected contingencies? What else can we do before our next trip to ensure

that it will be our best and not our worst trip ever?

Our work in national parks is important to us and to others, but nothing we do in the national parks is as important as ensuring that everyone returns home safely at the end of the day.



Phil Brease, 1950-2010



Meg Hahr, 1967-2009



NPS Photograph



NPS Photograph



Alaska Geographic Photograph



NPS photograph by Shelley Hall



NPS photograph by Christina Kriedeman

Photograph courtesy of Allen Fukuyama



Understanding Moraine Formation Around the Muldrow Glacier, Denali National Park and Preserve

By Jason M. Dortch, Lewis A. Owen, Marc W. Caffee, Phil Brease

Introduction

Recent climate change models show that Alaska is likely to see the effects of climate change at faster rates than mid-latitude areas, such as the lower-48 states (IPCC 2007). To understand how climate change

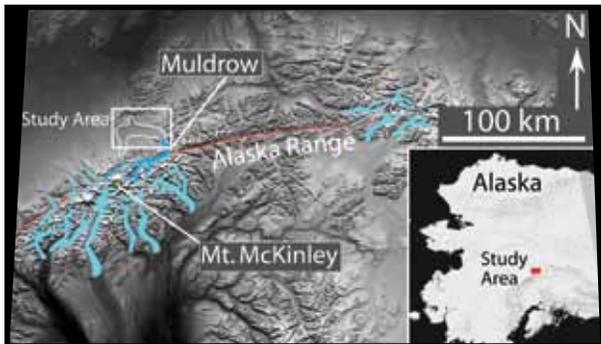


Figure 2. IKONOS satellite image of the Wonder Lake area, showing the McKinley River, the extent of glacial stages and sample locations (modified from Werner and Child 1995). Note that moraine X (green) and moraine Y (light blue) are two of many moraines in the area.

Image courtesy of IKONOS

Figure 1 (Left). Dr. Lewis A. Owen taking a photograph of a boulder surface that was sampled for this study.

Photograph courtesy of Dr. Jason Dortch

will affect geologic systems, we find clues about how geologic systems responded to past climate changes by examining glacial geologic records. Denali National Park and Preserve (Denali) is an example of a heavily glaciated area that contains such clues. In Denali, the sediments and landforms that glaciers produce record the nature and timing of past climate changes, and they hold the key to helping predict Alaska's future climate.

Glaciers are sensitive markers of current and past climatic conditions, mainly temperature and precipitation. Changes in temperature and precipitation alter the size and position of a glacier. Cooler temperatures combined with increased snowfall will cause a glacier to advance, whereas warmer temperatures and/or decreased snowfall will cause a glacier to thin and retreat.

The glaciers in Denali were considerably larger in the past than they are today (Figures 2-3). When glaciers melt they leave behind ridges of debris called moraines that can be used to reconstruct their former positions (Figure 3a). The McKinley River area contains several moraines left by Muldrow Glacier. These moraines are used as a standard to compare the timing of glaciation in other regions of Alaska (Reed 1961, Ten Brink and Waythomas 1984) (Figure 2).

Historically, radiocarbon dating and lichenometry (measurement of certain lichens that increase in size at a constant rate every year) were used to determine the ages of glacial landforms in the McKinley River area

(Bijkerk 1980, Werner 1982). These techniques can only be used to date organic material younger than ~50,000 years. Since much of the glacial debris and landforms are devoid of organic material and may be older than 50,000 years old, these techniques will not work. A relatively new method, cosmogenic radionuclide dating, can be used to obtain ages on glacial debris and landforms from 100 to over 1 million years old. The secondary neutron cascade produced by galactic cosmic rays (mostly hydrogen atoms stripped of their electrons) penetrates Earth's atmosphere and bombards the uppermost rock surfaces causing nuclear reactions in the atoms comprising the rocks. Beryllium-10 (^{10}Be), in particular, is produced from oxygen and silica in the rock. The ^{10}Be production rates are known. By determining the amount of this radionuclide in a sample, we can calculate how long that rock has been sitting on the surface of Earth.

However, there is a catch. Beryllium-10 dating of moraines that are less than 10,000 years old may give younger ages than radiocarbon or lichenometry ages from the same landform. This occurs because the methods are dating different stages of moraine development. For example, if a rock on a moraine rolls over, a new rock surface that has not accumulated ^{10}Be will be exposed. Sampling this new surface can give ages that are too young. In Alaska, many of the moraines have a core of ice that melts slowly and causes the boulders on the surface to roll. Cosmogenic dating

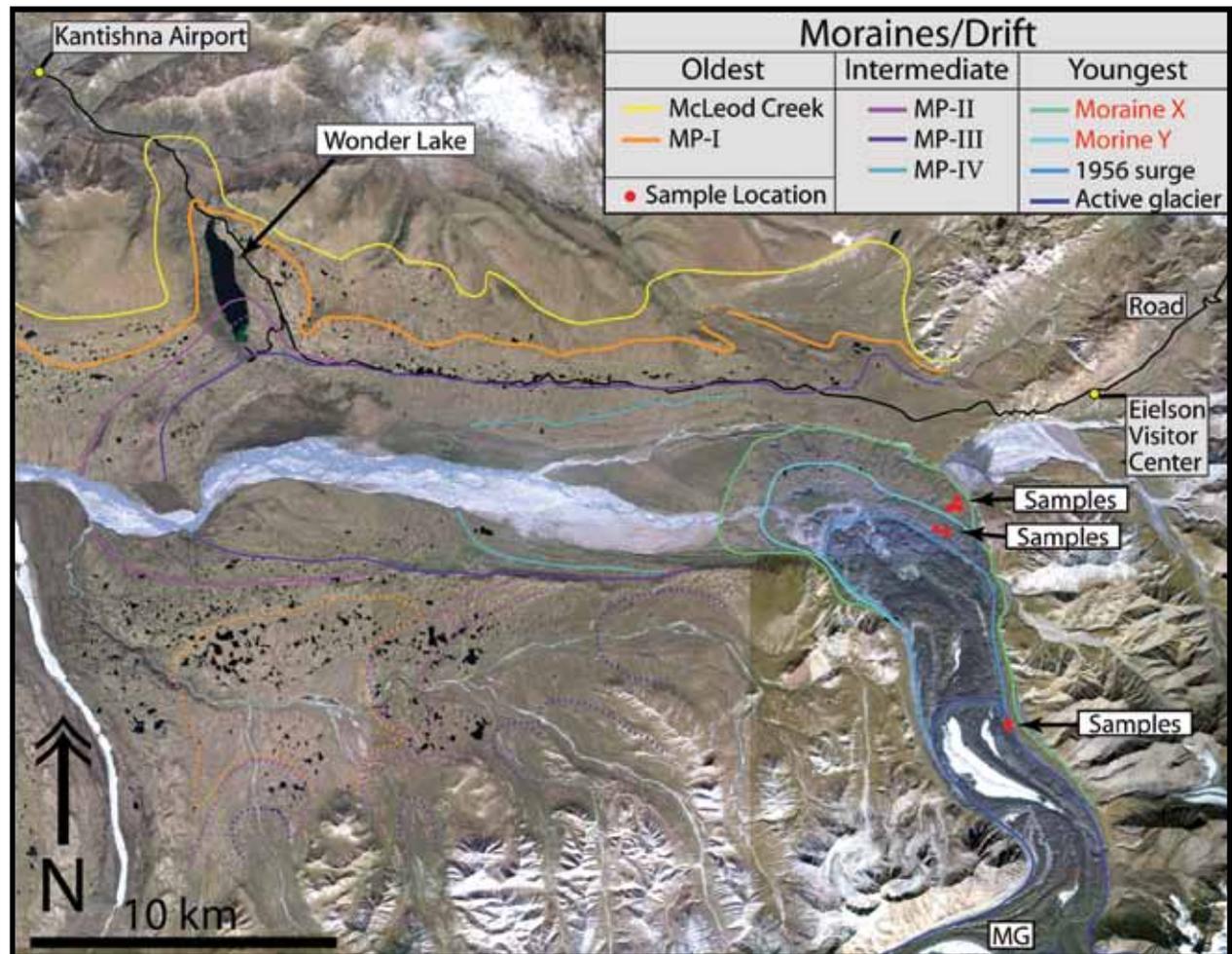


Figure 3. IKONOS satellite image of the Wonder Lake area, showing the McKinley River, the extent of glacial stages and sample locations (modified from Werner and Child 1995). Note that moraine X (green) and moraine Y (light blue) are two of many moraines in the area.

determines the stabilization age of glacial landforms, when the ice core has melted. Other dating techniques such as radiocarbon dating and lichenometry give the age of when the glacial debris was first deposited.

Many of problems associated with ^{10}Be dating have been addressed in numerous studies (Balco *et al.* 2009, Gosse and Phillips 2001, Hallet and Putkonen 1994, Owen

et al. 2008, Putkonen and Swanson 2003, Putkonen and O'Neil 2005); however, the time lag between deposition and stabilization of moraines has received little attention (Briner *et al.* 2005). Quantifying the time lag between deposition and stabilization is essential for understanding and comparing recent fluctuations in glaciation that are driven by climate change.

Purpose and methods

The primary issue we are exploring on the northern side of the Alaska Range is the lag time between deposition and stabilization of moraines. A key clue is whether unstable moraines have near zero ^{10}Be ages. To assess these two issues we refer to two test moraines, referred to here as moraine X and moraine Y.

The deposition age of moraine X has already been defined through lichenometry, so we can quantify the time lag between moraine X's deposition and stabilization using ^{10}Be dating. The time between moraine stabilization and moraine deposition is determined by subtracting the ^{10}Be age from the lichen age.

The second issue is explored in moraine Y. Werner (1982) argued that moraine Y is unstable and the active ice is by definition "unstable". If our hypothesis is correct, then unstable landforms should yield a zero ^{10}Be age.

Data gathering and research involved remapping the extent of moraines previously mapped by Werner (1982) in the McKinley River area using field methods, aerial photography, and IKONOS satellite imagery, provided by Denali National Park and Preserve. Samples for ^{10}Be dating were collected by chiseling small amounts of rock from the upper 1 to 2 inches (2.5-5 cm) of large granitic boulders on moraines. Multiple samples on each landform enabled statistical analysis of age populations as well as further examination of landform stabilization processes.

The rock samples were subjected to a series of chemical leaches, dissolution, and chemical separations to isolate the Be atoms. Measurements of the separated ^{10}Be atoms were obtained using an accelerated mass spectrometer at the Purdue Rare Isotope Measurement Laboratory at Purdue University. The number of measured ^{10}Be atoms is divided by the rate at which they accumulate in rock surfaces to yield an exposure age. The exposure age tells us how long the boulder's surfaces have been exposed to cosmic rays on Earth's surface.

Moraine ages

Moraine X

Moraine X is about 1 mile (1.6 km) wide, and is stable with no evidence for active slumping or exposed ice walls (Werner 1982) (Figures 3, 4b). Seven samples were collected from six boulders for ^{10}Be dating.

Statistical analysis of ^{10}Be ages revealed a strong grouping of ^{10}Be ages at 540 years. This age is interpreted to represent the stabilization of moraine X. The difference between the lichen age ($>1,800 \pm 100$ years) (Werner 1982) which represents moraine deposition and the ^{10}Be age which represents moraine stabilization (540 years) is the time lag between moraine deposition and stabilization (1,260 years).

While the lag time is not significant in relating glacial sediment that are $>100,000$ years old, it could have adverse affects on comparison of young moraines ($<10,000$ years old), and between areas using mixed chronology techniques, such as radiocarbon, lichenometry, and dendrochronology. This is particularly important for studies focused on recent climate change. For example, if several moraines were determined to be 2,700 years old, some dated using lichenometry and others using ^{10}Be , then comparing the extent of glaciation based on moraine ages would be inappropriate. The moraines dated using ^{10}Be may in fact be 1,300 years older (i.e. were actually deposited 4,000 years ago but stabilized 2,700 years ago), which would alter estimates of glacial retreat and provide an incorrect estimation of the 2,700 year old Neoglacial extent to climate modelers.

Moraine Y

Moraine Y ranges from 0.25 to 1.25 miles (0.4-2.0 km) wide (Figure 2). Werner (1982) argued that moraine Y is unstable based on the presence of active slumping, streams originating from outcrops, and several outcrops of glacial ice (Figure 3c). We concur with this view. Four samples were collected from four boulders for ^{10}Be dating.

The ^{10}Be ages did not pass statistical analysis. This

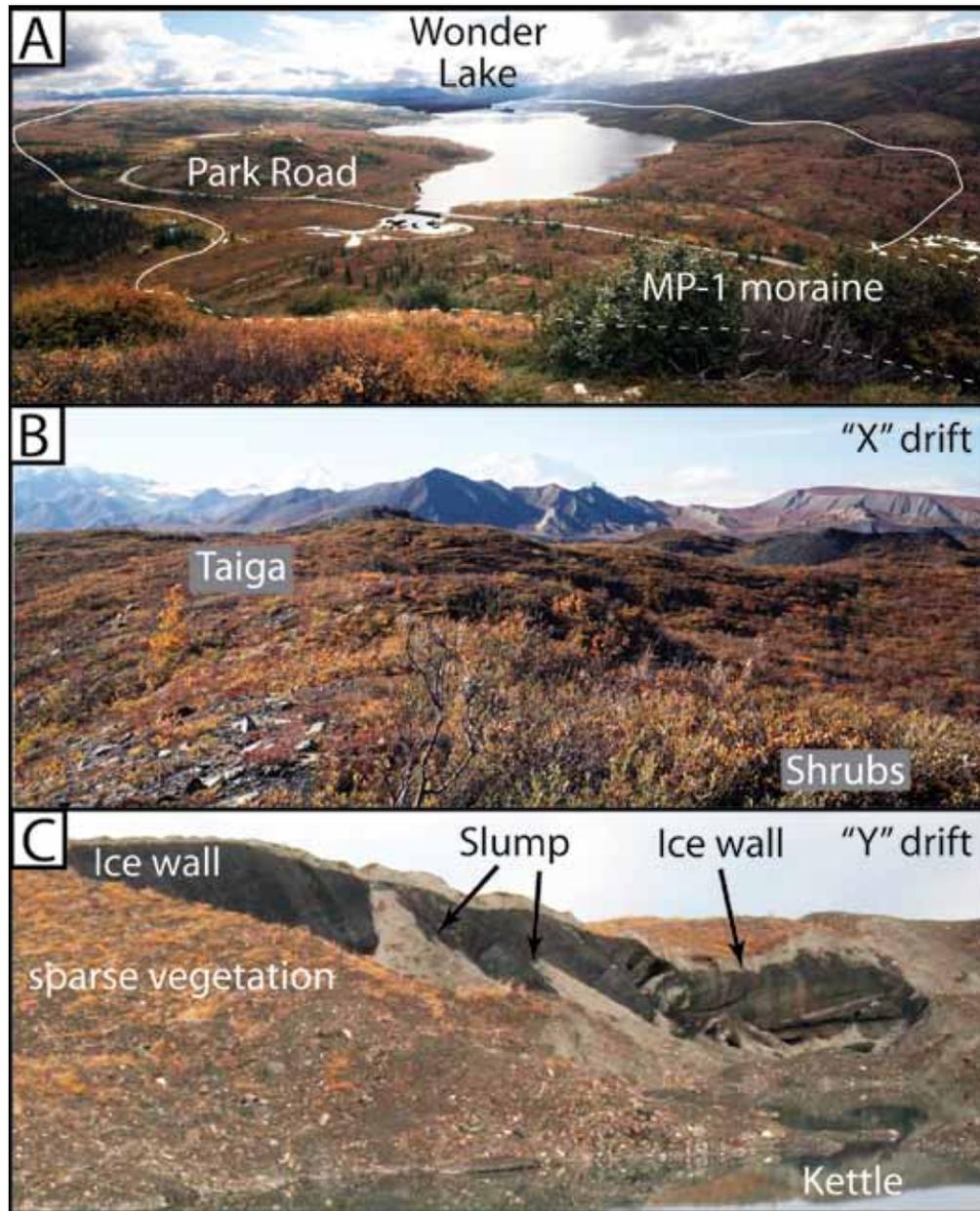


Figure 4. (Right) Views of recent moraines: A) looking south at Wonder Lake and the hummocky MP-1 ground moraine; B) view of moraine X; C) view of moraine Y ice core. Dense taiga and tundra cover all stable moraines making their morphology difficult to see. Dashed lines mark glacial limits obscured by vegetation or distance.

Photographs courtesy of Dr. Jason Dortch

was expected because moraine Y is unstable; the ^{10}Be ages should be close to zero and not cluster together. The ^{10}Be ages provide insight into the stabilization process. The age of moraine Y was estimated at 900 years using lichenometry (Werner 1982). Three boulders have a zero ^{10}Be age, which confirms our hypothesis that boulders very likely move as the ice core melts out and the moraine stabilizes. One ^{10}Be age was almost twice as old as the lichen age, which tells us that prior ^{10}Be accumulation occurred when the boulder surface was still part of Mt. McKinley or when the boulder was carried on top of Muldrow Glacier. This boulder will likely be broken and rolled during the stabilization period, which will eventually reset the ^{10}Be age to zero.

Active ice

The active Muldrow Glacier is mainly covered by thick debris on its surface (supraglacial debris). There is also bare glacial ice, exposed ice walls, and small kettle lakes. Samples collected from boulders on active ice should have a zero ^{10}Be concentration because they have only been recently exposed. Four boulders were sampled for ^{10}Be dating from the active glacier to check for prior ^{10}Be accumulation.

Three of the ^{10}Be ages on the active Muldrow Glacier are within error of a zero age, which confirms our second hypothesis that boulders will very likely move again as the ice core melts out and the moraine stabilizes. One sample, with an age of 1,900 years, has significant prior ^{10}Be accumulation. This one boulder will likely be broken and rolled during the stabilization period, which will eventually reset the ^{10}Be age to zero. As with moraine Y, the importance of ^{10}Be accumulation before moraine stabilization appears to be minimal.

Conclusions

Only two ^{10}Be ages, one each from moraine Y and the active ice, have prior ^{10}Be accumulation on boulder surfaces. This is likely due to the continued toppling, exhumation, and break up boulders experience dur-

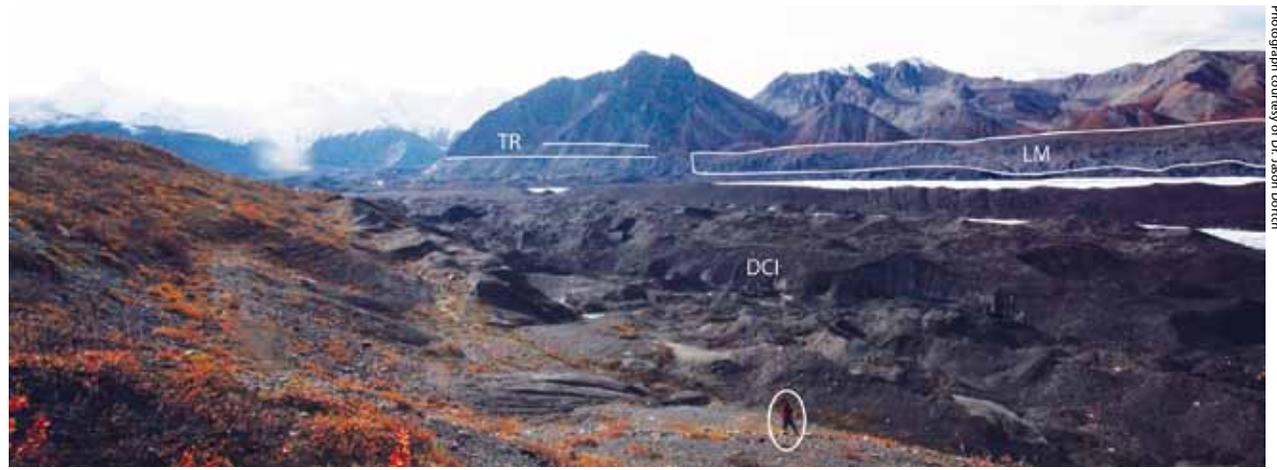


Figure 5. View of the Muldrow Glacier with common glacial features labeled. Note the person in the white oval for scale. TR are glacial trim lines; LM is a lateral moraine; and DCI is debris covered ice.

ing glacier transport and moraine stabilization. This shows that ^{10}Be ages are reset to “zero” until a moraine stabilizes, which confirms our second hypothesis that ^{10}Be dating records a moraine’s stabilization age.

Moraine X has an average ^{10}Be age of 540 years old. Using the lichen age (1,800 years old) shows that the lag time between landform deposition and stabilization is 1,260 years. Therefore, we argue that moraines with an ice core can take approximately 1,300 years to stabilize after initial deposition, although this might vary in different climatic settings. Stabilization times need to be quantified in different climatic regimes to build a model relating landform stability and ^{10}Be ages and determine if the lag time is consistent in both upper and lower latitude areas.

This study provides a preliminary framework for determining stabilization lag time. This data will help enable a clear understanding and more accurate comparison of ^{10}Be ages (less than 10,000 years old) with other dating methods. Our results suggest that correlation of glacial deposits less than 10,000 years old dated with different methods will need to be reevaluated. Incorrect correlation of glacial deposits will have a significant effect on climate models, as the models need to compare

changes in the position and size of glaciers over large areas that occurred at the same time. If the correlations are incorrect, the models will yield inaccurate results. Future work focused on refining the lag time between moraine deposition and stabilization will enable more accurate ages and climate driven changes in glaciation to be more narrowly defined and better understood.

The results of our studies have been published in Dortch et al. (2010a and 2010b).

We would like to thank the Murie Learning and Science Center for funding this project. Sadly, our co-author, Phil Brease, passed away on May 12, 2010. He was a kind person, interested in the processes that shape our planet. He will be greatly missed by all.

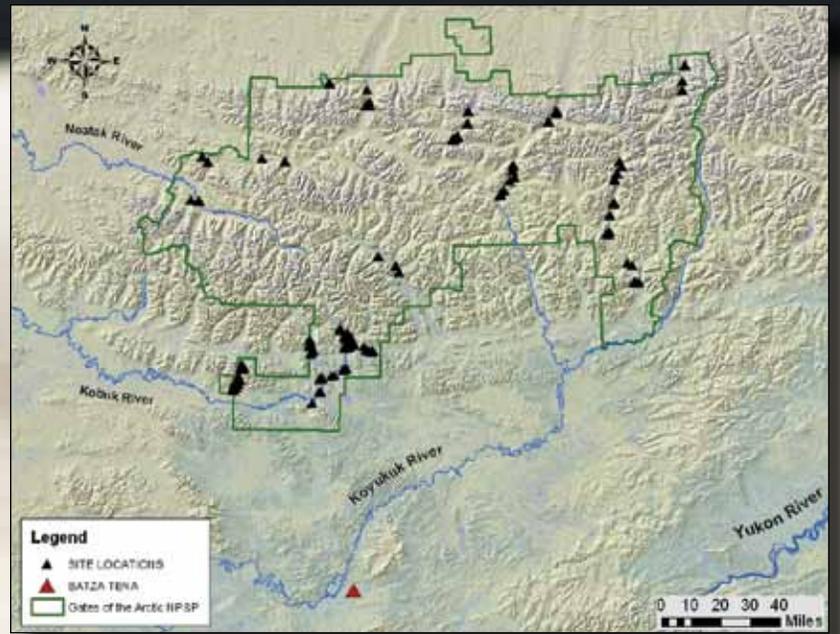


Photograph courtesy of Dr. Jason Dortch

Figure 6. View of the Muldrow Glacier. The active ice ends just right of the photo. Notice the large volume of rock debris that covers the active glacier.

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Prehistoric Obsidian Procurement and Transport in Gates of the Arctic National Park and Preserve

By Chris Houlette, Jeff Rasic, and Jeff Speakman

Abstract

Since the discovery of a prominent obsidian source near the Indian River, a tributary of the Koyukuk (*Griffen et al. 1969*), numerous researchers have investigated obsidian use in prehistoric Alaska (*Cook 1995, Slobodina et al. 2008*). Batza Tena, as it is known in the local Koyukon dialect, has been suggested to be the primary archaeological obsidian source in Alaska (*Clark and Clark 1993, Cook 1995*). Further research identified many other obsidian types associated with sources as far reaching as the Yukon Territory and British Columbia, as well as an even more distant source in Siberia (*Cook 1995, Slobodina et al. 2008*). These efforts have illuminated evidence of an elaborate network of long distance trade and cultural interaction throughout prehistoric Alaska and beyond.

There are no known geologic obsidian sources in Gates of the Arctic National Park and Preserve, meaning that any obsidian found at archaeological sites had to be procured elsewhere and transported into the region. The relative proximity of the Batza Tena source area (*Figure 2*) suggests that most obsidian present in archaeological sites in the area originated at this source. While this is generally true, previous research has shown that artifacts made from obsidian sources other than Batza Tena have also been found (*Cook 1995*). For this project, we sought to exhaustively analyze all archaeological obsidian from

Figure 1. Obsidian projectile point sourced to Batza Tena.

NPS photograph by Andy Tremayne

Figure 2. Location of the Batza Tena obsidian source in relation to the analyzed archaeological sites in Gates of the Arctic.

Map by C. Houlette

Gates of the Arctic in an effort to better understand where past inhabitants had acquired this resource and how it may have been transported throughout the region.

Introduction

The arctic and sub-arctic environment of the Gates of the Arctic landscape has not encouraged much soil development, leaving many archaeological sites exposed on the ground surface. These conditions have largely prevented the preservation of organic materials such as wood or bone. Thus, archaeologists often must turn to lithic artifacts, the physical evidence of stone tool manufacture and use, to investigate the prehistory of the region. While lithic artifacts only provide one piece of the prehistoric puzzle, analytical tools exist that allow investigators to glean interesting information from this relatively sparse dataset. One of the more powerful of these tools is geochemical provenance analysis, which can help identify the original geologic source location (or provenance) for the inorganic materials used to create artifacts discovered in archaeological sites (*Glascok et al. 2007*).

Provenance studies in archaeology are frequently undertaken in an effort to delineate otherwise elusive patterns of prehistoric human behavior such as contact between cultures or regions, long distance trade and exchange networks, or the identification of group ranges and/or seasonal rounds (*Phillips and Speakman 2009, Shackley 2003*). Obsidian, a type of volcanic glass, is an excellent material for such studies due to geochemical signatures, which are distinct for a given geologic source. By establishing the original source of the obsidian found in Gates of the Arctic archaeological sites, we could then look at the distribution of those sites and further investigate how this material might have been transported throughout the region.

Fingerprints in Stone

Obsidian is formed in an instantaneous geologic event. Because of this, individual sources exhibit homogenous signatures, determined by the relative abundances of trace elements such as strontium (Sr) and zirconium (Zr) from which the material is formed (*Glascok et al. 2007*). Each source has a unique “fingerprint” that, once identified, can be used to differentiate it from other, distinct sources (*Cook 1995, Glascok et al. 2007, Slobodina et al. 2008*). For example, Batza Tena exhibits relatively low levels of Sr and Zr, while the Okmok source from the Aleutian Islands has much higher values of both (*Figure 3*). This analysis allows us to trace the material used to make an artifact back to the original geologic location where it was first acquired. For this project we conducted our analyses using X-ray fluorescence (XRF), a non-destructive technique that measures the levels of trace elements in the obsidian without damaging the artifact (*Figure 4*).

Previous research efforts in the study area had analyzed 225 obsidian artifacts from 28 sites within Gates of the Arctic. For the current project, 489 additional obsidian artifacts from 133 sites were analyzed, for a total of 714 samples from 160 sites throughout the park area. Four distinct signature groups were identified following the analysis (*Figure 6*), with a fifth small group (labeled “Unassigned”) requiring re-analysis before a definitive signature can be determined. With most of the obsidian source signatures identified, the next step was to examine the relationship between the source locations and the archaeological sites.

Because site locations are well documented through the archaeological recording process, it was easy to compare them geographically to the location of Batza Tena. All of the 160 sites that we analyzed contained

obsidian artifacts which matched the signature for Batza Tena (n=691, 96.78%). However, a total of 12 artifacts (1.68%) from nine of the analyzed sites exhibited signatures that are known archeologically (Groups G, N, and P) but whose geologic source locations remain elusive. While it may be possible that the unknown source groups are related in some way to the Batza Tena source, another possibility suggests that these sources are to be found elsewhere, and the material was transported into the region through trade and interaction.

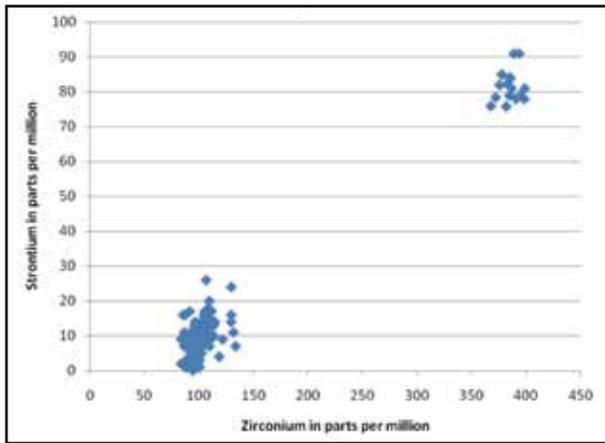


Figure 3. Comparison of the chemical signatures of the Batza Tena (lower left) and Okmok (upper right) obsidian sources.

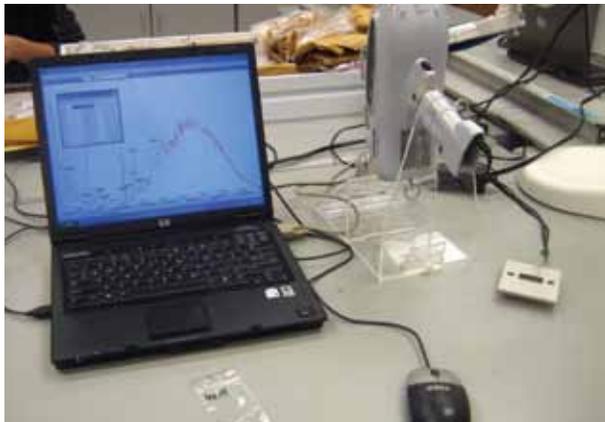


Figure 4. X-Ray Fluorescence (XRF) analysis lab equipment.

Footsteps of the Past

The cultural boundary in Gates of the Arctic has too commonly been simplified as a line dividing Athabascan and Inupiat (Kunz 1977). In contrast, ethno-historic research describes how the actual demographics included active and fluctuating interface zones between several populations throughout time (Burch 2005, McFadyen Clark 1974, Raboff 2001). One of the more complex of these interaction zones is in the Upper Kobuk River area. Raboff (2001) suggests that in the proto-historic period of the nineteenth century, home ranges in this region alternated between three different cultural groups: the Kobuk River Inupiat (to the west), the Kobuk River Koyukon (in the headwaters area), and the Too Loghe Koyukon (to the east). We know that archeologically, Batza Tena obsidian is found throughout Alaska, yet the source area lies well within the known geographic range of the Upper Koyukuk River Koyukon populations. This suggests that the upper Kobuk area may have been cut off from direct access to the Batza Tena source, due to conflicting range boundaries and complex cultural interactions.

However, a well defined network of overland travel routes throughout Gates of the Arctic (Figure 7) shows how cultural interaction and trade of goods in the area crossed these cultural boundaries (Burch 2005, McFadyen



Figure 5. Archaeologists recording a site near the Kobuk River.

Clark 1998). During the time period which these accounts describe, there is little evidence of flaked stone tool manufacture and use (McFadyen Clark 1998). Yet, much of the regional archaeological evidence suggests that an inter-cultural environment, similar to that described above, may have existed into the prehistoric past (Burch and Mishler 1995, Kunz 1977, Raboff 2001). It is reasonable to assume that at least some decades prior to the introduction of Euro-American implements, (such as metal tools and firearms which replaced flaked stone tool technology) similar trade networks and travel routes may have been utilized to transport obsidian. The upper Kobuk area specifically presents a sort of nexus of various boundaries and, interestingly, also exhibits the highest occurrence of non-Batza Tena obsidian in a single area.

Concluding Remarks

By increasing the database of identified obsidian we have uncovered some tantalizing possibilities regarding resource use in Gates of the Arctic National Park and Preserve. Analysis of the geographic distribution of obsidian has added to our understanding of the nature of prehistoric cultural interaction in the study area, especially in regards to the Kobuk River region. At the very least this provides another line of evidence for understanding

Group Name	N=	Percent of total
Batza Tena	691	96.78%
Group G	6	0.84%
Group N	1	0.14%
Group P	5	0.70%
Unassigned	11	1.54%
Total	714	100%

Figure 6. Gates of the Arctic archaeological obsidian by source group.



Scars on the Tundra: The Cultural Landscape of the Kiska Battlefield, Aleutians

By Dirk H.R. Spennemann, Janet Clemens, and Janis Kozlowski

The events of World War II transformed Kiska Island in the Aleutians into a cultural landscape that is truly unique on a global scale. The verdant green of the tundra can not mask the many scars caused by a short-term, but very intense, military occupation, first by Japanese and later by U.S. forces. The Kiska battlefield, a National Historic Landmark since 1985 and part of the World War II Valor in the Pacific National Monument since 2008, is only one of two battlefields world-wide where neither previous nor later settlement obscure military developments. Through its integrity and excellent preservation, Kiska provides a unique, and evocative insight into the conditions under which the Aleutian Campaign was fought.

Kiska is an approximately 30-mile long and 7-mile wide (48 by 11 km) volcanic island of the Rat Island group of the Aleutian Chain, located approximately 1,450 miles (2,330 km) west of Anchorage. Kiska Harbor, on the eastern side of the island, is one of the few safe and sheltered harbors in the western Aleutians. Early human occupation is evidenced through the prehistoric

Figure 1. The wing of a Consolidated B-24 'Liberator' bomber aircraft rests on a hill near Trout Lagoon. The aircraft, piloted by Captain Jack F. Todd, was shot down on June 11, 1942, during the first U.S. air raid on Japanese-occupied Kiska. None of the crew survived.

Photograph by Dirk H.R. Spennemann

sites on the island with some later occupation during the Russian period, that ended by 1812 (*USFWS 2003*). Today Kiska is uninhabited by people and is home to large sea-bird colonies. The lower reaches of the island are covered with tundra, while the upper reaches are covered with mossy vegetation, giving way to areas devoid of vascular plants. With the exception of the volcanic cone in the north, the landscape is dominated by undulating hills, intersected by deep drainage channels.

The Pacific War came to Alaska when Japanese carrier planes bombed U.S. installations at Dutch Harbor on June 3, 1942. Three days later, Japanese forces landed on and occupied Kiska and Attu Islands.

The initial Japanese landing on Kiska by an elite force of 550 men on June 6, 1942, met with little resistance by the sole island occupants, the ten men of the radio weather station. Along with equipment and supplies, the Japanese moved quickly setting-up anti-aircraft and coastal defense guns on North Head.

The following day, an American patrol plane spotted enemy ships in the harbor. Soon U.S. bombers were making regular 1,200-mile (1,930-km) runs from Umnak Airfield to Kiska, facing adverse weather and difficult navigation conditions. The Kiska Blitz had begun.

Over the following months, the Japanese expanded their presence, receiving additional personnel and equipment. A naval installation was established in Kiska Harbor, comprised of a submarine base and a sea plane base. Relocating all troops from Attu, the Imperial Japanese Army set up a 3,500 men strong presence

protecting Gertrude Cove, a potential U.S. invasion beach south of Kiska Harbor. At the height of development, the Japanese had more than 7,200 men on the island.

American bombing efforts to oust the Japanese were boosted by the development of airfields closer to Kiska, on Adak and on Amchitka. The Navy's torpedoing of a significant number of Japanese vessels left the garrison dependent on the supplies that could be transported by submarines. The American bombing runs, which dramatically increased prior to the U.S. invasion of Attu, disrupted the Japanese occupation efforts including their attempts to complete an airfield and to provide reinforcements. More than six million pounds of bombs were dropped on Kiska over the 14-month period.

With the U.S. forces successfully recapturing Attu on May 30, 1943, the Kiska garrison was isolated and became unsustainable. As U.S. and Canadian forces of more than 34,000 men prepared to invade Kiska, a Japanese evacuation fleet managed to slip through the fog, board the remaining 5,100 troops in less than one hour and escape without being detected. Within two weeks, the Allies poured ashore, sustaining substantial casualties by friendly fire, mines and booby traps. To deny the Japanese an opportunity of return, the Allies established camps by setting up Quonset and Pacific huts, tents, and frame structures, finished the runway and built two docks and a wharf. While the invasion marked the end of the Aleutian Campaign, the U.S. military maintained a firm presence on Kiska through the end of the war, abandoning the island in 1946.



Photograph by Dirk H.R. Spennemann

Figure 2. A Japanese revetment constructed from tundra sod, for a barrack building. Trout Lagoon area, Kiska Harbor.

Part of a U.S. Naval reservation since 1903, sections of Kiska were at various times reserved for military use. Handed to the U.S. Fish and Wildlife Service (FWS) in 1955, Kiska was made part of the Aleutian Islands National Wildlife Refuge, and in 1980 integrated into the newly created Alaska Maritime National Wildlife Refuge. The Japanese occupation areas and the U.S. landing beaches were declared a National Historic Landmark (NHL) in February 1985.

An initial cultural resources survey, part of an explosive ordnance and chemical contaminants survey (Dowell 1977) was carried out in 1976. The NPS carried out further work in 1989, assessing the submerged cultural

resources of Kiska Harbor and documenting some of the resources on land through photographs (Murphy 1990). This was followed by additional unexploded ammunition and cultural resource surveys in 1996 (Moblely 1996). More recently, the NPS in collaboration with the FWS, carried out an in depth condition assessment of the Japanese guns in 2007 (Spennemann 2008), and in 2009 undertook a general assessment of the cultural landscape as part of an American Battlefield Protection Program grant project. In the meantime, sections of the Kiska battlefield have been declared part of the World War II Valor in the Pacific National Monument in December 2008.

The findings of the 2007 and 2009 projects have



Photograph by Dirk H.R. Spennemann

Figure 3. A fire hydrant with the emblem of the Japanese Navy. Main Valley area, Kiska Harbor.

brought into sharp relief the significance of the cultural landscape of the Kiska battlefield on a truly global scale. The cultural resources present on the island are manifold, ranging from Japanese, U.S. and Canadian occupation sites, such as barracks and tents, to defense positions, such as antiaircraft and coastal defense guns, to material, such as lumber yards, vehicles and shipwrecks.

The Japanese occupation of Kiska was concentrated in two areas: the hills and valleys surrounding Kiska Harbor were occupied and developed by the Imperial Japanese Navy (IJN), while Gertrude Cove in the southeast of the island was the focus of the Imperial Japanese Army (IJA) occupation. In addition, the IJA maintained an anti-

aircraft battery on north central Kiska and a number of smaller observation posts at various coves and bays of the island.

Even though the entire Kiska operation was planned and executed in less than three months, the Japanese Navy developed their base with great care. Sod cut from the surrounding tundra covered the roofs of barracks and staff buildings, and enveloped the high earthen walls that surrounded these buildings (*Figure 2*). This effectively insulated the occupants from the strong and occasionally bitter cold winds for which the western Aleutians are known. While these sod walls also provided some protection from bomb shrapnel, they played no role in camouflage (as is often suggested) as they show up very clearly on war-time aerial imagery.

Throughout, extensive Japanese defenses, such as foxholes, personnel trenches and barbed wire entanglements can be found. In addition, a number of underground bunkers were dug into the hillsides. The Japanese established a network of roads connecting Kiska Harbor with Gertrude Cove, constructed a power and telephone network and erected a major Shinto shrine. But nothing illustrates better the Japanese desire to make Kiska a semi-permanent base than the installation of a system of fire hydrants (*Figure 3*).

While the Japanese development of Kiska was designed for semi-permanent occupation, the subsequent U.S. and Canadian presence on Kiska was based on the sole premise to merely deny the Japanese the opportunity to re-occupy the island. In consequence, the U.S. and Canadian establishments were built for short-term usage, with many of the tent sites and bases for Quonset huts erected in comparatively shallow revetments that provided little protection from enemy shrapnel or the winds. Like the Japanese, the Allies used small cast-iron solid-fuel stoves for heating. Unlike the Japanese, however, who relied on dirt tracks in addition to their well-built roads, the U.S. forces erected a series of boardwalks that connected the barracks buildings, largely built in areas away from Japanese occupation sites and around numer-

ous bomb craters that marked the landscape (*Figure 4*).

The sheer size of the Japanese garrison, with about 3,700 Navy personnel at Kiska Harbor and some 3,500 Army personnel at Gertrude Cove (*Romig 1944*), resulted in a large number of barracks. In addition, the over 34,000 U.S. and Canadian troops that had landed on Kiska on August 15, 1943 also created temporary encampments, followed by a smaller number of permanent ones. As a result, the landscape is scarred by patches of bare soil clearly demarcating the location of the encampments.

Apart from a short period in the very beginning when Kawanishi H6K 'Mavis' flying boats were stationed on Kiska, the Japanese air presence was provided by floatplane fighters (Nakajima A6M2-N 'Rufe') and floatplane bombers/reconnaissance aircraft (Aichi E13A 'Jake') all of which could use Kiska Harbor. While effective against U.S. bombers, the floatplanes were no match for fighter aircraft. As a result the Japanese began the development of an airfield on North Head, using manual labor in the absence of heavy earth moving equipment. Progress was slow, and the airfield remained largely incomplete at the time of the U.S. landings. The airfield was completed by U.S. forces soon after. Scattered on various parts of Kiska are the remains of U.S. bombers, flying boats and other aircraft shot down by the Japanese in the early days of the U.S. raids. Additionally, sections of Japanese float planes can be found in some of the material dumps created by U.S. forces after their landing.

Both the Japanese and the U.S./Canadian occupation required a range of infrastructure and war material. Both forces landed a range of construction material, trucks and vehicles. Whereas the Japanese relied on a large number of lighters and small landing craft to ferry the supplies from the ships to the shore, the U.S. built two piers, remains of which are still extant. Abundant on the island today are the remains of damaged Japanese trucks (*Figure 5*), some even of American manufacture (under license). Most of these had been amassed by U.S. forces in two main 'clean-up' dumps, one located at Kiska Harbor and one at Gertrude Cove. While



Figure 4. Parts of a tracked trailer rest against the sides of a tent revetment of the Canadian camp.



Figure 5. A Japanese six-cylinder truck at the material dump at Kiska Harbor.

Photograph by Dirk H.R. Spennemann

Photograph by Dirk H.R. Spennemann



Figure 6. The remains of a Japanese midget submarine. The submarine was blown up by the Japanese before they evacuated the island.

U.S. trucks had been shipped back to other bases on Alaska and beyond once the U.S. occupation ended, researchers located some Canadian trucks that had been cannibalized for spare parts and dumped down a hillside. Elsewhere can be found stockpiles of coal, Japanese and U.S. lumber, and Marston matting (for the runway).

The strategic value of Kiska for the Japanese rested in Kiska Harbor serving as a base from which submarines and floatplanes could carry out sea patrols guarding the North Pacific approaches to the Japanese homeland. To this effect, a number of submarines were stationed there. The Japanese also built a slipway and repair facilities

for midget submarines. At the time of their evacuation, three such submarines were left behind but irreversibly disabled through small explosive charges (*Figure 6*).

The sustained U.S. air attacks damaged and sunk a number of Japanese vessels. Submerged cultural resources in Kiska Harbor consist of Japanese transports, flying boats and at least one submarine. The Japanese managed to run aground and thus salvage the cargo from five of the damaged ships. Their remains can still be seen in Kiska Harbor and Gertrude Cove.

Some of the most evocative artifacts on Kiska are the various large guns that the Japanese had placed

at strategic positions on the island. Japanese defense doctrine required defense against both air and naval forces. At the height of development, Kiska Harbor was surrounded by an array of light, medium (*Figure 7*) and heavy anti-aircraft guns. In addition, three batteries of coastal defense guns had been installed, two on North Head, and one on Little Kiska. These guns were all pre-World War I vintage and encompassed both Japanese and British-built weapons. The latter had come from British-built warships, which had been purchased by Japan at a time when their own naval architecture capability was not yet developed (*Spennemann 1995*).

The serial numbers of the breechblocks allow us to identify the vessels from which the British guns once came. These include the battleships *Fuji* (launched 1896) and *Mikasa* (launched 1902). Both vessels carry a very high level of significance in global naval history. The *Mikasa* was Admiral Togo's flagship in the Battle of Tsushima in the Japanese-Russian War of 1905, a battle that heralded Japan's arrival as a World Power. While the *Mikasa* survives as a museum ship in Japan, nothing remains of the *Fuji*. The gun on Little Kiska is the sole known survivor of the first battleship the Japanese had ordered at British shipyards.

Indeed, the *Fuji* represents the start of a long military and economic cooperation between Great Britain and Japan, which led to Japan siding with the Allies against Imperial Germany in World War I. As a result, Japan was awarded the former German colonies in Micronesia for administration. It was from these islands that many attacks on U.S. territories were launched in World War II, islands that had to be conquered by U.S. forces in several bloody battles (Kwajalein, Eniwetok, Saipan, Peleliu). The global significance of the *Fuji* gun cannot be overrated. This single object can be used to interpret the history and politics of the Pacific region during first half of the twentieth century.

The events of World War II transformed Kiska Island into a cultural landscape that is truly unique. For over 120 years, up until WWII, there was little human

activity on the island other than fur trapping. Kiska was then occupied by over 7,000 Japanese troops (Roethke 1944). After the end of the war Kiska was abandoned. Since no new development has taken place since that time, much of the military landscape remains. The only other WWII battlefields that can lay similar claims are El Alamein and other sections of the North African desert.

The resource surveys have found the environmental conditions produce circumstances that are very favorable to preservation: low UV due to near constant fog delays the decay of wood and rubber; removal of corrosion-conducive aerosols by rain and mist; and the containment of bacteria and other bio-decay by cold temperatures. Compared to other World War II resources in the Pacific (Look and Spennemann 1996), the heritage assets on Kiska are remarkably well preserved.

The uninhabited nature of Kiska and the concomitant uncontrolled visitation poses some management problems, such as the theft of small artifacts that will be need to be addressed as part of a management plan for the monument. Managing Kiska's unique cultural landscape

is a complex process with many agencies involved: Kiska is federally owned and forms part of the Alaska Maritime National Wildlife Refuge, which is administered by the Fish and Wildlife Service; Aleut archaeological sites are owned by or in the future be conveyed to the Aleut Corporation; all submerged cultural resources in Kiska Harbor fall under the jurisdiction of the State of Alaska; and, the National Park Service, through its Affiliated Areas Program and the NHL Program, provides ongoing technical assistance and guidance on historic preservation matters to all land managers involved. Future work by the NPS will see the revision of the existing NHL nomination of Kiska to include the U.S. and Canadian occupation. In the light of this assessment of Kiska, an in-depth examination of cultural resources on Attu seems highly desirable.



Photograph by Dirk H.R. Spennemann

Figure 7. A Japanese 75mm Type 96 anti-aircraft gun on North Head. This is the most ubiquitous type of weapon on Kiska and was used by both the IJN and the IJA.

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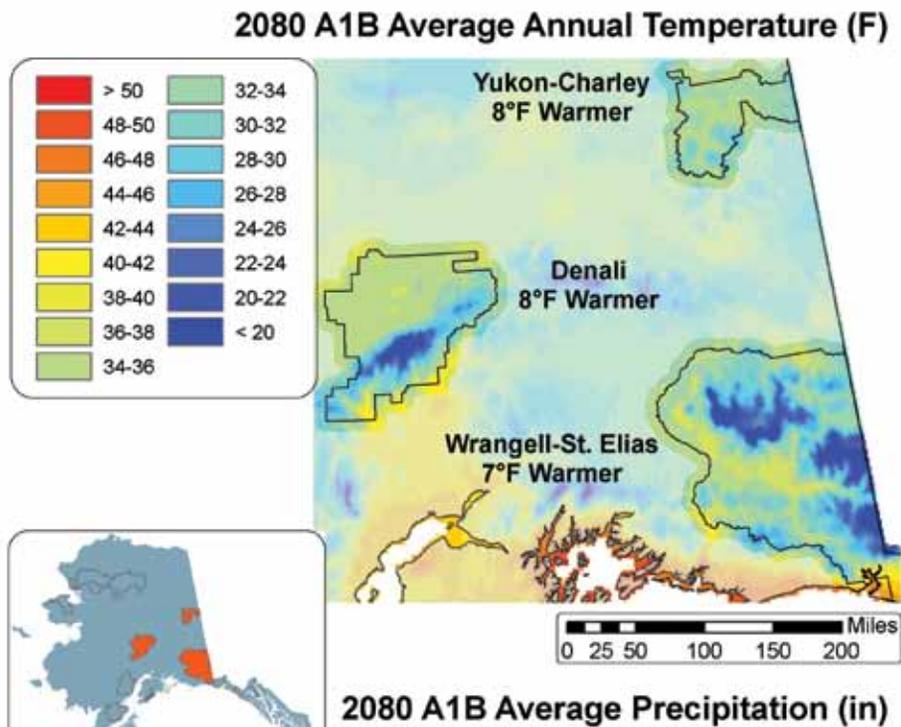


Figure 1.

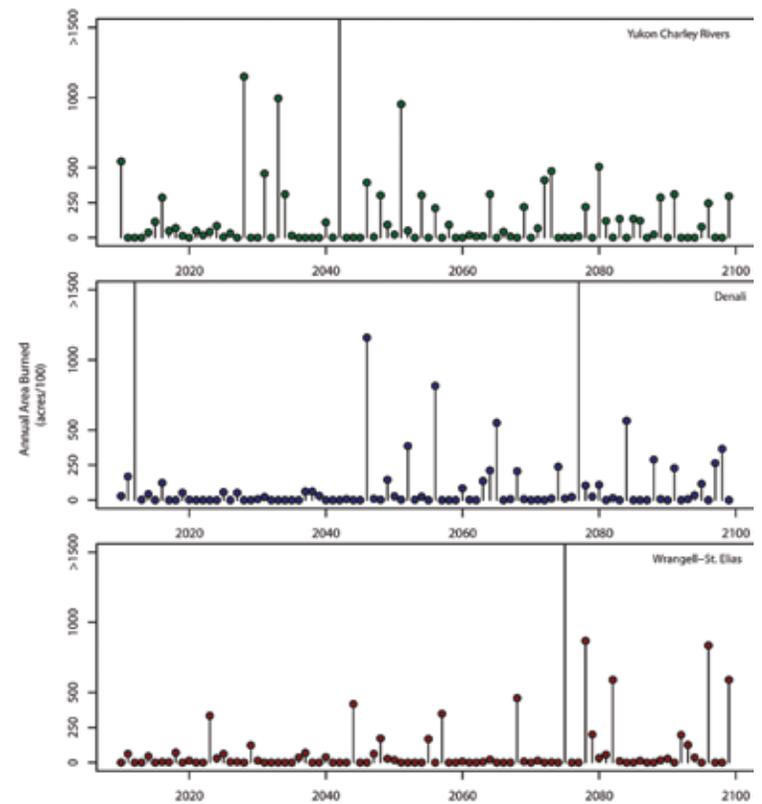


Figure 2.

Fire Return Interval 2001-2099 (yr)

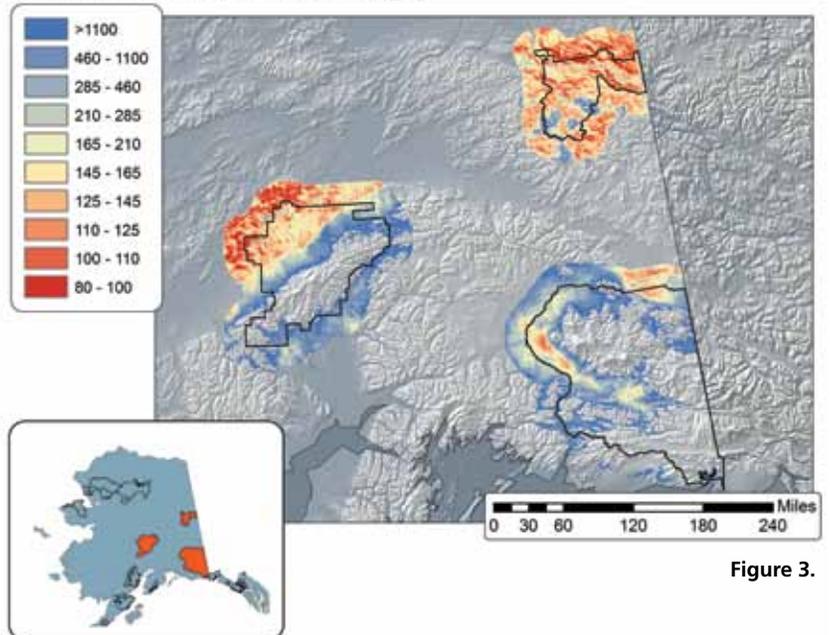


Figure 3.

Projected Vegetation and Fire Regime Response to Future Climate Change in National Parks in Interior Alaska

By Wendy Loya, Anna L. Springsteen, Jennifer L. Barnes, and Scott Rupp

Introduction

The arctic and boreal ecosystems that dominate Alaska's landscape are undergoing changes in response to rising temperatures and changes in precipitation regimes (Hinzman *et al.* 2005). Alaska has seen a warming trend over the past several decades, with an average increase in mean annual temperature of 3.4°F/1.9°C since 1950, and lengthening of the growing season (Karl *et al.* 2009). Some of this temperature increase is correlated to a 1976 phase shift of the Pacific Decadal Oscillation (Shulski and Wendler 2007), and General Circulation Models (GCMs) attribute additional warming to the increase in greenhouse gases (IPCC 2007). Since climate is a major driver for many ecological and biophysical processes, climate change is expected to have substantial impacts on fire-adapted northern ecosystems (Duffy *et al.* 2005). Fire in the boreal forests of Alaska already appears to be increasing in frequency, size and severity (Kasischke *et al.* 2010).

Climate change presents a significant challenge to managing our natural and cultural resources. Ecological models that project effects of climate change on plants, animals, and other system components can be used by

Figure 1. Projected mean annual temperature and precipitation for the decade around 2080, derived from a composite of five GCMs.

Figure 2. Predicted area burned for national parks in interior Alaska, based on one simulation run of ALFRESCO using the composite of 5 GCMs and the A1B emissions scenario.

Figure 3. Map of predicted fire return intervals for the coming century based on the probability of fire occurring during 200 simulations of ALFRESCO run, using the composite of 5 GCMs and the A1B emissions scenario.

managers to understand how these effects will impact park resources. For example, the Boreal ALFRESCO model provides a tool to simulate future fire regimes and changes to vegetation under different climate scenarios. We utilized this model and future climate predictions from several GCMs to explore the potential changes in fire regime and vegetation composition for three parks. The interior Alaska parks selected have significant acreages of boreal forest: Denali National Park and Preserve, Yukon-Charley Rivers National Preserve, and Wrangell-St. Elias National Park and Preserve.

Methods

The boreal forest version of ALFRESCO was developed to explore feedbacks and interactions between fire, climate, and vegetation in interior Alaska (Rupp *et al.* 2007, Duffy *et al.* 2007) as well as associated impacts to natural resources (Rupp *et al.* 2006, Butler *et al.* 2007). ALFRESCO does not predict fire behavior, but rather provides future fire regime and extent scenarios, including estimates of annual area burned and fire return intervals. These estimates are based on an empirical relationship between monthly temperature and precipitation, and total annual area burned. ALFRESCO also simulates changes in vegetation flammability associated with the successional shifts from deciduous to needleleaf forests, as well as between tundra stages.

ALFRESCO begins with a vegetation map that includes the aforementioned vegetation types and estimated time since the last fire. Fires simulated by the model are ignited randomly and are driven by climate and vegetation type (Rupp *et al.* 2007). The fire can then spread to adjacent vegetation as a function of vegetation flammability and natural firebreak effects (e.g. non-vegetated mountain slopes and large water bodies).

GCMs are the most widely used tools for projections of global climate change over the next century. For this study, climate projections were based on five climate models from the IPCC Fourth Assessment (2007) deemed to best perform in Alaska (Walsh *et al.* 2008): ECHAM5, GFDL2.1, MIROC3.2MR, HadCM3, and CGCM3.1. The models were run with a greenhouse gas scenario (A1B) that assumes emissions will increase through mid-century and then decline as lower carbon-emitting energy sources are developed.

Results

Future climate scenarios

Based on a composite of the five best-performing GCMs, temperatures in interior Alaska's national parks are projected to increase over the coming decades at an average rate of about 1°F (0.56°C) per decade. Average annual temperature is expected to rise by about 5°F (2.8°C) by 2040 and as much as 8°F (4.4°C) by 2080 (Figure 1). This would result in a transition from average annual temperatures below the freezing point (<25°F/-3.9°C) to temperatures near or above the freezing point (>32°F/0°C). Average annual rainfall is expected to increase by 10 to 27%, however it is uncertain whether this will be enough to offset an increase in evapotranspiration caused by warmer temperatures and a longer growing season.

Acreage Burned Annually

We used Boreal ALFRESCO to simulate future fire activity under different climate scenarios from the best performing GCMs, and present one that best represented recent fire history. Based on simulation results from the composite scenario (Figure 2), the model suggests that Yukon-Charley would likely experience more frequent

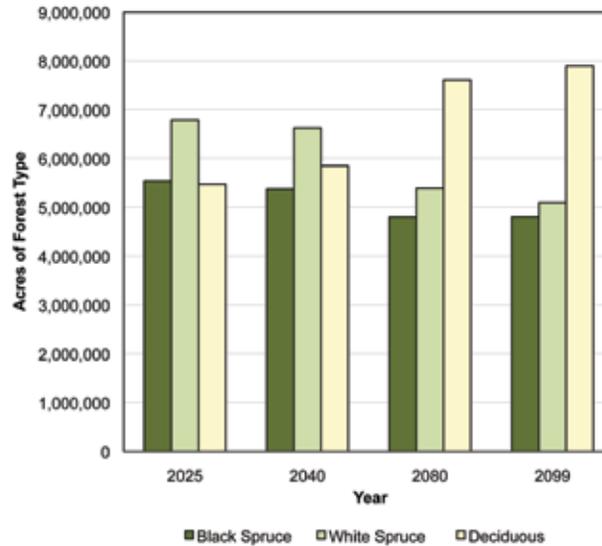
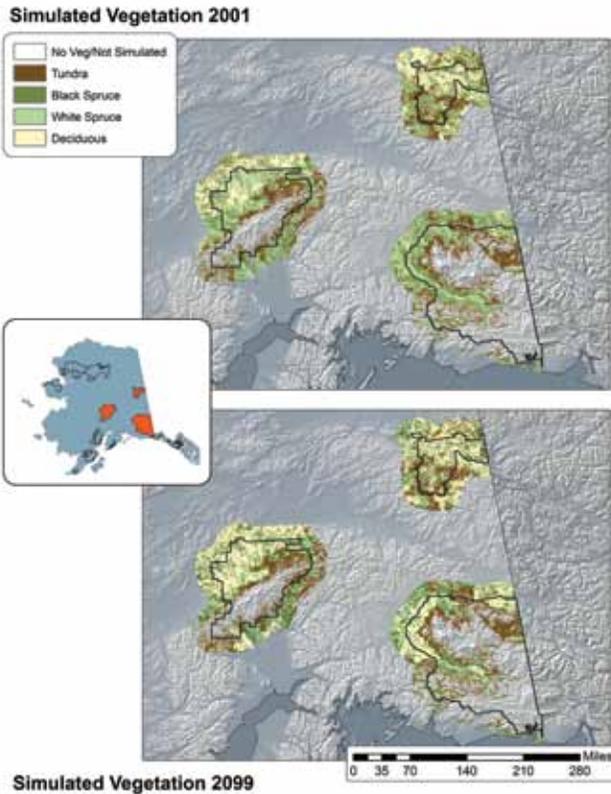


Figure 4. (Left) Map showing the simulated distribution of vegetation types from a single run of ALFRESCO, using the composite of 5 GCMs and the A1B emissions scenario.

Figure 5. (Top) Changes in the acreage of three forest types over the century as predicted by a single run of ALFRESCO, using the composite of 5 GCMS and the A1B emissions scenario.

large fire seasons over the course of the next century, with several fire seasons approaching and/or exceeding 250,000 acres. Modeled fire patterns in Denali identify the potential for very large fire seasons (>1,500,000 acres) in the near future, which may result in a less flammable landscape for several decades following, and then the eventual return of large fire seasons (~250,000-700,000 acres) occurring more frequently. The simulation results also suggest that Wrangell-St. Elias would likely experience large fire seasons at decadal intervals.

Fire Return Interval

The ALFRESCO model does not provide a direct prediction of where a fire will occur. It does, however, convey the likelihood of fire activity based on the flammability of the vegetation and climatic conditions. By analyzing many replicate simulations, maps can be made

of where fire activity is most likely to occur. The number of times an area burns can be divided by the number of simulations (200 for this study), and the number of years (100 yrs) to create a fire risk map for that time frame – i.e., the probability of an area burning in any one year. The inverse of that probability is the fire return interval.

ALFRESCO simulation results predict that much of Yukon-Charley, the northwestern section of Denali, and areas along the Copper River on the western edge of Wrangell-St. Elias will experience fire return intervals of less than 100 years. Therefore these areas may burn more than once in the next century (Figure 3). These regions are dominated by spruce forests (Figure 4) and the climate will be warmer and drier than other areas within the parks (Figure 1). Regions currently dominated by deciduous vegetation or with slightly more moderate climates are likely to burn at least once in the next century, and thus may experience fire return intervals closer to 200 years.

Vegetation Change Simulations

The simulated response of vegetation to increased burning suggests the potential for a substantial shift in the future proportion of conifer and deciduous forest on the landscape (Figures 4-5). Acreages for each forest type were summed for all three interior national parks for intervals across the coming century. Acreage of white spruce forests are predicted to decline by approximately 30% as a result of fire, while black spruce forests are predicted to decline by nearly 15%. As spruce forest burns across the interior, they are assumed to be replaced by early successional deciduous forest, which is estimated to increase in area by 45%.

Summary of Preliminary Simulation Results and Management Implications

Temperatures across most of Alaska’s national parks are projected by climate models to increase by approximately 1°F (0.56°C) per decade. For parks within the fire-prone interior region of the state, this warming would result in a transition from annual temperatures averaging below freezing (<32°F/0°C) to temperatures substantially above this biologically important threshold. The largest temperature increases are predicted to occur in winter, increasing on average by 10°F (5.6°C) or more. This could increase the length of the growing season and, therefore, the fire season. Precipitation projections suggest an increase of about 20% in summer for interior Alaska, although conditions could become drier due to warmer temperatures resulting in greater evapotranspiration. Drier conditions during any part of the summer could result in further increases in fire activity and severity.

The ALFRESCO model simulations for Alaska’s parks suggest a general increase in fire activity through the end of this century (2099) in response to projected warming temperatures. Examination of the projected cumulative area burned suggests the next 20-30 years will experience the most rapid change within the next century in both fire activity and associated changes

in vegetation dynamics. Future fire activity suggests more frequent large fire seasons and a decrease in magnitude of, and time between, small fire seasons.

The predicted increase in fire activity strongly suggests that boreal forest vegetation will shift from spruce-dominated forest, prevalent across the landscape during the last century, to deciduous dominated forest.

These forests will be younger due to more frequent fires, and older forests would decrease across the landscape (Duffy *et al.* 2005). This change could occur over the next few decades if changes in climate lead to increased fire activity. In fact, such a change may already be occurring, with the recent occurrence of multiple large fire seasons across interior Alaska (Duffy *et al.* 2005). If fire frequency as well as fire severity continue to increase, early successional deciduous and spruce forests could self-perpetuate for many decades if not centuries. Additionally, because there would be more frequent

burning, there would be an overall increase in annual acres burned.

Because climate is an important driver of fire, GCMs that predict warmer temperatures produce different results than those that predict less warming. In this study we have evaluated the results of combining five models; however, by running ALFRESCO using the results of individual models we would get a broad range of future fire regime predictions. Our results suggest a shift in dominance from conifer to deciduous vegetation within the next 50 years. However, it is important that the range of predictions be considered when making land and resource management decisions.

Decisions made by fire and land managers during this current period of climatic change will influence the structure and pattern of vegetation across the boreal forest in Alaska. The boreal ALFRESCO model can be used to simulate how climatically driven changes in the

fire regime and corresponding management may change the potential future landscape. This includes the characterization of how particular vegetation of a particular age class that may represent habitat conditions for important wildlife resources may be affected by the fire, vegetation and climate interactions predicted into the future. Thus, ALFRESCO can be used to guide monitoring and research to better understand how fire regimes are changing, which will be critical towards achieving management objectives

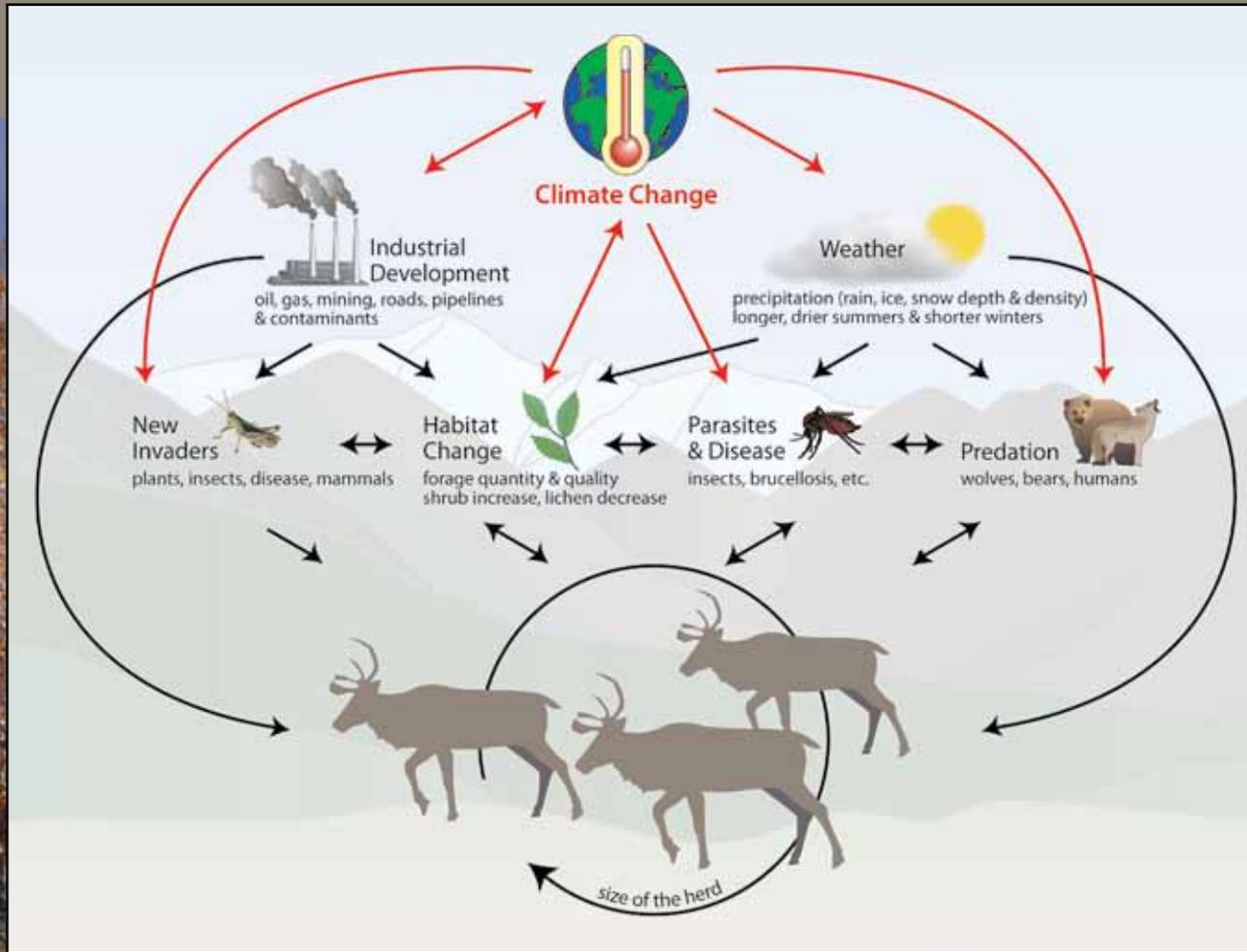
Acknowledgements

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Caribou Population Ecology



Complexity of Caribou Population Dynamics in a Changing Climate

By Kyle Joly and David R. Klein

Vast, migrating herds of caribou are an iconic image of the North. Yet, there is concern that a changing climate may drive this magnificent species the way of the Great Plains bison. The complexity that characterizes the ecology of caribou includes their extreme interconnectedness with other ecosystem components, including thousands of years of interactions with humans.

Numbers of caribou naturally oscillate in dramatic fashion on the time-scale of decades (Gunn 2003). Key influences driving population dynamics include climate, habitat, predation, parasites, insects and diseases, human influences, invasive species, competition, stochastic events, and the caribou themselves (Figure 1). The relative influence of each factor varies throughout the vast range of the genus *Rangifer* (both reindeer and caribou, hereafter referred to as caribou). Humans affect caribou through hunting, disturbance, industrial pollution, facilitating invasive species and reindeer grazing. While human influence is increasing in the Arctic, it is much greater in the southern areas of caribou distribution.

Figure 1. A graphic model illustrating the complexity of caribou population ecology under the influences of a changing climate.

Designed by L. Weaver

Figure 2. Shrubs are expected to increase in the range of caribou under most climate change scenarios. This could benefit them in summer by increasing forage, but caribou often avoid dense brush because of predators and low lichen abundance.

NPS photograph by K. Joly

The southern extent is where populations have been extirpated and most endangered populations reside (Hebblewhite *et al.* 2010). Our goal is to explain, within the limits of our present understanding, how the changing climate can be expected to influence caribou populations through its affect on these primary influences.

Climate, Stochastic Events, Parasites, Insects and Diseases

Climate is an ultimate driver influencing caribou population ecology by directly affecting growth, quantity and nutritional quality of forage plants forage; through its influence on insects that harass and parasitize caribou in summer; through its control over snow characteristics that determine forage accessibility in winter; and the vulnerability of caribou to predation. Subcomponents of the climate system, namely snow, icing, rain, solar input, temperature, wind, clouds, and seasonality, vary dramatically in their importance to the ecology of different caribou populations.

Snow is present during a major portion of the year within all caribou ranges. The greatest depths are in the temperate, moist mountainous regions of southwest Canada, and the lowest are in the polar deserts of the High Arctic. Greater snow depth increases the energy expended for movement and to reach winter forage species such as ground-dwelling lichens (Fancy and White 1985), which can contribute to poor body condition and greater vulnerability to predation. Snow can also influence the timing of green up, which may have serious nutritional and reproductive consequences. Deep snow years have been associated with poor physiological condition of cows in spring, lower calf birth weights,

reduced calf survival, slower growth of surviving calves, poor body condition of calves entering winter, reduced pregnancy rates the following year, and delayed parturition the following spring (Adams *et al.* 2006).

Icing or rain on snow events that restrict forage access are more critical to northern populations of caribou, which are reliant upon ground-dwelling lichens in winter, in contrast to southern populations that rely primarily on arboreal lichens. Similarly, wind can be detrimental to caribou by hardening the snowpack, restricting access to winter forage (Fancy and White 1985) or increasing energy costs of thermoregulation for young caribou after calving or for all caribou during extreme cold. However, wind can blow snow clear making it easier to access forage and evade predation. In summer, windy locations are sought to reduce insect harassment. Rain can also directly affect thermoregulation in calves, influence growth of forage species, as well as the prevalence of wildfire upon the landscape (Duffy *et al.* 2005).

The presence and extent of cloud cover, through its influence on solar insolation and temperatures at ground level, can affect caribou either directly or indirectly. Cloud cover in summer usually is associated with cool ambient temperatures, and thus, reduced activity of insects, especially mosquitoes, allowing for increased time available for optimal foraging by caribou (Moerschel and Klein 1997) and a prolonging of peak summer forage quality (Bø and Hjeljord 1991). Precipitation, temperature, winds and clouds can all be affected by large-scale, long-lived climate patterns, such as the Pacific Decadal Oscillation (Hartmann and Wendler 2005).

Seasonality, a function of climate, is the overriding annual variable influencing caribou ecosystem compo-



NPS photograph by K. Joly

Figure 3. Western Arctic Herd caribou in Kobuk Valley National Park. Warmer temperatures in winter and spring could lead to more dangerous crossings of rivers and lakes that have been frozen solid in previous years.

nents. Quantity and quality of forage species are governed by the rate of summer growth, whereas in winter, snow depth and density conditions alter availability of forage. Variables in summer weather influence the intensity and duration of insect harassment. Fall is the period when caribou must replenish their energy and protein reserves before facing the long winter when protein-rich forage is limited. Fall body condition is a strong determinant of pregnancy rates (Cameron *et al.* 1993).

Climatic conditions also strongly affect the distribution and abundance of parasites, insects and diseases that exert varying levels of influence on caribou population dynamics. The importance of these influences decline with latitude. Increased movements, due to insect harassment, have been linked to reduced growth of caribou calves over summer (Couturier *et al.* 2009). A suite of diseases and parasites can negatively affect caribou body condition, influencing their ability to survive and reproduce, cause mortality or loss of the fetus.

Climate change is expected to modify current patterns of snow, icing, rain, temperature, wind, clouds, and seasonality within the range of caribou. Temperatures



NPS photograph by K. Joly

Figure 4. A summer wildfire where caribou overwinter. Warmer, drier conditions in the future could lead to more wildfire in both boreal forest and tundra ecosystems. Lichens, an important winter forage for many caribou herds, can take many decades to recover to previous levels following burning.

are predicted to increase under all climate change scenarios, raising a suite of problems for caribou. Warming increases summer forage quantity but can reduce its quality (Callaghan *et al.* 2004), while quantity of lichens is reduced (Joly *et al.* 2009). Conversely, caribou will presumably benefit from shorter winters, with lower energy costs for winter activities and body maintenance. Warmer winters may allow for greater in-season snow

melt, which also may be beneficial for caribou (Tyler *et al.* 2008). Drier conditions in summer are expected to result in increased prevalence of wildfire (Duffy *et al.* 2005). Caribou are known to avoid burned winter habitat for decades, both in the tundra and boreal forest, (Joly *et al.* 2007) likely due to the destruction of forage lichens, which can take up to a century or more to recover. Thus, fire can influence the nutrition and movements

of caribou and in turn affect their population dynamics. Even small increases in temperature and growing season will dramatically increase the abundance, global distribution and impacts of parasites, insects and diseases.

Variation in other climate subcomponents due to climate change cannot be reliably predicted at this point. Given the extent of predicted warming, drier conditions are expected to occur even if precipitation does increase. Significant signs of drying (e.g., declines in vegetative productivity) in the boreal forest have already been detected (Verbyla 2008). Increased summer winds could help reduce insect harassment in summer or scour snow from elevated terrain exposing forage plants in winter, and thus be beneficial to caribou. Increased wind can act to harden snow, which would be detrimental to caribou. Increased clouds reduces vegetative productivity, but would extend the length of peak nutritional quality of some forage species (Bo and Hjeljord 1991), which would be beneficial for caribou. Earlier spring green up and access to highly digestible forage may or may not benefit caribou. Stochastic events, such as avalanches and drownings (due to flood conditions or thin ice), will have varying degrees of influence but will likely be greater on smaller herds. Stochastic events, such as flooding, drought and extreme storms, are predicted to increase under climate change scenarios, which would be detrimental to caribou.

Habitat, Human Influences, Density-dependent Factors and Competition

Habitat, encompassing areal extent, topography, vegetation, forage quantity, forage quality and forage availability, is a key influence on the population ecology of all species. Total available habitat can be an important and obvious influence on population dynamics where density of humans is high. Topography affects vegetation as well as precipitation, wind, temperature and phenology, and thus plays an important role in caribou ecology. Vegetation is crucial because caribou must travel through, exist in and also consume it to survive. Caribou generally avoid dense brush because it is difficult to travel through,

to detect predators in, and are low in forage quantity and quality in winter. Deciduous forests are avoided in winter for similar reasons. Forage quantity is critical for obvious reasons; if any animal cannot obtain sufficient forage they will fail to reproduce and/or die. While more subtle, forage quality is extremely important to nutrition, affecting birth weights, survival, growth, pregnancy rates, timing of primiparity, timing of parturition, and body condition in general (Parker *et al.* 2009). Spring and early summer are the most nutritionally demanding periods for female caribou as they deal with reduced body condition from winter, the demands of a growing fetus and, after birth, lactation. Accessing high quality forage during the summer is important for body and antler growth, pelage replacement, and rebuilding nutrient stores for the upcoming winter. Lichens, because they provide a major source of energy that minimizes the need to catabolize body reserves, constitute a large proportion of the winter diet of migratory caribou that face predation. Forage availability is also important for obvious reasons; quantity and quality of forage are irrelevant if forage is not available. Typically, forage availability is limited by snow conditions. Caribou must balance foraging requirements with risk of predation throughout most of their range.

Caribou can exert density-dependent influences on their own population dynamics through grazing, trampling, disease transmission, and competition with each other. As caribou populations grow to relatively high numbers, they have the potential to reduce the overall quantity of food that is available to them – sometimes referred to as overgrazing or exceeding ‘carrying capacity’. By reducing the quantity of food available, nutritional condition can be reduced. Herd sizes are small in the southern and polar regions, thus these areas should be under less influence of density-dependent influences.

It has been shown repeatedly that caribou avoid areas affected by human created noise and activity (e.g., Johnson *et al.* 2005), which can displace parturient caribou from preferred calving ground, lower calf recruitment or reduce body condition due to increased



NPS photograph by K. Joly

Figure 5. Caribou cratering (digging) for forage in winter. Snow characteristics, such as depth and hardness, are critically important for caribou populations, yet they are poorly understood and often ignored.

energy expenditures to avoid the perceived disturbance. Industrial pollution, which can reduce the quantity and quality of forage available over large areas (Klein and Vlasova 1991), is more likely to affect populations in countries with more lax environmental regulations. This can lead to decreased body condition through the uptake of lower quality forage or by requiring caribou to increase movement to find unaffected areas. Both invasive flora and fauna have the potential to be detrimental. For example, the parasitic brain worm carried by white-tailed deer invaded habitats further and further north to the detriment of caribou as forests were cleared. Reindeer grazing could potentially affect wild caribou populations by deleterious gene flow, disease transmission, reduction forage availability on shared ranges

Caribou habitat is likely to see dramatic changes over time due to changes in climate and human land use patterns. Patch sizes are likely to decrease for many populations. Caribou habitat will continue to be converted for human development and degraded by logging, which has hastened the decline of woodland caribou in Canada. Rising ocean levels due to melting

glaciers will also reduce available habitat in low lying areas (e.g., Alaska's coastal plain), but may actually increase it in areas currently covered in ice (e.g., Greenland). Climate change is likely to induce substantial changes to vegetation throughout the distribution of caribou. It has been predicted that 50% of the tundra biome globally could be colonized by trees by 2100 (*Callaghan et al. 2004*). Tundra habitats are very important for caribou (*Klein 1970*), and its decline will likely be detrimental to caribou.

Interspecific competition has the greatest potential to influence caribou populations in the southern regions where ungulate biomass and diversity is the greatest. In the northern regions, physiological and behavioral differences between potential competitors (e.g., muskox, snowshoe hares, Dall's sheep) have limited the relevance of competition (*Klein 1996*). Climate warming and increased human disturbance should make the landscape more favorable to species utilizing early seral stages, such as deer, elk and moose, increasing potential interspecific competition.

The expansion of shrubs into tundra habitat has already been documented and is expected to increase (*Tape et al. 2006*). Extensive summer foraging by caribou has the potential to retard shrub expansion in the Arctic (*Post et al. 2009*). However, substantial drying and/or increased fires could allow for entirely novel biomes to replace current caribou habitat (*Rupp et al. 2000*). In total, there is likely to be significantly less caribou habitat overall.

Predation

The influence of predation on caribou populations varies depending on location, from virtually non-existent (e.g., Svalbard) to very important. Predators, including wolves, bears, wolverines, coyotes, eagles and humans, have greater potential to influence the population dynamics of small herds relative to large herds. Predation will exert more influence where alternative prey exists (*Dale et al. 1994*). Alternative prey biomass is greater in southern regions of caribou range, thus the influence

of predation should be more important in that region.

Predation of calves is high in many locales, with bears often taking the most during the first few weeks following calving, and wolves after that. Predation by other animals tends to be focused on very young, very old, and debilitated caribou; however, predators are capable of killing healthy adult animals. In years where snow conditions tip the balance in favor of wolves, the focus on weaker animals is lessened (*Ripple et al. 2001*). Predation is thought to be capable of regulating caribou populations, especially at lower population numbers and densities. This regulation takes place through lowering recruitment of calves into the population, but in very small populations the mortality of adult females has been implicated.

Human predation, on the other hand, tends to focus on healthy, mature caribou. Sport hunters generally take bulls, while subsistence hunters take both males and females. Hunting pressure has been shown to influence the size, speed and age of first reproduction in ungulate populations. Human harvest from some populations is likely compensated for because the caribou might have died due to other causes. Much of the human harvest, however, is additive, because hunters tend to select larger healthier animals less subject to predation, accidents, and other "natural" causes of mortality. As a consequence, human predation can have significant impacts on caribou population dynamics. The main mechanisms for this influence (besides the actual numeric reduction of animals) are the loss of the most productive and resilient age-sex classes and, in extreme cases, sex ratios can be reduced to a point so low that it can affect pregnancy rates.

Predation is likely to be increasingly important under climate warming scenarios and expanding human development within caribou range. Predators utilize human-created linear features to increase their efficiency in stalking prey. Smaller caribou populations are more easily regulated by predators. Human land use patterns also make the landscape favorable to species utilizing early seral stages, such as deer, elk and moose, and making caribou more vulnerable via habitat fragmentation.

Conclusion

The relatively rapid changes in climate we are experiencing today are difficult to model; however, a warmer and drier landscape is predicted over wide swaths of the current distribution of caribou. Extreme weather events are predicted to be more frequent and may test the resilience of caribou. Their adaptability has allowed caribou to survive previous radical changes in climate but has entailed major population fluctuations, as well as localized extinctions (*Klein 1999*). While some climate-induced changes will likely be of benefit to caribou, there is a fine line between benefits and when these changes become large enough that they become detrimental (*Tyler et al. 2008*). Major shifts in biome distribution will have the largest impact on caribou by altering habitat that may enable other ungulates, such as moose, and their predators to increase. These changes will also likely encourage humans to expand their footprint within caribou range. These changes will likely overshadow the effects of other population drivers if the rate of these expected changes exceed the ability of caribou to adapt. Consequently, we should expect dramatic reductions in caribou distribution and populations globally.

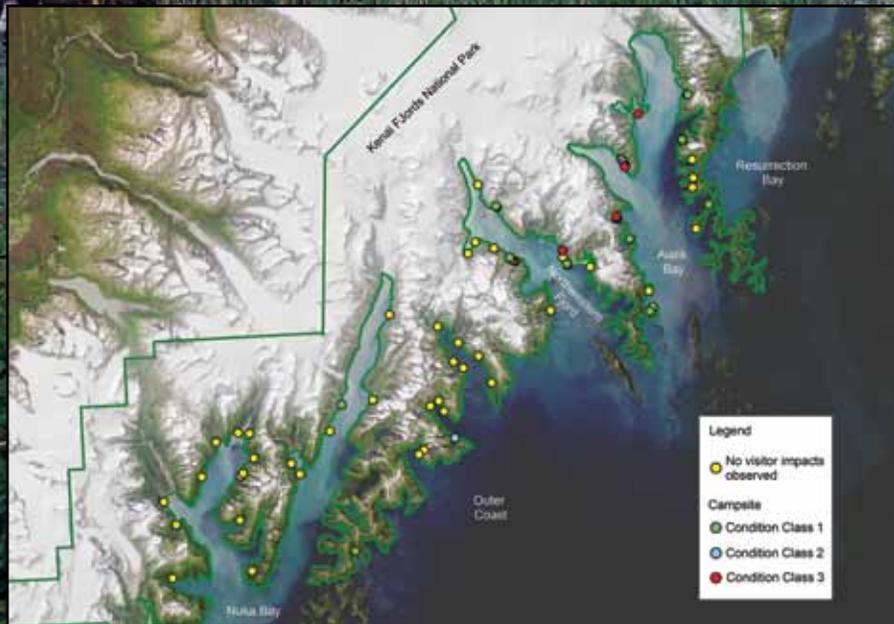


Figure 6. Fortymile Herd caribou in Yukon-Charley Rivers National Preserve. Warmer, cloudier summers may enhance conditions for plant growth, benefiting caribou, but they may also allow for the increase of mosquitoes and flies that endlessly harass caribou.

NPS photograph by K. Joly

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Development of Campsite Monitoring Protocols in Kenai Fjords National Park

By Fritz Klasner, Christopher Monz, and Joel Cusick

The coastal campsite experience

A night on the coast; it comes with spectacular waterfront views, peace and quiet, and fresh air. Camping on the Kenai Fjords National Park (NP) coast is an amazing experience that draws hundreds of visitors to the park each summer.

Although the park is comprised of over 500 miles of spectacular coastline, most of the coast is characterized by steep, rocky headlands, cliffs, and boulder beaches that are virtually inaccessible to boaters and campers. As a result, opportunities for camping are limited to only about 80 sheltered sand/gravel beaches scattered along the length of the park from Nuka Bay in the southwest to Resurrection Bay in the northeast (*Figure 2*). About half of these potential campsites are located in the more remote southern end of the park, the outer coast, and Nuka Bay, and consequently receive very little overnight use. As a result, nearly all backcountry camping is concentrated at about 40 beaches located in Aialik Bay and Northwestern Lagoon. These same areas also contain sensitive cultural, archeological, and natural resources, including

Figure 1. Kayaks on the beach at Kenai Fjords National Park, where kayaking is one of the primary modes of transportation for visitors traveling between campsites.

NPS photograph

Figure 2. Map of landing beaches surveyed during a 2007 rapid assessment. Visitor (campsite) impacts are concentrated in Northwestern Fjord and Aialik Bay. Rapid assessment results are used to inform multiple management concerns, from campsite impacts to invasive species and marine debris accumulations.

salmon spawning streams, ground-nesting marine birds, coastal sedge meadows and, bald eagle nests.

Management need

Kenai Fjords has a history of periodic campsite surveys that dates to at least 1988 (*Tetreau 2004*). This work revealed impacts to park resources such as fire rings, charred wood, cut stumps, root exposure, vegetation trampling, trash, human waste, soil erosion, campsite proliferation, increased human-wildlife interactions, and social trails. Trends of increasing resource impacts raised concerns of altered ecologic condition, impacts to visitors' wilderness experience, and for visitor safety (*Figure 3*). From 1988 to 2004 various monitoring methods were used to document conditions, and a review highlighted the need to improve the consistency, accuracy, and efficiency of field assessment and data analysis (*Tetreau 2004, Monz et al. 2006*).

Former Kenai Fjords NP ecologist Meg Hahr turned the recommendations of *Tetreau (2004)* and *Monz et al. (2006)* into a collaborative effort that integrates science, mapping technologies, management, and visitor perspectives to inform and provide adaptive recommendations to park managers. Needed management information included details about condition of landing beaches, trends in visitor (camping) impacts at known campsites, size and number of tent sites, use and condition of bear-resistant food storage lockers, and other visitor impacts. Since the park does not require permits for camping or most other forms of visitor use, managers needed a clear understanding of changes in the spatial distribution of preferred camping locations in a landscape where tidewater glaciers can retreat at rates approaching 246 feet

(75 m) per year (*Giffen et al. 2009*), vegetation succession is equally as rapid, and shoreline or beach morphology changes are poorly understood due to the interaction of tectonic forces with sea level rise (*Pendleton et al. 2006*).

In 2007, Hahr led a rapid assessment of campsite impacts at 55 landing beaches between Nuka and Aialik Bays (*Figure 2*). From 2008 to 2010, Dr. Christopher Monz, a recreation ecologist from Utah State University, spent several weeks in the park testing, refining, and implementing campsite monitoring protocols. During this same time NPS Alaska Regional Office Geographic Information System (GIS) staff were enlisted to develop Geographic Positioning System (GPS) data collection tools, protocols, and databases for managing the collected data in a streamlined manner (*Figure 4*). Park staff involvement included resource, visitor and resource protection specialists to ensure diverse management perspectives.

Science

Backcountry camping has the potential to affect resource conditions both intensively at the on-site scale and extensively due to site expansion and proliferation (*Leung and Marion 1999, Cole 2004*). Campsites are important from a managerial and visitor perspective as they serve as destinations and focal points for visitor activities, thereby creating areas of concentrated use. Although numerous studies of campsites in parks and protected areas have examined the degree to which visitor use can affect change on site conditions (*e.g., Frissell 1978, Cole 1983, Marion 1995*), studies examining change over long periods are few (*e.g., Cole et al. 2008, Twardock et al. 2010*).

Campsite assessment methodologies have a long



Figure 3. Campsites, such as these at Pedersen Lagoon, include impacts from tents, trails, cooking areas, as well as beach activities.

history of use in parks and protected areas, dating back to the work of Sumner (1942) and Frissell and Duncan (1965), to the more recent contributions of Cole (1989), Marion (1995) and Newman et al. (2006). While campsite studies are commonplace in the lower 48 states, relatively little work has been accomplished in Alaska environments with the exception of long-term studies conducted in Prince William Sound (Twardock et al. 2010, Monz and Twardock 2010). Lake Clark National Park and Preserve has maintained backcountry campsite inventories as early as the 1980s, but protocols and quantitative measurements have not been standardized.

Based on reviews of the historical campsite work in Kenai Fjords NP and consultation with park staff, the development of new assessment protocols was initiated with four overall goals. First, the protocols needed to be more clear in definition of terms and descriptions of ratings-based procedures. Second, campsites needed established reference points that could easily be relocated. Relocation of sites had been problematic by the lack of established reference points and consequently site area re-



Figure 4. A campsite monitoring team discussing methods at a training session.

measurement was not possible. Third, efficiently planning field work needed to be addressed in terms of staff time during an assessment trip and integrating program work into park operations. Last, protocols must withstand a changing field staff without sacrificing accuracy and repeatability.

We were able to accommodate these concerns in several ways. We relied on contemporary campsite protocols developed in intervening years (e.g., Marion 1995) and on the extensive work conducted in Prince William Sound (Twardock et al. 2010) to make wholesale revisions to the methods. Improvements occurred to condition class ratings criteria and definitions, use of radial transect methods for termination of site areas, and to ratings-based systems for visual estimation of various impacts. Next, we conducted two extensive assessments with a large team that brought researchers, field staff and resource managers together in the field to refine and troubleshoot the methods. Last, we incorporated the best available camera and GPS technology to streamline and enforce consistency in data collection, site relocation, and data processing.



Figure 5. Alaska Regional Office database programmer Greg Daniels collects GPS data and records campsite attributes in the field. Photograph watermarks embed site and date information, helping ensure collected information is retained and accessible.

Technology

The technological aspects of establishing protocols were daunting. We developed standardized, electronic data templates to ensure consistent data collection and integration with GPS data. Collection of photographic documentation, a critical component for comparisons with previous work, was also standardized, and its collection was integrated with GPS data (Figure 5). A geodatabase compatible with GIS was developed, serving as a shell to organize and manage this diverse information. One noteworthy benefit of integrating data collection into protocols is that multiple components of collected data are linked in GIS, in database applications, and in reporting tools. For example, electronic campsite maps coded by condition class and linked with site photographs are easily generated.

Limited GPS reception in the steep-sided fjords of the park, wet conditions necessitating waterproof electronics, and the need for tools that can be used by staff with a range of technical knowledge were challenges encountered. Having the technical experts experience

first-hand the field data collection and data management challenges proved essential to bridging these challenges.

Applications of campsite assessments

One of the opportunities that came with revising campsite monitoring methods has been to encourage park staff participation in monitoring efforts. The monitoring protocols provide a structure and clarity of purpose to field efforts, providing field staff with specific monitoring objectives integrated into other responsibilities while still allowing for opportunities to interact with visitors. Additional opportunities include invasive plant and coastal mortality (avian influenza and sea otters)

surveys that can occur alongside campsite assessments.

Direct improvements to campsite management were the intent of and are an outcome of this process. One example is the bear-resistant food storage lockers, which are one of the main tools the park has to promote or direct use to selected areas. The systematic visits and documentation of campsite and food storage lockers identified high visitor use areas with missing or sub-standard lockers. Since implementing updated campsite monitoring methods, Kenai Fjords National Park has been able to rapidly respond to changes in visitor use patterns, with data in hand to support management directed changes to campsite amenities.

Acknowledgements

This work would not have occurred without the tireless efforts of Meg Hahr (see dedication in this issue) and was made possible in part by grants from the National Park Service and National Park Foundation. We are also grateful for the support of NPS Alaska Region GIS Team member Greg Daniels for his efforts in developing GIS, GPS, and geodatabase tools. Kenai Fjords National Park staff Janette Chiron, Shelley Hall, and Christina Kriedeman and Utah State University doctoral student Kelly Goonan were instrumental in helping to start this monitoring. We would also like to thank the many field and office staff and crew for their assistance.

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The Burning Tundra: A Look Back at the Last 6,000 Years of Fire in the Noatak National Preserve, Northwestern Alaska

By Philip E. Higuera, Jennifer L. Barnes, Melissa L. Chipman, Michael Urban, and Feng Sheng Hu

Introduction

More than 5.4 million acres (2.2 million hectares) of Alaska tundra have burned over the past 60 years (Figure 2), indicating its flammable nature under warm, dry weather conditions. Tundra fires have important impacts on vegetation composition (Racine *et al.* 1987, 2004), permafrost dynamics, nutrient and carbon cycling (Wookey *et al.* 2009), and wildlife populations (Jandt *et al.* 2008, Joly *et al.* 2010). Despite the impacts of tundra burning, relatively little is known about natural variability in fire occurrence and links to climate and vegetation change. This lack of knowledge hinders land-management and resource-planning efforts.

Increasing evidence suggests that Arctic environmental change is affecting tundra fire regimes. In 2010 for example, 37 fires burned more than 106,696 acres (43,180 ha) in Noatak National Preserve (Figures 1, 2b), the largest number of fires occurring in this area since record keeping began in 1950. Three years prior, the Anaktuvuk River Fire on Alaska's North Slope more than doubled the total area burned north of 68° N in Alaska since 1950

Figure 1. One of the 37 tundra fires that burned in Noatak National Preserve in the summer of 2010. The Kaluktavik River fire (Fire #561) burned more than 23,000 acres (9,300 ha) in July.

NPS photograph

(Figure 2) (Hu *et al.* 2010, Jones *et al.* 2009). This event, associated with record-high temperatures and record-low precipitation and sea-ice extent, marked the first time this area burned in at least 5,000 years (Hu *et al.* 2010). Changes in fuel characteristics associated with increased shrub density over the past several decades (*e.g.*, Tape *et al.* 2006) may also be changing tundra flammability. Paleocological evidence from 'ancient' shrub tundra in and around Gates of the Arctic National Park and Preserve (Figure 2) indicates the high flammability of birch shrubs that dominated this region circa 13,000–11,000 calendar years before present (cal. yr BP) (Higuera *et al.* 2008). In combination with studies documenting increased birch abundances in recently-burned areas (*e.g.*, Joly *et al.* 2010), these patterns raise the possibility of positive feedbacks between increased shrub density and increased tundra burning.

We investigated fire history of the past 6,000 years in the Noatak National Preserve, with the goal of understanding how fire regimes varied in relation to climate and vegetation. This work places modern tundra fire occurrence in the context of natural variability, provides critical fire-history information for fire managers, and elucidates drivers of tundra fire regimes with relevance to past, present and future tundra ecosystems.

Methods

Our study capitalized on the ability to reconstruct both vegetation and fire history using lake-sediment

records. Pollen grains dispersed from plants and charcoal pieces dispersed from fires are well preserved in the sediments at the bottom of lakes, where a lack of oxygen prevents decomposition. As sediments accumulate over time, so too does a record of vegetation and fire history. By collecting and analyzing individual layers of lake sediments, we reconstructed vegetation and fire regimes spanning the past 6,000 years.

We collected lake-sediment cores from four lakes along an east–west transect in Noatak National Preserve (Figure 2b). These lakes span a modern gradient in climate and vegetation, with down-valley sites characterized by slightly warmer, drier summers and a greater abundance of tussock-shrub tundra and white spruce. Each lake-sediment core was sliced at 0.10–0.20 inch (0.25–0.50 cm) intervals, representing 15 years on average, and geochemical techniques (carbon 14 and lead 210 dating) were used to establish the timing of past events.

To estimate vegetation composition within approximately 0.6–3.1 miles (1–5 km) of each lake, we counted pollen grains in sediment samples at circa 250 to 500 year intervals. To reconstruct when fires burned within approximately 0.6 mi (1 km) of each lake, we counted macroscopic charcoal pieces (> 0.0071 in/180 μm diameter) in each sediment layer, and used statistical methods to identify fire events in the record (*as described by Higuera et al.* 2009). Estimated fire events were used to calculate fire-event return intervals (FRIs, years between fire events), providing a conservative estimate of site-

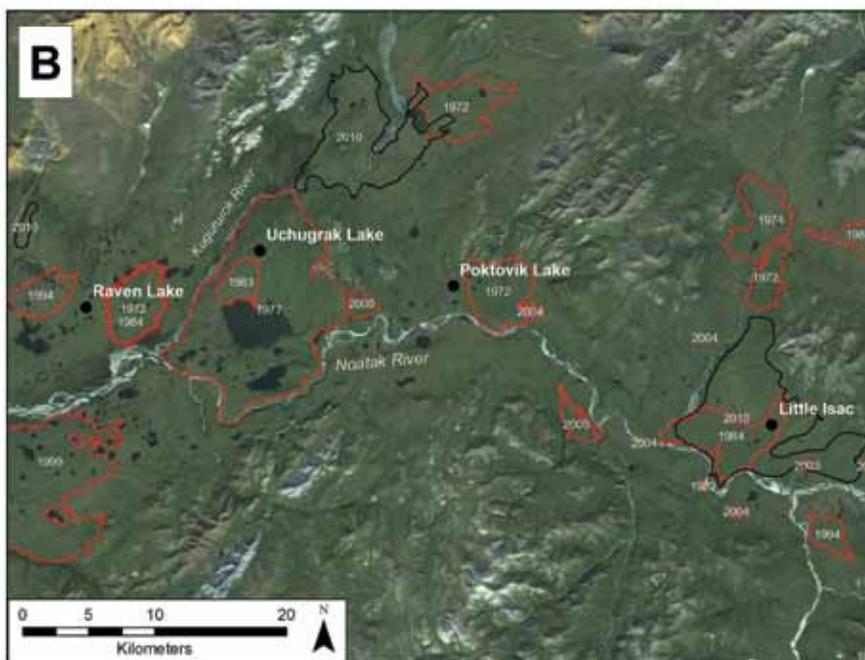
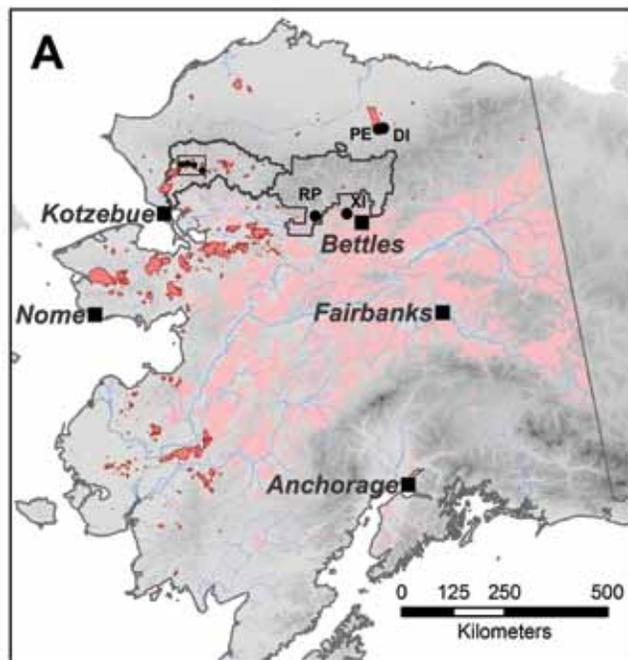


Figure 2. Regional and local location of study sites. (A) Alaska fire history (red polygons) from 1950-2009, with tundra fires highlighted in dark red. Other tundra fire-history records from lake sediments are identified by black dots: Ruppert (RP) and Xindi (XI) lakes, in the south-central Brooks Range, and Perch (PE) and Dimple (DI) lakes, within the 2007 Anaktuvuk River Fire. (B) The Noatak study area: large fire perimeters from 1950-2009 are shown in red, fires that burned in 2010 are outlined in black, and the location of four lakes cored in 2007 are identified by black dots.

specific fire return intervals.

Results and Discussion

Charcoal records from the study area provide unambiguous evidence of burning over the past 6,000 years, with individual FRIs ranging from 30 to 840 years (Figures 3-6). This variability reflects differences across space and changes in climate and vegetation through time.

Estimated fire-return intervals for the ‘recent’ past

Our best estimates of recent FRIs come from the charcoal records of the past 2,000 years, a period long enough to capture multiple fire events for a statistical assessment. Median FRIs varied among sites, from 113 years (95% confidence interval [CI] 75-150) at Uchugrak Lake to 240 years (CI 105-548) at Little Isac Lake (Figure 3). When pooled, the two down-valley sites of Raven and Uchugrak had shorter FRIs (median 150 yr, CI 101-150) than those from the two up-valley sites of Poktovik and Little Isac (median 218 yr, CI 128-285) (Figure 3).

Our charcoal-based mean FRIs across the study area are shorter than previous estimates for two portions of the Noatak River watershed, based on circa 30-60 years of observational data. Down-valley sites had estimated fire cycles (equivalent to the point-specific mean FRI) of 175-193 years (Kobuk Ridges and Valley Ecoregion) (Joly et al. 2009, Kasischke et al. 2002), and up-valley sites had estimated fire cycles of 480 years (Gabriel and Tande 1983). These differences likely reflect the difficulty in estimating fire cycles greater than 150 years with a < 60-yr dataset. They may also represent real but yet undetectable changes in tundra fire occurrence and/or an overestimation of local fires in the charcoal records.

Differences in burning rates between down- and up-valley sites correspond to spatial variability in climate and vegetation. Lower growing season temperature and increased precipitation at up-valley sites limited fuel drying and thus the probability of fire ignition and spread, relative to down-valley sites. The importance of climate in controlling tundra fires is also apparent in

Alaska over the last 60 years. Tundra fire regimes are most active in regions with warm and/or dry seasonal climate (Higuera et al. 2008), and tundra fires occur during years with above average temperatures and below average moisture (Hu et al. 2010; Jones et al. 2009). Interestingly, the site with the highest median FRI in the past 2,000 years (i.e., Little Isac Lake) burned in the summer of 2010, making it the second fire at this site in 26 years (Figure 2). Return intervals nearly this short (i.e., 30 yr) also occurred at this site in the past (Figures 3, 5).

Vegetation and fire history over the past 5000-6000 years

Over the past 6,000 years, vegetation and fire regimes fluctuated in the Noatak study area in response to millennial-scale changes in effective moisture (Clegg and Hu 2010) (Figures 5-7). An increase in *Picea* (spruce) pollen in all records indicates the regional expansion of white spruce circa 2000-3000 cal. yr BP, and at most sites *Alnus* (alder) pollen percentages gradually decreased since 4000-6000 cal. yr BP. Coincident with

Time period	Sub-region	Site(s)	Fire-history parameter (95% CI)			
			n_{FRI}	Range of fire-event return intervals (yr)	Mean fire-event return interval* (yr)	Median fire-event return interval (yr)
2000 cal. yr BP to present	Down-valley	Raven	13	30 - 285	151 (108 - 199)	150 (90 - 195)
		Uchugrak	16	45 - 345	135 (98 - 176)	113 (75 - 150)
		Raven + Uchugrak	29	30 - 345	142 (115 - 174)	150 (101 - 150)
	Up-valley	Poktovik	9	45 - 525	227 (139 - 327)	195 (105 - 300)
		Little Isac	7	60 - 840	309 (134 - 521)	240 (105 - 548)
		Poktovik + Little Isac	16	45 - 840	263 (175 - 374)	218 (128 - 285)
6000 cal. yr BP to present	Down-valley	Raven	30	30 - 735	201 (139 - 264)	143 (105 - 195)
		Uchugrak	41	30 - 645	149 (119 - 184)	120 (90 - 150)
	Up-valley	Poktovik	19	45 - 750	248 (180 - 329)	240 (135 - 270)
		Little Isac	37	30 - 840	169 (121 - 221)	105 (90 - 180)

*Theoretically, the point-specific mean fire return interval is equivalent to the fire cycle, calculated in other tundra fire history studies (e.g. Gabriel and Tande 1983, Joly et al. 2009, Kasischke et al. 2002).

Figure 3. Fire-history statistics for the Noatak study area, stratified by time period, sub-region, and site. Statistics include the total number of fire-event return intervals detected (n_{FRI}), mean, and median FRIs. Confidence intervals (95% CI) were approximated with the 2.5th and 97.5th quartiles from 1,000 boot-strapped samples, with replacement.

these vegetation changes, long-term mean FRIs also varied over time (Figure 5). Most sites experienced less frequent burning (i.e., longer FRIs) prior to 2000 cal. yr BP, when alder pollen percentages were higher and spruce pollen percentages were lower. The exception was at Little Isac Lake, where alder pollen percentages increased over time, and *Betula* (birch) pollen percentages in the past were higher than at other sites. Likewise, fires were more frequent prior to 2000 cal. yr BP at Little Isac Lake, despite the opposite pattern at other sites.

The variability in millennial-scale mean FRIs was significantly correlated with changes in pollen percentages of select taxa ($0.35 < |r| < 0.74$) (Figure 6). Alder was most consistently correlated with fire frequencies, with an increase in alder associated with a decrease in fire frequency. Correlations with spruce, grasses, sedges and birch were more variable, but in general these taxa

were positively related to increased fire frequencies.

Conclusions

This study provides estimated fire return intervals (FRIs) for one of the most flammable tundra ecosystems in Alaska. Fire managers require this basic information, and it provides a valuable context for ongoing and future environmental change. At most sites, FRIs varied through time in response to changes in climate and local vegetation. Thus, an individual mean or median FRI does not capture the range of variability in tundra fire occurrence. Long-term mean FRIs in many periods were both shorter than estimates based on the past 60 years and statistically indistinct from mean FRIs found in Alaskan boreal forests (e.g., Higuera et al. 2009) (Figure 2). These results imply that tundra ecosystems have been resilient to relatively frequent burning over

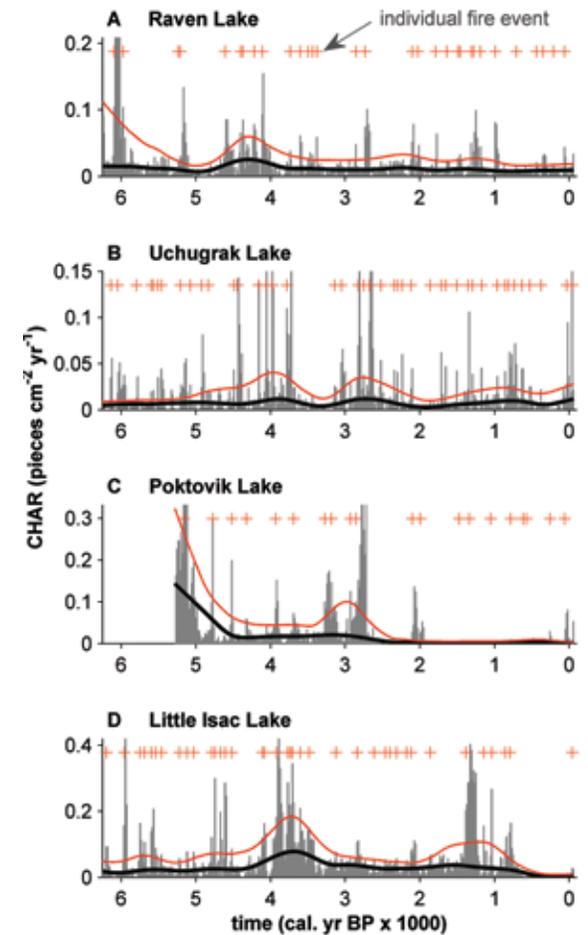


Figure 4. Charcoal records from the Noatak study area for the past 6,000 years, with inferred fire events. The most recent fires to burn around Uchugrak (1977) and Little Isac (1984) register as detected peaks (red '+' symbol) in the most-recent sediments of each charcoal record.

the past 6,000 years, which has implications for both managers and scientists concerned about environmental change in tundra ecosystems. For example, increased tundra fire occurrence could negatively impact winter forage for the Western Arctic Caribou Herd (Joly et al. 2009). Although the Noatak is only a portion of this

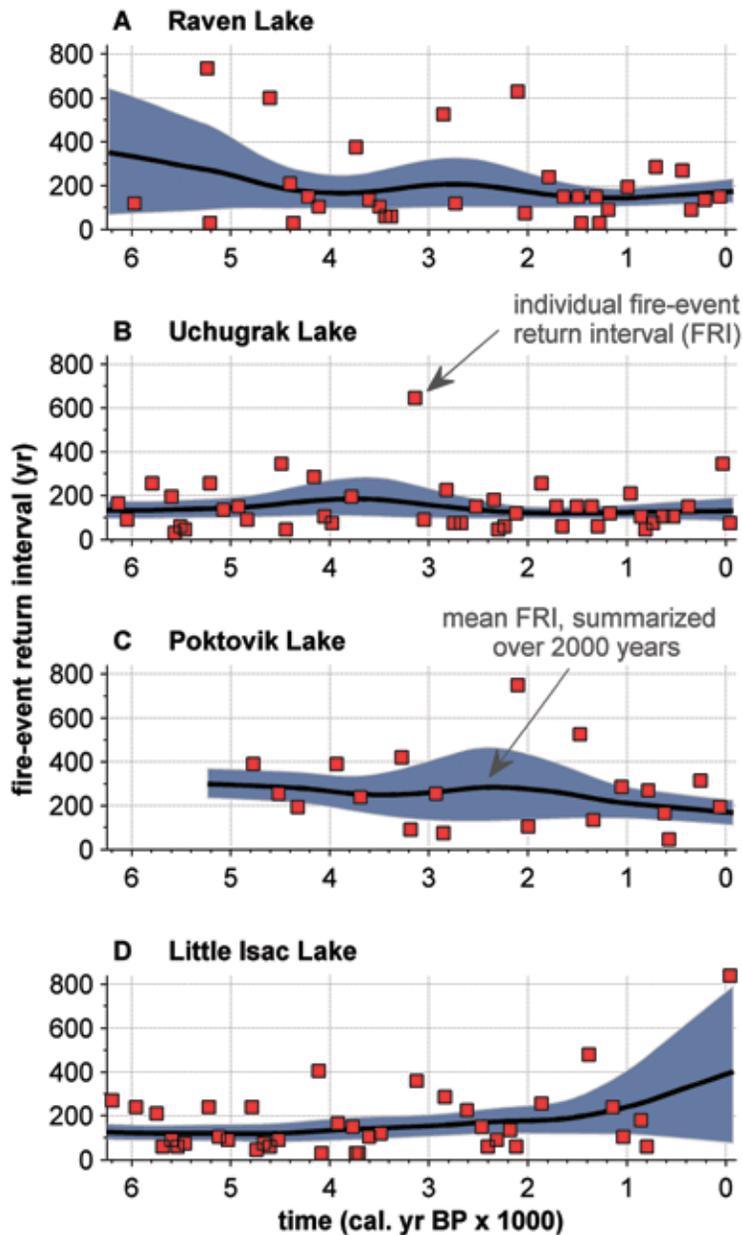


Figure 5. Fire-event return intervals (FRI) from the Noatak study area for the past 6,000 years. Red squares are individual fire events, and their location relative to the y-axis represents the FRI. The black line represents the mean FRI, when summarized over 2000-yr periods. The blue envelope is an estimated 95% confidence interval.

Site(s)	Timescale (yr)	Correlation coefficient*				
		Picea**	Betula	Alnus	Cyperaceae	Poaceae
Raven	1000	0.65	-0.58	-0.69	--	0.47
Uchugrak	1500	--	--	-0.35	0.43	--
Poktovik	1500	0.74	--	-0.67	0.74	0.52
Little Isac	2000	-0.58	0.52	-0.39	--	--

*Spearman's rank correlation, with significance evaluated to account for autocorrelation.
 **Picea pollen represents regional pollen dispersal at all sites except Raven Lake. Thus, correlations with this taxon should be interpreted at Raven Lake only, and negative correlations with Betula at this site are likely an artifact of increased Picea.

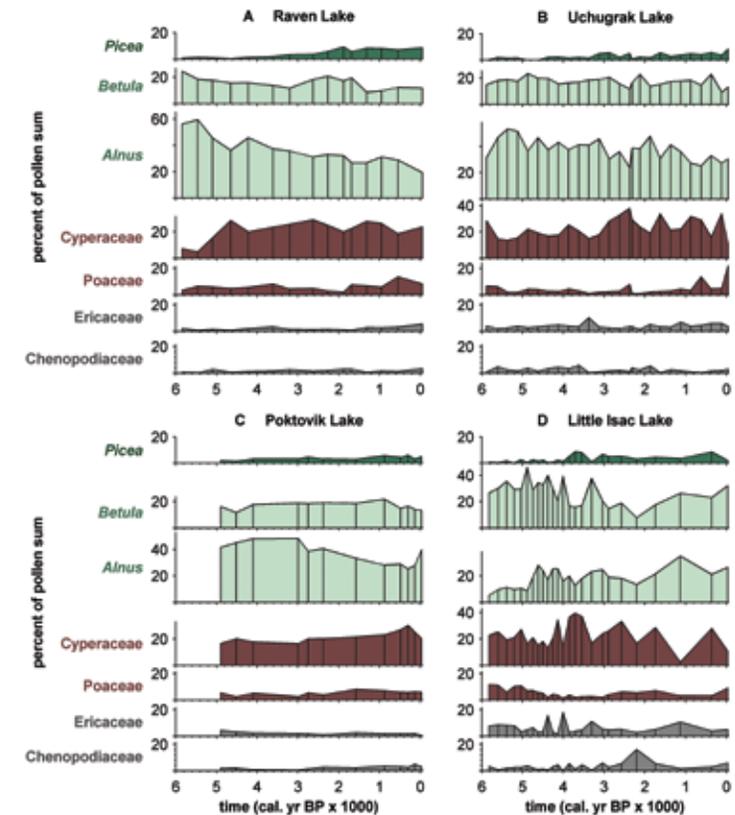


Figure 7. Correlations between fire frequencies, summarized at 1,000 to 2,000 year time scales, and selected pollen types: Picea (white spruce), Betula (birch), Alnus (alder), Cyperaceae (sedges), and Poaceae (grasses). Values indicate correlations with $p < 0.10$; bold values indicate correlations with $p < 0.05$. "Timescale" indicates the timescale over which fire frequency was summarized, selected to maximize the correlations at each site.

Figure 6. Correlations between fire frequencies, summarized at 1,000 to 2,000 year time scales, and selected pollen types: Picea (white spruce), Betula (birch), Alnus (alder), Cyperaceae (sedges), and Poaceae (grasses). Values indicate correlations with $p < 0.10$; bold values indicate correlations with $p < 0.05$. "Timescale" indicates the timescale over which fire frequency was summarized, selected to maximize the correlations at each site.

herd's range, our results indicate that if caribou utilized the study area over the past 6,000 years, then they have successfully co-existed with relatively frequent fire.

Fire history in the Noatak also suggests that subtle changes in vegetation were linked to changes in tundra fire occurrence. Spatial variability across the study region suggests that vegetation responded to local-scale climate, which in turn influenced the flammability of surrounding areas. This work adds to evidence from 'ancient' shrub tundra in the southcentral Brooks Range suggesting that vegetation change will likely modify tundra fire regimes, and it further suggests that the direction of this impact

will depend upon the specific makeup of future tundra vegetation. Ongoing climate-related vegetation change in arctic tundra such as increasing shrub abundance in response to warming temperatures (e.g., *Tape et al. 2006*), could both increase (e.g., birch) or decrease (e.g., alder) the probability of future tundra fires.

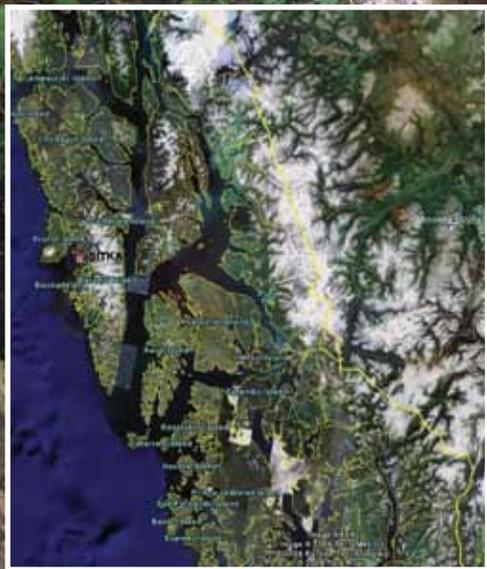
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Tlingit Archeology, Legends, and Oral Histories at Sitka National Historical Park

By William J. Hunt, Jr.

Located on the Pacific face of Baranof Island in southeastern Alaska, Sitka National Historical Park is Alaska's oldest national park unit. The Russian Bishop's House, in downtown Sitka, commemorates Russian-American history. About one-half mile to the east is the Fort Unit, where interpretation focuses on the park's natural resources and Northwest Coast culture. This unit is also the site of a major event that changed the course of Alaska history: an 1804 battle resulting in Russian colonization of Tlingit lands. Every year, around 300,000 people visit the park learning about the region's natural attractions as well as Tlingit culture and art. Few understand, however, that people have lived in the area for thousands of years. Recent archeological investigations by the National Park Service's Midwest Archeological Center have revealed details of this history.

Environment

Baranof Island is a mist-shrouded land of impenetrable mountains and deep fjords sculpted by eons of uplift, subsidence, and erosion. Although the island is

Figure 1. Volunteer Laura Crawford and NPS archeological technician Arlo McKee conducting a test excavation at the T'ooch' Aan (Charcoal Village) site.

NPS photograph by William Hunt

Figure 2. (Map) Location of Sitka.

ancient, the park lands are relatively young, the oldest portion only emerging from the ocean about 5,500 years ago. Over time, the lands of Sitka continued to rise until about AD 1250 when the park's characteristic boot-shaped peninsula was fully in place (*Chaney et al. 1995*).

The island's rugged landscape and mild, wet environment combine to generate a wealth of ecological niches. Park habitats include temperate rainforest, open meadow, estuary, anadromous river, and marine intertidal shore. The bulk of the park is a temperate rainforest of Sitka spruce/western hemlock and dense understory of devil's club, skunk cabbage, salmonberry, and other shrubs (*Kriechhaus et al. 1993, McNab and Avers 1994*). The only large mammals are brown bears and Sitka deer. Birds, particularly seabirds, are abundant and aquatic life occurs in profusion where the Indian River, tidal flats, and deep oceanic waters meet (*Sitka National Historical Park 2008, Sitka Tribe of Alaska Kayaani Commission 2006, Thornton and Hope 1998*).

History

The earliest known human occupation on Baranof Island occurs on the northeastern shore at the Hidden Falls site. In the 1980s, archeological investigations demonstrated people were here by at least 8,000-8,600 years ago (*Davis 1989*). Tlingit oral history places people in Sitka Sound during an eruption of Mt. Edgecumbe, a stratovolcano on the sound's west shore. Edgecumbe's

last eruption occurred 2500-2900 BC, placing the Tlingit here for at least 4,500 years ago (*Thornton and Hope 1998*). Oral histories of the Tlingit Kiks.ádi clan, traditional owners of resources in the park, place themselves at Sitka from that time through the present.

The course of this long occupation was altered in 1798 with the arrival of Russians who, in search of fur riches, lusted for Tlingit lands. In 1804, a force of Russian traders, their Aleut allies, and the Russian navy attacked. Anticipating Russian naval bombardment, the Tlingit had taken refuge in *Shis'ki-Noow*, a unique fortification constructed on flatlands west of the Indian River. The short confrontation ended when the Tlingit, out of gunpowder, were forced to withdraw to Chatham Strait. The Russians then built Novo Arkhangelsk (later called Sitka) on the site of the Tlingit winter village as their colonial capital and headquarters of the Russian American Company. Within a short time, the Tlingit returned and continued to use park lands in many of the traditional ways (*Lisiansky 1814; 2008*).

Sitka Archeological Project

Given the park's environmental diversity, its complex physical and cultural histories, and difficulties of working in dense rain forest, several investigative techniques were used to identify the archeological resources. These included metal detection, geophysical surveys, as well as typical archeological methods of



NPS photograph by William Hunt

Figure 4. NPS archeologist Steve De Vore conducting a resistance survey in the Fort Clearing using a resistance meter with twin probe array.

shovel testing and small-scale test excavations.

Metal detection is generally not useful for identifying prehistoric sites but is an excellent method for locating historic sites. Through metal detection, the 1804 battleground site was identified. Lead musket balls indicated use of .69-caliber smoothbore muskets in the battle along with .36, .44, and .45-caliber small arms (Figure 2). Cannonballs, canister, and grapeshot provided formidable evidence for Russian use of 3-pounder, 4-pounder, and 12-pounder guns.

Tlingit oral histories place the 1804 fort at two



NPS photograph by William Hunt

Figure 5. Shovel testing in the Fort Clearing.

locations on the peninsula: an area near its center and the other in the Fort Clearing in the south end. The goal of the geophysical inventory was to identify which was the most likely location. Investigative tools included magnetic gradient survey, resistance survey, and ground penetrating radar (Figure 4). Analysis of geophysical data suggested the Fort Clearing as the more plausible location. Unfortunately, massive modern disturbances prevented unambiguous identification of the fort.

Shovel testing was the workhorse for the inventory as it can identify both historic and prehistoric sites (Figure 5). Eighty of the over 1,200 shovel tests proved positive, demonstrating a very low artifact recovery rate. Prehistoric artifacts were recovered from 23 tests with all but three on the west side of Indian River. These tools (quickly made, minimal shaping, used briefly, and thrown away), made from flakes, cobbles, and split pebbles, appear to have been used for chopping, scraping, and perhaps digging. Prehistoric tools largely occurred on landforms younger than 2,000 years old with the overwhelming majority (84%) associated with landforms less than 900 years of age. Only three

tools are from landforms older than 2,000 years.

Though no patterned tools were recovered, they have occasionally been found in the park. Northwest Coast ground stone “nipple top” mauls were recovered during 1940s bridge construction and during 1958 archeological excavations at the Fort Clearing. These tools were typically used to pound wedges into a cedar log to split off planking for construction of houses and as utilitarian hammers used to drive stakes or crush food (Stewart 1973). Two cobble choppers were discovered by geologists studying the developmental history of the park in 1995. In 1999, a 3/4-grooved granite maul was recovered in the Fort Clearing during an archeological excavation preceding installation of a Kiks.ádi totem pole commemorating the 1804 war leader K’alyáan. The most recent discovery, in 2009, occurred when a blown down tree exposed an enigmatic lozenge-shaped siltstone hammer-abrader. The ages of these tools remain unknown.

Charcoal is an important cultural resource indicator because rainforest wildfires are rare. Charcoal was observed in 76 shovel tests, with 20 of these having charcoal of such concentration to suggest the presence of a midden or feature. Radiocarbon dates from 23 samples ranged from 80 ± 50 to 2580 ± 50 years ago. Assuming the charcoal is from cultural activities, the dates indicate people lived in the park from the Middle Northwest Coast Developmental Stage (3,500 to 1,500 years ago) to the historic era. Twenty samples date to the Late Northwest Coast Developmental Stage (1,500 years ago to historic contact) to the early historic era (Davis 1990, Matson and Coupland 1995). Three areas in the park exhibit multiple prehistoric occupations. Patchwork distributions of charcoal in two of these locations suggested the possibility of associated structures.

After shovel testing, small scale test excavations were undertaken to clarify the cultural and temporal associations of various deposits. Eleven locations (four historic, one multi-component prehistoric and historic, and six prehistoric) were tested.

Among the more interesting discoveries was a

rectangular hearth. Its superimposition by layers of charcoal and decomposed wood along with artifacts indicate this is an element of a prehistoric structure. Radiocarbon dates indicate a circa AD 1153-1228 occupation. Additional shovel testing suggested the building may be less than 26 ft (8 m) long and wide, about the size of early historic Tlingit summer houses (Figure 6). Such structures often functioned both as fish smokehouse and single family dwelling (Emmons 1991).

Another exciting find was an anvil stone recovered from a pit feature in the Fort Clearing. Charcoal from the pit dated to circa AD 606-996. Initially, the anvil was believed to be a striking platform used in stone tool production; however, Kiks.ádi elders and Tlingit artists suggested cedar bark may have been pounded on it to produce fibers for weaving, or berries or meat were crushed on it for food preparation. As a result, the artifact was sent to the Laboratory of Archaeological Sciences at California State University-Bakersfield for protein analysis. Using immunological methods similar to an allergy test, both animal (bear and deer) and plant residues (*Amaranthaceae* and kelp) were identified. Brown bear and Sitka deer are the only bear and deer species inhabiting Baranof Island, and the Tlingit commonly ate a variety of seaweeds gathered from late winter through summer. The positive amaranth test may point to use of Alaska or Gmelin's orach, saltbush plants in the pigweed subfamily of *Amaranthaceae* commonly found along the coast of Baranof Island. Although no sources consulted identify either orach variety as Tlingit foods, they have been used for food throughout the world (Davidson 1999, Newton and Moss 1984, Thornton and Hope 1998, Sitka Tribe of Alaska Kayaani Commission 2006). Based on positive tests for three known Tlingit foods and another possible plant food, it was concluded that the anvil stone was used as a tool in food preparation, possibly in production of a Northwest Coast "pemmican."

Four intriguing ovate pits about 9.8-13 ft (3-4 m) long and wide and about 5 ft (1.5 m) deep were also recorded. One pair lies within the 1804 battlefield, a position

suggesting possible association with *Shis'ki-Noow*. Both Tlingit and Russians describe one or more pits within the fort that provided the Tlingit with refuge from Russian cannon fire. If these depressions are associated with the fort, the position of the fort shifts northwestward from that proposed by Frederick Hadleigh-West after his 1958 excavations (Hadleigh-West 1959). These and the other two depressions, however, may represent remnants of traditional Tlingit cache pits. Such pits were up to 13 ft (4 m) on a side and commonly dug behind houses to store food. Although Tlingit cache pits were commonly associated with winter villages, they also occurred in summer

fish camps (de Laguna 1972, Maschner 1992) and suggest the possibility of undiscovered domestic features nearby.

Several Sitka spruce trees have had patches of bark removed by adze or axe. This may have been done to collect pitch or gum. Spruce pitch was used in traditional Tlingit culture as a fire starter, to repair damaged watercraft, and in traditional medicine (Thornton and Hope 1998, Sitka Tribe of Alaska Kayaani Commission 2006). Most of the trees are believed to be less than 200 years old, indicating continued use of traditional medicines through the historic period.



Figure 6. Nineteenth century fish camp, Sitka, Alaska.

Summary

The inventory at Sitka National Historical Park is the first in this part of southeastern Alaska to intensively study an area along an important salmon fishing tributary. Eighteen sites were recorded within an 112-acre area of rainforest. Ten of these reflect occupation by prehistoric Native Americans and their descendants, the Sitka Tlingit and the Kiks.ádi clan, from 2,600 years ago to the modern era. Archeologists identified the 1804 Tlingit-Russian battleground and refined the probable location of the Tlingit fort to an area within or adjacent to the Fort Clearing. Archeological research at Sitka has provided insights into prehistoric manufacture and utilization of opportunistic tools, site distributions, and food preparation. Finally, the project confirmed the viability of a multidimensional approach to archeological research by combining information from fieldwork, oral and written history, and the natural sciences to create a more holistic interpretation of past lifeways.

Acknowledgements

The 2005-2008 Sitka National Historical Park inventory was funded through the NPS Systemwide Archeological Inventory Program. The project's success was due to the efforts of many individuals, but particularly Chief of Resource Management Gene Griffin. It concluded Gene's nearly 30-year initiative to document park cultural and natural resources, a process that involved historians, oral historians, geologists, geophysicists, ecologists, soils scientists, archeologists, cultural landscape architects, and botanists from 12 tribal, federal, state, and private organizations. These investigations led to a broad understanding of the park's natural and cultural history from circa 4,500 years ago when the park lands emerged from the sea through the twentieth century. Although Gene retired shortly after the fieldwork was completed in 2008, his legacy will be of great importance to park planning, interpretation, and research for decades to come.



NPS photograph by William Hunt

Figure 2. (Bottom Left) Bullets and cartridge case recovered during metal detecting: 23523 and 23540 are 0.63 inch balls, 23519 is a 0.44- or 0.45-caliber ball with measured diameter 0.43 inch, and 23532 is a lead ball embedded in wood.

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Recent Mammals of Alaska

By S.O. MacDonald and Joseph A. Cook

Summary

From diminutive shrews to the majestic blue whale, there are 116 species of mammals in Alaska that have never been fully documented until now. Biologists Joseph A. Cook and S.O. MacDonald have compiled the first comprehensive accounting of Alaska's recent mammals, big and small, common and rare.

Through extensive fieldwork and research, supported by the Alaska NPS Inventory and Monitoring Program and others, the authors have produced the first authoritative reference. Detailed entries for each species include distribution and taxonomic information, status,

habitat, and fossil history. Appendices include quick reference listings of mammal distribution by region, specimen locations, conservation status, introductions and translocations, and the incidence of Pleistocene mammals. The guide is generously illustrated with line drawings by Alaska artist W.D. Berry and others, and includes maps indicating the distribution of species. *Recent Mammals of Alaska* is an accessible, easy-to-use source for scholars and amateur naturalist alike.

Available at www.alaskageographic.org

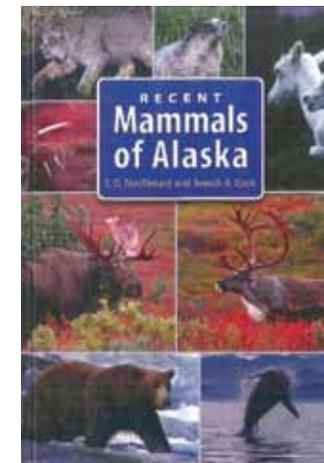


Figure 1. Book cover *Recent Mammals of Alaska*.

Alaska Park Science

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