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Table of Contents

Cover photo: Muskoxen in Cape Krusenstern National Monument.
Photo courtesy of Jared Hughey

Alaska's Northern Parks: The Wonder of the Arctic

James P. Lawler, Jeff Rasic, and Peter Neitlich, National Park Service

February 12, 2014 - Howard Pass, Noatak National Preserve, Alaska; temperature: -42 °F; average wind speed: 71 mph; wind chill: -97 °F (Sousanes and Hill 2014).

This weather event exemplifies one of the challenges of living in the Arctic: It can be cold. Then, of course, there is the light, or lack of it. Here at Howard Pass, the sun disappears for close to a month in the dead of winter, but in the midst of the summer, it stays above the horizon for a month. Another thing to consider regarding Howard Pass is the caribou (*Rangifer tarandus*). For thousands of years, caribou herds have migrated from the North Slope of Alaska to more southerly climates through this pass and back again. This can be a big event. In 2003, the Western Arctic Caribou Herd, whose range encompasses Howard Pass, numbered approximately 490,000 animals (Dau 2015). Given the predictable migratory corridor, as well as periods of great abundance of caribou, it's not surprising that people are closely attuned to this resource. For thousands of years, hunters have converged on Howard Pass and it contains one of the densest concentrations of archaeological sites in northern Alaska.

The National Park Service manages five parks that fall partially or entirely within the Arctic tundra biome, the ecoregion situated north of tree line. These five parks—Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Noatak National Preserve—encompass 19.3 million acres of land and constitute approximately 25% of the land area managed by the National Park Service nationwide. These are undeveloped places with free flowing rivers and extremely few facilities. Only a single road crosses these lands, a 23-mile gravel industrial road through the northern end of Cape Krusenstern National Monument. The Interior parks in this cluster span the rocky and barren mountains of the western Brooks Range to the southern Chukchi Sea to the east. They include a variety of ecosystems: dry alpine tundra, lowland wet tundra, boreal forest, coastal tundra, lagoons, and estuaries. This is wilderness at a massive scale with largely intact ecosystems, but also a land that has been inhabited by people for thousands of years.

Fifteen thousand people live in northwestern Alaska, and many of them access and transit the parks to continue the long tradition of subsistence, including harvesting resources from this wild area. Inupiat people living in Shishmaref, Wales, Deering, and Kotzebue enjoy the bounty of coastal resources, including sea mammals and fish. Other communities like Anaktuvuk Pass, Kobuk, Shungnak, and Ambler travel inland rivers and mountains and harvest caribou, sheep, fish, and berries. But it's not all about food. Time on the land is time spent connecting and reconnecting with friends and relatives, places, stories, and other values. Protecting the ecology, history, archaeology and subsistence lifestyle of the U.S. Arctic is the reason parks were established in northern Alaska.

As exemplified above, one of the defining characteristics of ecosystems is the climate. Large bodies of open water tend to moderate climate. Temperatures tend to be more extreme inland compared to the coast. The twist here is due to the annual formation of pack ice. This ice largely moderates the effect of the sea and for this reason, even coastal areas in Arctic parks can be intensely cold with little precipitation during the winter months. To deal with these temperatures, winds, and the limited food and energy resources often associated with the winter months, plants, animals, and people can adapt and survive in place, or they can move to more favorable conditions.

Movement is not an option for plants. What to do? One strategy is to get low. Plants here hug the ground. This not only allows them to take advantage of any heat the earth has absorbed

◀ Devil Mountain, Bering Land Bridge National Preserve.
NPS photo courtesy of Ken Hill

Arctic alpine forget-me-not, Bering Land Bridge National Preserve.
NPS photo

from the sun, it also removes them from the desiccating effects of the wind. Another strategy is to insulate. Insulation for a plant can take a couple of forms. The tussock-forming sedge *Eriophorum*, benefits from dead leaves left from previous seasons to trap warm air next to the green growing portions of the plant. Another advantage of this leaf litter, if you are a plant, is that any nutrients that you have managed to capture in previous seasons are close at hand. Because of the cold, decomposition occurs at a very relaxed pace. Best to be close and ready to use any nutrients that become available before your neighbor has a chance. Hair is another option for providing a bit of insulation. Technical manuals describing leaves of Arctic plants include terms like "hirsute," "pilose," "pubescent." All descriptions of a vegetative version of fleece. Not all arctic plants are hairy however. Wax isn't a bad option either. Wax can help with the abrasion caused by being pelted by snow crystals in the winter, and dust and sand particles in the summer. Wax also slows desiccation. Water, after all, is only available for use by plants as a liquid. In Arctic parks, its most common form is snow and ice. These are but a few of the adaptions plants use to survive in the Arctic.

Unlike plants, animals have the option of moving. The migration by some arctic wildlife is one of the most extraordinary phenomena known in the natural world. Wildlife migrate from, through, and past these Arctic parks by land, sea, and air. On land, caribou are the champions. Some individuals have been known to cover more than 3,000 miles in a year (Fancy et al. 1989). In northwestern Alaska, caribou cycle between their calving areas on the North Slope of Alaska, to mid-summer insect-relief in coastal and mountainous areas before turning south to spend their winter on the Seward Peninsula; an annual migration of approximately 1,900 miles (Joly 2012).

By sea, gray whales (*Eschrichtius robustus*) are acknowledged migration champions. The eastern stock of gray whales spend their summers feeding in the Chukchi, Beaufort, and northwestern Bering Seas. In the fall, the whales start their migration south swimming past Cape Krusenstern National Monument and Bering Land Bridge National Preserve. A few months later, they arrive at their winter destination off the coast of Mexico's Baja Peninsula to breed and calve. By mid-February, some whales are already heading north for the summer season. This equates to a travel distance of approximately 10,000 miles (NOAA 2016a). Others like the bearded seal (*Erignathus barbatus*) migrate with the annual formation and disappearance of pack ice. Bearded seals are an "ice seal." They use pack ice as a platform for resting between feeding bouts and for delivering their pups (NOAA 2016b). In the winter, they can be found in open leads and by breathing holes (that they maintain with their claws) offshore of both coastal Arctic parks.

The majority of the birds present in Arctic parks in the summer take their leave in the early fall to migrate south. Some of these migrations are epic not only in the distance covered by some very small animals, but in the routes chosen. The Northern Wheatear (*Oenanthe oenanthe*)

◀ Arctic ground squirrel, Yukon-Charley Rivers National Preserve.
NPS photo

Ancient stone cache, Bering Land Bridge National Preserve. ▲
NPS photo

nests in the mountains of the Brooks Range. Come fall, this bird, that is slightly smaller than an American Robin (*Turdus migratorius*), heads west to Russia and then cuts across southwest Asia to eventually end up in sub-Saharan Africa, over 18,000 miles round trip (Bairlein et al. 2012). Not to be outdone, the Bar-tailed Godwit (*Limosa lapponica*), a medium-sized shore bird that nests in coastal areas of northwestern Alaska, leaves in the fall and begins its southern migration to New Zealand. The route chosen is rather interesting. Instead of playing it safe and flying over land, Bar-tailed Godwits head out over the open ocean. Godwits aren't built to land and feed on the open water. As a consequence they need to stay in the air until they reach their destination meaning 7,200 miles of flying, eight days in the air, in one push (Gill et al. 2005).

Not all animals migrate though. Reducing your metabolic rate to minimize the need for resources is another strategy. Arctic ground squirrels (*Spermophilus parryii*) are prime examples of this and can spend up to nine months of the year hibernating. Arctic ground squirrels are able to let their body temperature drop below the freezing and allow their brain to cool to just above freezing (Barnes 1989). Reducing metabolism to conserve resources isn't limited to small- and medium-sized mammals, however. Although they don't hibernate, muskox (*Ovibos moschatus*), a large mammal, reduce their metabolic rate by one third in comparison to what it is during the summer (Lawler and White 1997). Common Redpoll (*Acanthis flammea*), a small bird found in the Arctic and boreal forests, undergo controlled bouts of hypothermia at night to reduce energy expenditure (Reinertsen and Haftorn 1986). All are variations on the theme of energy conservation.

People too have adapted to the arctic environment, but in this case, largely through behaviors—know-how, technology, and social strategies—rather than physiology. From at least the end of the last Ice Age 13,000 years ago, people have lived in Arctic Alaska. When the Bering Land Bridge was still intact, extinct animals like steppe bison (*Bison priscus*), horses (*Equus* spp.), tundra lions (*Panthera atrox* spp.), and mammoth (*Mammuthus* spp.) traversed the dry, cold, steppe landscape. Some of the earliest-dated archaeological sites in Alaska are found in Noatak National Preserve. The sites are often situated in narrow mountain passes where caribou migrations converged and were easily intercepted by hunters, but also, not incidentally,

Beach ridges at Cape Krusenstern National Monument.
NPS photo

where some of the planet's most extensive and high-quality sources of "toolstone" are located. Glassy, sharp-edged rocks like chert are abundant in the Brooks Range and were vital raw materials prehistoric people used to fashion tools needed for hunting weaponry, hide working, and food processing. These prehistoric workshop sites are littered with millions of pieces of flaking debris, the accumulated byproducts from shaping the tools needed for survival over many millennia.

In no other Arctic park are the archaeological traces of the prehistoric human past as dense and well organized as in Cape Krusenstern National Monument. Congress wisely highlighted the monument's archaeological record as the primary purpose for designating these lands for conservation in the National Park System. Here thousands of archaeological features—remains of ancient houses, camp sites, and food storage pits—dot the low coastal plain interspersed with ponds and lagoons. But it isn't the number of sites that is so noteworthy here, but rather how they are arrayed on the landscape. More than 100 beach ridges have built up at Cape Krusenstern over the past 4,000 years as ocean currents deposited sand along this stretch of coast and the waves and wind piled it into raised ridges paralleling the shoreline. Over time, new ridges gradually accrued in a seaward direction, and because people have always camped on the ridges nearest the shore, the archaeology written across the succession of ridges can be read like a history book with the earliest chapters farthest inland and the more recent ones near the modern shoreline. In no other locale in the Arctic is there a richer and more complete picture of prehistoric Arctic cultural developments. Sites at Cape Krusenstern document evolving techniques of seal, walrus, and whale hunting, and numerous technological innovations that allowed people to survive and thrive in the Arctic—warm houses with cold-trap entrance tunnels, skin boats, toggling harpoons, oil lamps, dog sleds, pottery vessels, and the ulu. Today archaeologists are scrambling to understand how coastal erosion and thawing permafrost threaten to erase the irreplaceable pages of prehistory, and plan ways to save the most significant sites.

Howard Pass February 12, 2014. Cold and foreboding, but maybe not so much. Cold helps define this place, but clearly, so to do the plants, wildlife, and human cultures that have thrived here for thousands of years. This edition of *Alaska Park Science* describes some of the research and science conducted in the U.S. Arctic parks on natural and cultural resources as well as some of the challenges that face these remote and wild areas. This work is being conducted to learn about these special places and to help the NPS manage them for the American public.

REFERENCES

Bairlein, F., D. R. Norris, R. Nagel, M. Bulte, C. C. Voigt, J. W. Fox, D. J. T. Hussell, and H. Schmaljohann. 2012.
Cross-hemisphere migration of a 25 g songbird. *Biology Letters* 8: 505-507. doi:10.1098/rsbl.2011.1223

Barnes, B.M. 1989.
Freeze avoidance in a mammal: body temperatures below 0 Degree C in an Arctic hibernator. *Science* 244 (4912): 1593-1595. doi:10.1126/science.2740905

Dau, J. 2015.
Units 21D, 22A, 22B, 22C, 22D, 22E, 23, 24 and 26A. Chapter 14, pages 14-1 through 14-89 In P. Harper, and Laura A. McCarthy, editors. Caribou management report of survey and inventory activities 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2015-4, Juneau.

Fancy, S. G, L. F. Pank, K. R. Witten, and W. L. Regelin. 1989.
Seasonal movements of caribou in arctic Alaska as determined by satellite. *Canadian Journal of Zoology* 67(3): 644-650. doi:10.1139/z89-093

Gill, R. E., Jr., T. Piersma, G. Hufford, R. Servranckx, and A. Riegen. 2005.
Crossing the ultimate ecological barrier: evidence for an 11,000-km-long nonstop flight from Alaska to New Zealand and eastern Australia by Bar-tailed Godwits. *Condor* 107:1-20. doi: 10.1650/7613

Joly, K. 2012.
Caribou vital sign annual report for the Arctic Network Inventory and Monitoring Program: September 2009-August 2011. Natural Resource Data Series NPS/ARCN/NRDS— 2012/233. National Park Service, Fort Collins, Colorado.

Lawler, J. P. and R. G. White. 1997.
Seasonal changes in metabolic rates in muskoxen following twenty-four hours of starvation. *Rangifer* 17(3) 135-138. doi.org/10.7557/2.17.3.1365

National Oceanic and Atmospheric Administration (NOAA). 2016a.
Marine Mammal Laboratory, Marine Mammal Education Web: Gray Whale. Available at: http://www.afsc.noaa.gov/nmml/education/cetaceans/gray.php (accessed November 19, 2016)

National Oceanic and Atmospheric Administration (NOAA). 2016b.
Marine Mammal Laboratory, Marine Mammal Education Web: Bearded Seal. Available at: http://www.afsc.noaa.gov/nmml/species/species_bearded.php (accessed November 19, 2016)

Reinersten, R. E. and S. Haftorn. 1986.
Different metabolic strategies of northern birds for nocturnal survival. *Journal of Comparative Physiology* 156: 655-663.

Sousanes P. and K. Hill 2014.
Arctic Network Natural Resource Brief: Western Arctic parklands winter 2013-2014 weather summary. National Park Service, Fairbanks, AK.

Animal Icons as Peaceful Warriors—Beyond Science and Culture to Achieve Conservation

Joel Berger, Colorado State University and Wildlife Conservation Society

When you go to a natural history museum, you see the past, including extinct species such as dinosaurs or mammoths. You might view some that are still present, too, such as penguins or polar bears. What you'll not see is the future, which is determined by a combination of environmental change and human behavior, the latter is at times difficult to predict. Under the right circumstances, one can look to the past and imagine a future, even a brighter one.

People entered the New World about 13,000 years ago, most crossing a massive land bridge that connected Asia to America. Some of that connection is now under water, the oceans above teeming with more than 150,000 walrus, nearly 20,000 bowhead whales, and uncounted number of seals. The region, known as Beringia, offers critical summer habitat for 280 migratory bird species from every continent and, importantly, is the permanent home for caribou, snow sheep, wolves, and polar bears. It's also where there's a shared responsibility for the proud and natural heritage of both Russia and the United States. It's where both Presidents Putin and Obama visited their respective sides of the remote Chukchi Sea and the doomed land bridge. Science and conservation have perhaps more sunny prospects in this sensitive geo-realm given a collaboration that reaches back in history, continues, and is fueled by joint interests in a mammoth-like beast, one with thick luxuriant fur that drapes like a skirt to the ground—the muskoxen.

Neither maker of musk or an oxen, this misnamed species was driven to extinction in Arctic Alaska by the late 1800s. The downward spiral began with the introduction of guns when Alaska was still managed by Russian dominance from St. Petersburg, and before the land was purchased by Washington in 1867. Governance and conservation often go hand in hand, and international diplomacy can be and has been packaged in creative shapes. Animals play roles that transcend symbols and lovability.

Among the most heralded displays of diplomacy occurred during a tense era when the world's super powers were hardly speaking (1972). That's when a colorful gift, jostling pandas, arrived in the U.S. following President Richard Nixon's historic visit to Beijing. Nixon followed in turn with the gift of an Arctic regal and its largest land animal, one whose fur-ball babies outrival panda cubs for cuteness: two muskoxen, a species the world has truly yet to recognize, let alone embrace. Cooperation follows unpredictable paths.

The year following Nixon's 1974 resignation, the U.S. government took a further step, but not with China. On behalf of Moscow, it flew muskoxen from Alaska to Russia to establish a wild population in northern Siberia. The locale, Wrangel Island, is the Arctic's only World Heritage Site. It's also where I continue to work with committed Russian biologists and with support from both governments. While international conservation successes are not especially frequent, panda diplomacy and polar bears are useful tokens. The true unsung heroes in this case are muskoxen.

A 1968 essay, On War and Peace in Animals and Man, written by 1973 Nobel Laureate Niko Tinbergen, touted neither diplomacy nor animal heroes. He argued we need to offer a gentler world. Neither Tinbergen nor President Nixon knew much about biodiversity, but both realized that environment and animals matter. So does President Putin. While it's too early to judge the commitment the new U.S. administration will have to Arctic conservation, former President Obama's 2015 visit to Kotzebue on the Chukchi shoreline is further testimony that local culture, food security, and climate all connect.

The fact that the Russian government enables biological investigations to continue on a remote frozen isle is one thing; more relevant is that the misnamed muskox is an eerie success story, one that unites a conservation mission crossing five northern countries, the scale of which dwarfs the marveled recoveries of North American bison and Yellowstone wolves. The true-to-life saga for success was reignited when pre-statehood

◀ Muskoxen in defensive formation.
Photo courtesy of Joel Berger

Alaska's 1930 funding request for an ambitious re-introduction was approved by the U.S. Congress. Wild muskoxen were most accessible then in Greenland, and the challenge was how best to capture and transport the helmeted warriors with lethal upturned horns and whose defensive groups are reminiscent of modern elephants or their now-extinct comrades, the wooly mammoths. Greenland hunters solved the problem: they killed adult *moschus*, nabbed the wailing babies, and sent them by ship to Norway. From there, they voyaged across different oceans, arriving by ship to shores near the Bronx Zoo. Then the real journey began.

Animals were loaded in railroad cars and moved by train 2,500 miles to Seattle; from there it was only 1,400 miles by boat to Seward, Alaska; and then a mere 486 miles by rail to Fairbanks. Youngsters were later floated hundreds of miles down the Yukon and Tanana Rivers to the Bering Sea, and then just a short 20-mile hop across choppy open seas to Nunavik Island.

Forty more years passed and the progeny from the original Greenland transplant were airlifted to sites throughout Alaska's Arctic. Today, the wild Alaskan population numbers more than 4,000; Siberia now has even more. My continuing efforts are with Russian scientists from Chukotka's Autonomous Region including the director of Wrangel Island Reserve, Dr. Alexander Gruzdev, where our science and conservation goals target two topics.

The first is how we establish ecological baselines so that it's possible to understand the nature of change. If we don't know the past, we can't say there is change. In this case, we're engaged in photogrammetry, the science of photo-imaging, as a technique to chart muskoxen physical parameters in relationship to potential environmental drivers. We're measuring the head dimensions of young muskoxen, which are sensitive to nutrition. We can assess growth rates as they are linked to weather and food (Berger 2012). In the spirit of bilateral cooperation, Gruzdev came from Moscow to Montana in 2012 and then Yellowstone for initial familiarizations with the approach, techniques, and then we followed up with my work and capacity building with his staff on Wrangel.

A female polar bear and her cubs on a muskox carcass.
Photos courtesy of Olga Starova

The second target is focused on the changing nature of nature, that is, the predator-prey relationships between bears and muskoxen, some of which indirectly involves people. The idea is simple; with more male muskoxen harvested for meat or trophy, herds have an increasingly biased sex ratios (i.e., fewer males; Schmidt and Gorn 2013), yet males might be important arbiters of effective herd defense, or there may be other factors affecting juvenile recruitment. Few empirical data on predator-prey dynamics are available; we're unsure if relationships are changing, especially in places like Wrangel.

In Alaska, grizzly bears are increasingly viewed as a potential agent governing muskoxen population trends. Polar bears, too, prey on muskoxen. My work in both Russia and the U.S. is to improve our understanding of how muskoxen might fare when encountering bears, either white or brown, when herds vary in composition, some with bulls and some without.

Science is one thing, geopolitics quite another. What does cold war and collapsed land bridges, warming temperatures, and muskoxen have to do with the realpolitik of diplomacy? Much.

It's about life on this planet; one of limited resources and countries trying to do better for their people. Critically, it's also about animals and the systems that support them, and us. Beasts of nature's creation carry meaning beyond breath and blood or a slab of meat tossed on the dinner table. They can be amulets of peaceful unification or for ecological restoration and food security. The gift of the misnamed *moschus* transcends the polar sovereignties of Canada, the U.S., Norway, Denmark, Greenland, and

Russia. If differences are set aside for a broader good, animals benefit, and so do people.

Neither the U.S. nor Russia has wild pandas, but there are polar bears and muskoxen, and other wildlife and a commitment to protect them, to share knowledge, and to infuse conservation in the global community because biodiversity is at the core of every country's heritage and should be its future. Icons like pandas and polar bears help raise issues that affect all of us—governance and ecosystems, climate and international relations. The offering of *moschus*, a species clearly in need of a new name, is both symbol and reality. Understanding people without animals is to divorce us from our past. Seeing specimens in a museum can be fascinating and inspirational; likewise conserving living species while understanding the past is a prudent entry to a better future.

REFERENCES

Berger, J. 2012.
Estimation of body-size traits by photogrammetry in large mammals to inform conservation. *Conservation Biology* 26:769-777.

Schmidt, J. H. and T. S. Gorn. 2013.
Possible secondary population-level effects of selective harvest of adult male muskoxen. *PloS One* 8(6):e67493.

Understanding an Arctic icon like the muskox within its social and political system will allow us to successfully conserve them into the future.
Photo courtesy of Joel Berger


MOUNTAIN HARD WEAR

Understanding Arctic Sea Ice in a Period of Rapid Climatic Change

Andrew R. Mahoney, Geophysical Institute, University of Alaska Fairbanks and Martin Robards, Wildlife Conservation Society

Sea ice is the thin floating skin that forms on the surface of the ocean as it freezes. Though few of us encounter sea ice in our daily lives, the shrinking and thinning of the Arctic ice pack as a result of regional warming has global implications that will be felt by all of us. Sea ice plays a fundamental role in the global climate system (Barry et al. 1993) and provides critical habitat for a wide range of species (Laidre et al. 2015, Melnikov et al. 2001). At the same time, the increasing extent of open water in summer is making its mark on offshore oil exploration and development, global shipping routes, and the geopolitical landscape in the North (Blunden 2012). However, for those people who live at the shores of the Arctic Ocean, sea ice is more than just a component of the global climate and ecosystems, or a subject of discussion in boardrooms and conferences. For Inuit, the shrinking Arctic ice pack is changing a way of life, one that relies on sea ice as a source of food and clothing and a place to call home (Gearheard et al. 2013, ICC 2015).

Over the last three decades, satellite records show that the amount of sea ice in the Arctic Ocean at the end of summer has decreased by approximately 40% (Serreze and Stroeve 2015), exposing an area of previously ice-covered ocean one and a half times the size of Alaska.

Historical observations recorded in ice charts and ship log books indicate that this loss of ice is unprecedented in at least 150 years (Mahoney et al. 2011 and 2008). Sea ice helps keep the Polar Regions cool by reflecting the majority of solar energy back into the atmosphere. Thus, any reduction in ice extent creates a self-reinforcing cycle whereby the retreating ice edge exposes more ocean during the summer, allowing more heat to be absorbed, which accelerates the loss of ice and rate of warming. Scientists call this process the “ice-albedo-feedback” (Perovich et al. 2007). Partly due to the loss of sea ice in the North, the Arctic has warmed on average by 0.6 °C (1.1 °F) per decade (Comiso and Hall 2014), faster than any other region on Earth. The loss of sea ice also has profound ecological implications that extend well beyond the Arctic.

The seasonal expansion and contraction of the ice pack sets an annual rhythm to the ecology of the Polar Regions and the Inuit way of life. At the beginning of each winter, new ice forms around the margins of the old and the ice-covered area of the ocean grows. The annual southward advance of the ice edge drives most of the summer visitors away leaving behind only those species adapted to the polar winter. For example, ringed seals and polar bears remain while walrus, bowhead whales, and guillemots migrate southward with the ice edge. Conversely, in spring when the ice retreats north, it has historically provided a platform for tens of thousands of female walrus and their calves during summer. Now with the ice retreating so far north, it lays over waters too deep for them to forage. These female walrus and their calves now come ashore in vast congregations that endanger the young animals that can be trampled as the herd comes and goes. The rhythm of the Arctic is shifting in response to changing ice pack conditions.

In addition to the charismatic wildlife so visible on and around sea ice, pockets of liquid brine trapped within sea ice provide a winter habitat for ice algae. Sheltered from grazing krill and located at the top of the water column, these algae are positioned at the front of the line ready to take advantage of the sunlight when it returns in spring. Released by melt into nutrient-rich waters, the algae multiply rapidly and provide the foundation of a food chain that supports the entire Arctic Ocean ecosystem (Arrigo et al. 2008). The life cycles of the Arctic’s year-round residents and its migratory summer visitors are timed to take advantage of this seasonal pulse of food. Thus, when female polar bears emerge from their dens with cubs, they feed on seals fattened by fish that eat the krill that thrive on the algae, which also feed the bowhead whales during their migration to summer feeding grounds. In fact, the algal bloom that accompanies the retreating ice edge is so abundant that its leftovers nourish the seafloor, supporting vast populations of clams that are gorged on by bottom-feeding walrus.

◀ Marguerite Tibbles collecting water data.
Photo courtesy of Trevor Haynes, Wildlife Conservation Society

A whaling party waits in their *umiaq* (traditional boat made from whalebone and seal skin) for a bowhead whale to surface in the open lead near Barrow, Alaska.
Photo courtesy of Andrew Mahoney

A hunter watches for whales at the edge of the shorefast ice near Barrow, Alaska.
Photo courtesy of Andrew Mahoney

All of these relationships between life and ice are well known to the Inuit, whose subsistence activities have long been timed to take advantage of this abundance (Gearheard et al. 2013). The close connection with sea ice places the Inuit on the frontlines of rapid Arctic change. Indeed, they are at the forefront of observing and experiencing the repercussions of these changes. Furthermore, a long history of traditional ecological knowledge about sea ice presents a rich context for the suite of contemporary changes affecting their own uses as well as that of the wildlife they rely on for food security.

The emergence of new weather patterns, species assemblages, and behaviors have all been astutely observed and increasingly documented by local experts (Krupnik 2010, Krupnik and Jolly 2002, Gearheard et al. 2006). In concert, residents of Arctic coastal communities are facing impacts related to the changes that directly affect their traditional way of life. For example, the delayed formation of sea ice during the fall is leading to increased wave energy reaching the coast during storms, resulting in increased erosion of village sites (ACIA 2005). At the same time, the reduced stability of shore-fast ice increases the risk of detachment and endangerment of hunters during the spring hunting season (Druckenmiller et al. 2013), while the early onset of the spring melt is shortening the ice-based hunting season and impacting the health of ice-dependent seals (Gearheard et al. 2006).

While these changes in sea ice may bring some new opportunities for local communities (e.g., new species from warmer waters such as whales and salmon, or new industries), the current pace of change is without recent precedent and poses significant challenges for effective adaptation. Current models predict that the Arctic will experience effectively ice-free summers (<1 million square kilometers) as early as 2040 (Wang and Overland 2012). Understanding and planning for the impacts of this will require science that responds to the priorities of local communities and incorporates the expertise of their indigenous knowledge holders. By doing so, we may help support the resilience of local communities in the Arctic.

REFERENCES

Arctic Climate Impact Assessment (ACIA). 2005.
Arctic Climate Impact Assessment—Scientific report. Cambridge: Cambridge University Press.

Arrigo, K. R., G. van Dijken, and S. Pabi. 2008.
Impact of a shrinking Arctic ice cover on marine primary production. *Geophysical Research Letters* 35(19).

Barry, R. G., M. C. Serreze, J. A. Maslanik, and R. H. Preller. 1993.
The Arctic Sea-Ice Climate System - Observations and Modeling. *Reviews of Geophysics* 31(4):397-422.

Blunden, M. 2012.
Geopolitics and the Northern Sea Route. *International Affairs* 88(1):115-129.

Comiso, J. C. and D. K. Hall. 2014.
Climate trends in the Arctic as observed from space. *Wiley Interdisciplinary Reviews: Climate Change* 5(3):389-409.

Druckenmiller, M. L., H. Eicken, J. C. C. George, and L. Brower. 2013.
Trails to the whale: Reflections of change and choice on an Iñupiat icescape at Barrow, Alaska. *Polar Geography* 36(1-2):5-29.

Gearheard, S., L. Kielsen Holm, H. P. Huntington, J. Leavitt, A. R. Mahoney, M. Opie, T. Oshima, and J. Sanguya, eds. 2013.
The Meaning of Ice: People and Sea Ice in Three Arctic Communities. International Polar Institute: Hanover, New Hampshire. 365pp.

Gearheard, S., W. Matumeak, I. Angutikjuaq, J. Maslanik, H. P. Huntington, J. Leavitt, D. M. Kagak, G. Tigullaraq, and R. G. Barry. 2006.
"It's not that simple:" A collaborative comparison of sea ice environments, their uses, observed changes, and adaptations in barrow, Alaska, USA, and Clyde River, Nunavut, Canada. *Ambio* 35(4):203-211.

Inuit Circumpolar Council-Alaska (ICC). 2015.
Alaskan Inuit Food Security Conceptual Framework: How to assess the Arctic from an Inuit perspective. Available at: http://iccalaska.org/wp-icc/wp-content/uploads/2016/05/Food-Security-Full-Technical-Report.pdf (accessed November 30, 2016)

Krupnik, I., ed. 2010.
SIKU: Knowing our ice: Documenting Inuit Sea-Ice Knowledge and Use. Springer: London. 523.

Krupnik, I. and D. Jolly. 2002.
The Earth is faster now: Indigenous observations of Arctic environmental change. Fairbanks, Alaska: Arctic Research Consortium of the United States.

Laidre, K. L., H. Stern, K. M. Kovacs, L. Lowry, S. E. Moore, E. V. Regehr, S. H. Ferguson, Ø. Wiig, P. Boveng, R. P. Angliss, E. W. Born, D. Litovka, L. Quakenbush, C. Lydersen, D. Vongraven, and F. Ugarte. 2015.
Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. *Conservation Biology* 29(3):724-737.

Mahoney, A. R., J. R. Bockstoce, D. B. Botkin, H. Eicken, and R. A. Nisbet. 2011.
Sea-Ice Distribution in the Bering and Chukchi Seas: Information from Historical Whaleships' Logbooks and Journals. *Arctic* 64(4):465-477.

Mahoney, A. R., R. G. Barry, V. Smolyanitsky, and F. Fetterer. 2008.
Observed sea ice extent in the Russian Arctic, 1933-2006. *Journal of Geophysical Research-Oceans* 113(C11).

Melnikov, I. A., L. S. Zhitina, and H. G. Kolosova. 2001.
The Arctic sea ice biological communities in recent environmental changes. *Polar Research, Special Issue* 54:409-416.

Perovich, D. K., B. Light, H. Eicken, K. F. Jones, K. Runciman, and S. V. Nghiem. 2007.
Increasing solar heating of the Arctic Ocean and adjacent seas, 1979–2005: Attribution and role in the ice-albedo feedback. *Geophysical Research Letters* 34(19).

Serreze, M. C. and J. Stroeve. 2015.
Arctic sea ice trends, variability and implications for seasonal ice forecasting. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 373(2045).

Wang, M. Y. and J. E. Overland. 2012.
A sea ice free summer Arctic within 30 years: An update from CMIP5 models. *Geophysical Research Letters* 39.

Tracking the First Marine Mammal Hunters at Cape Espenberg, Bering Land Bridge National Preserve

Andrew Tremayne, National Park Service

Traditionally people in northern Alaska have practiced a maritime economy. Life in the Arctic would be nearly impossible without a keen knowledge of how to harvest resources such as seals, walrus, and whales from the sea. A major archaeological research problem in Alaska concerns the timing and development of the Eskimo maritime economy. When and how did the technology and knowledge about maritime resources first develop? What kinds of evidence do archaeologists use to document the use of coastal resources in the past?

Scientists believe that the earliest maritime culture found in northern Alaska was from people bearing tools of the Arctic Small Tool tradition (ASTt), referred to locally as the Denbigh Flint complex. The ASTt appears in Alaska around 5,000 years ago and soon after is found across the North American Arctic all the way to Greenland (Dumond 1987). The ultimate origin of the ASTt is still debated and this has important implications for understanding the origins of their maritime adaptations. Some have postulated the ASTt originated in the interior habitats of northern Alaska from caribou hunters who learned to be seal hunters (Anderson 1988, Clark 1982). Others contend the ASTt originated in Asia and spread across the Bering Strait into Alaska (Powers and Jordan 1990). If this is true, it implies ASTt foragers arrived to Alaska with a certain set of maritime hunting and navigation skills already in place. So which is it?

Sleuthing Out the Timing of Coastal Settlement and Evidence for Maritime Adaptations

One way to answer the question of whether people arrived with maritime hunting and navigation skills or developed them later is to test the archaeological record by radiocarbon dating organic materials found in coastal and interior settlements. If the oldest ASTt sites are consistently found in an interior setting, it would support the hypothesis that life on the coast began *after* ASTt people had been in Alaska for an extended period of time. If, however, the coastal settlements appear older or contemporaneous with those in the Interior, the hypothesis that maritime adaptations were already well-developed when they first arrived as migrants from Asia is supported. However, just because sites are found on the coast does not mean they were used for fishing or hunting marine mammals. Caribou, muskox, and other terrestrial mammals could have been targeted in these areas as well. Strong evidence for maritime adaptations comes from two main sources: (1) preserved animal bones and (2) hunting and boating technology. When bones or other parts of animals are discovered in archaeology sites, researchers are often able to demonstrate through cut marks, fracture patterns, or simply through association, that the animals were hunted and processed by humans. Fishing and hunting of marine mammals requires specialized technologies that are unnecessary for hunting terrestrial mammals, such as lines, hooks, toggling harpoon heads, and other tools designed to prevent animals from escaping beneath the water. In sum, the evidence we seek to demonstrate a maritime adaptation includes: occupation of coastal habitats, specialized hunting technology, and processed marine animals preserved at the site.

Archaeological Studies at Cape Espenberg

ASTt sites have been reported at Cape Espenberg, located in Bering Land Bridge National Preserve on Alaska's Seward Peninsula (Figure 1). Cape Espenberg is a geologic formation of beach ridges and sand dunes that have built up in a chronological sequence due to the continuous deposition of sediment from ocean currents and wave action. The beach ridge sequence extends approximately 25 km from start to tip. The youngest beach ridges are found to the north end of the cape adjacent to the Chukchi Sea, where yearly deposition continues to occur; and the oldest occur on the south side (Figure 1). The Cape Espenberg beach ridge sequence contains 126 recorded sites and a history of human occupation that spans at least 4,500 years (Tremayne 2015).

◀ Aerial view of Cape Espenberg.
Photo courtesy of Jared Hughey

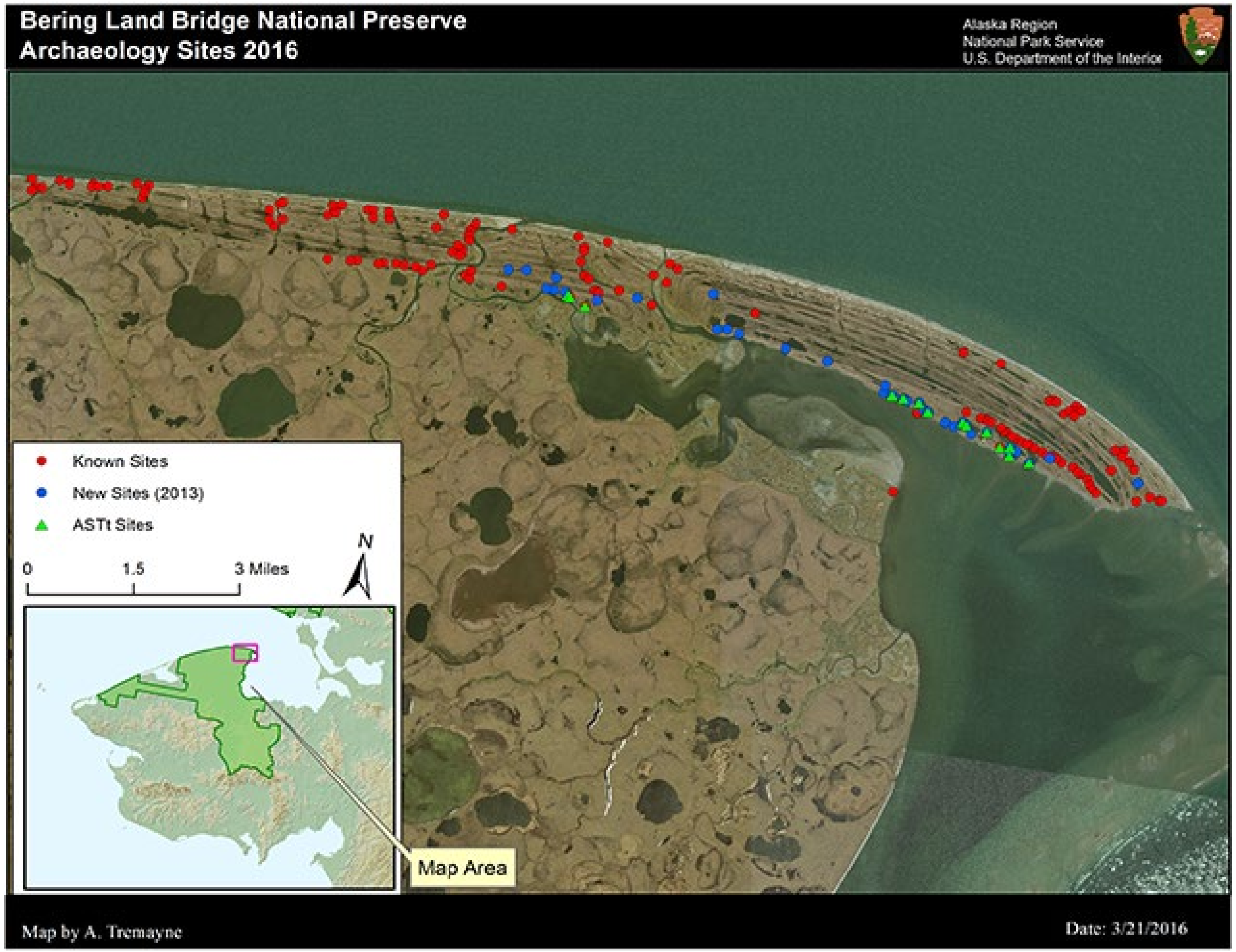


Figure 1. Archaeological sites at Cape Espenberg. Blue dots indicate 34 new sites surveyed in 2013; 12 sites were confirmed ASTt. Inset map shows Bering Land Bridge National Preserve in green.

Prior to the recent round of research at Cape Espenberg, it was unclear how frequently the ASTt camped at this location and how early their settlements dated. In the 1960s, J. L. Giddings became the first to discover evidence for the Denbigh/ASTt at Cape Espenberg (Giddings 1967). Diagnostic stone tools were collected and taken back to Brown University, but no bones or datable material were recovered (Giddings and Anderson 1986). Detailed location information was also lacking, making it difficult for later archaeological investigations to relocate these sites. It wasn't until three decades later that NPS archaeologists returned to Cape Espenberg to systematically survey these ancient beach ridges (Harritt 1994, Schaaf 1988). The results of these NPS investigations led to the clear identification of four ASTt/Denbigh sites, two that produced radiocarbon dates indicating occupations between 3,800 and 4,200 years ago.

Goals and Methods

Our primary goals were to locate and test archaeology sites on the oldest beach ridges at Cape Espenberg to look for diagnostic ASTt artifacts, datable organic material, evidence of animal remains, and specialized maritime hunting technologies from these sites. To accomplish the survey we used systematic and random transects to locate sites. Placement of subsurface shovel tests was randomly chosen, but areas with disturbances by Arctic ground squirrels or wind erosion received careful scrutiny as buried artifacts were frequently revealed in these locations. In order to look for intact deposits, we conducted subsurface tests at locations where artifacts were observed on the surface of an erosional blowout (Figure 2). It is important to find buried artifacts and charcoal because objects found on the surface have been disturbed and might contain a mix of artifacts representing multiple events. We sifted all sediment through a ¼" (0.5 cm) screen to capture artifacts, charcoal, or bones. We estimated the size of each site based on location of positive tests and surface distributions. We collected artifacts and samples to study back in the lab or sent them to specialists for further analysis.

Archaeological Findings

We discovered 34 new archaeological sites (see blue dots in Figure 1) and revisited 10 known. Of the new sites found, 10 confirmed usage of the area by ASTt people. The total number of ASTt sites at Cape Espenberg is now 14, with another six probable, but requiring further testing to confirm. This project added sixteen radiocarbon dates to the record, 11 from ASTt sites. Dates range between 3,300 and 4,600 calibrated years ago (Figure 3). From these data, we can surmise ASTt people camped at Cape Espenberg repeatedly for nearly 1,300 years.

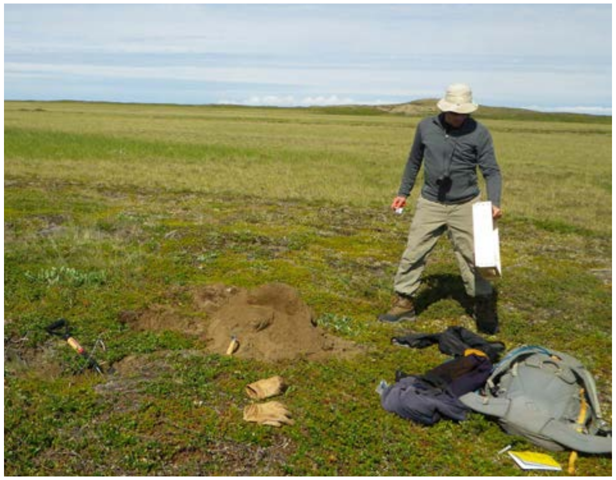


Figure 2. University of California-Davis graduate student Jeremy Foin processes items from shovel tests at Cape Espenberg.
NPS photo courtesy of Andrew Tremayne

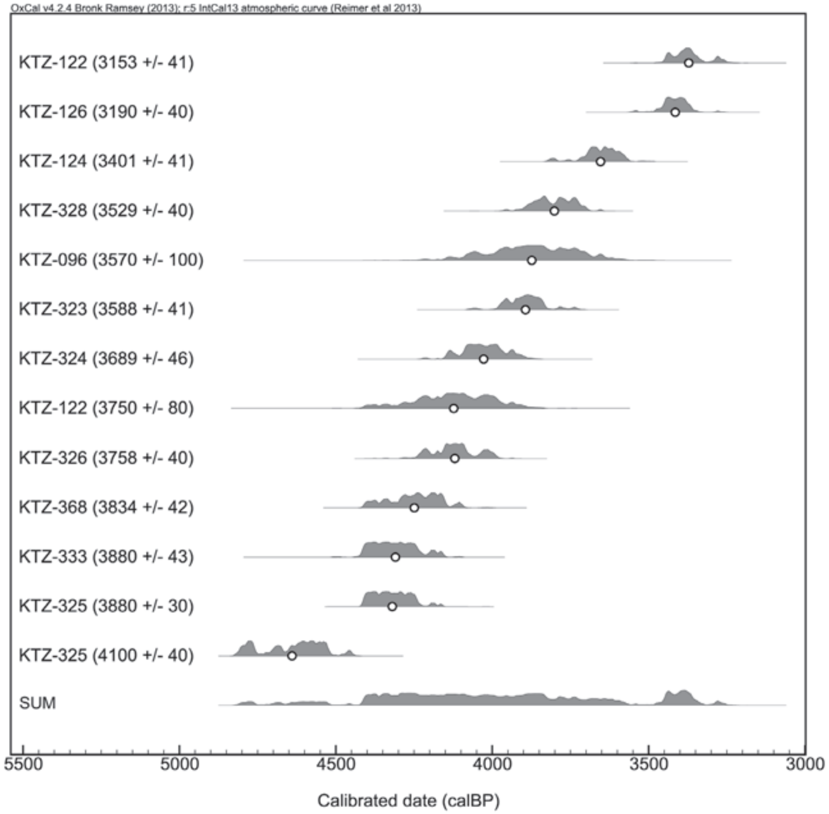


Figure 3. Plot of the probability mass for calibrated radiocarbon dates from ASTt sites at Cape Espenberg (using Oxcal 4.2 calibration software).

The earliest date of 4,600 years ago was found directly associated with ASTt artifacts and a large cluster of marine-mammal-oil-encrusted sand (Figure 4). Cemented sand occurs when seal oil mixes with sandy ground. As the oil hardens it cements the sand together forming a concentration as hard as sandstone. To confirm these concretions were derived from marine-based fats and were cultural in nature, we conducted a lipid analysis using gas chromatography and compound-specific stable isotope analysis (Buonasera et al. 2015). These methods allowed us to show that all of the samples were formed from marine-based fatty lipids. A total of five ASTt sites contained cemented sands, indicating common use of marine mammals, and providing the earliest direct evidence for marine mammal exploitation in northwest Alaska.

In addition to the cemented sand, we found a number of stone tools (n=20) at the ASTt sites (see Figure 6 for a selection); some of which are thought to be for marine mammal hunting. These tool forms are considered diagnostic artifacts of the ASTt culture and are used as “type fossils” to identify their sites. The function of these tool forms are generally inferred to be components of hunting technologies and tools for working antler and ivory. Of particular importance is one end blade discovered eroding into Kotzebue Sound (Figure 5). End blades such as this are interpreted to be the tips of harpoon heads used to pierce the skin of seals or other marine mammals. These ASTt tool types are typically only found at coastal sites (Giddings and Anderson 1986), supporting interpretations of their specialized use for hunting seals.

Implications for the Timing of Maritime Skills

While the evidence is still scant, these newly discovered ASTt sites at Cape Espenberg preserved the oldest evidence for marine mammal hunting in northern Alaska to date. In fact, the radiocarbon dates also indicate the earliest ASTt occupations here predate their settlements in Interior Alaska (Tremayne 2015). If the oldest ASTt sites are consistently found in an interior setting, it supports the hypothesis that life on the coast began *after* ASTt people had been in Alaska for a long period of time. Contrary to this, we suggest the ASTt peoples developed maritime adaptations *before* their arrival in Alaska or as they arrived, instead of after a prolonged period of adaptation inland. The full extent of ASTt maritime capabilities and the timing of their appearance in Alaska both require further research, but evidence is building that Arctic maritime adaptations 4,500-5,000 years ago were probably more complex and important to colonizing populations than previously realized.

A selection of ASTt tool forms discovered on the oldest beach ridge at Cape Espenberg. Tool types include: (a) spear point, (b) flake knife, (c) end blade, (d) side blade, (e) scraper fragment, (f) burin, (g) harpoon end blade, (i) blade, (j-k) burin spalls, (h, l, and m) microblades. ▶
NPS photo courtesy of Andrew Tremayne

Figure 4. Cemented sand hardened from mixing with sea mammal fat and oil with embedded seal sesamoid bone (scale bar is in centimeters).
NPS photo courtesy of Andrew Tremayne

Figure 5. A blade (approximately 1.6 cm long) interpreted as a harpoon end blade was found at an ASTt sites eroding into Kotzebue Sound.
NPS photo courtesy of Andrew Tremayne

REFERENCES

Anderson, D. D. 1988.
Onion Portage: an archaeological site on the Kobuk River northwest Alaska. *Anthropological Papers of the University of Alaska* 20(1–2).

Buonasera, T., A. H. Tremayne, C. M. Darwent, J. W. Eerkens, O. K. Mason. 2015.
Lipid biomarkers and compound specific δ13C analysis indicate early development of a dual-economic system for the Arctic small tool tradition in northern Alaska. *Journal of Archaeological Science* 61:129–138.

Clark, D. W. 1982.
From just beyond the southern fringe: a comparison of Norton Culture and the contemporary Kachemak tradition of Kodiak Island. *Arctic Anthropology* 19(2):123–132.

Dumond, D. E. 1987.
The Eskimos and Aleuts, rev. ed. Thames and Hudson, London.

Giddings, J. L. 1967.
Ancient Men of the Arctic. A.A. Knopf, New York.

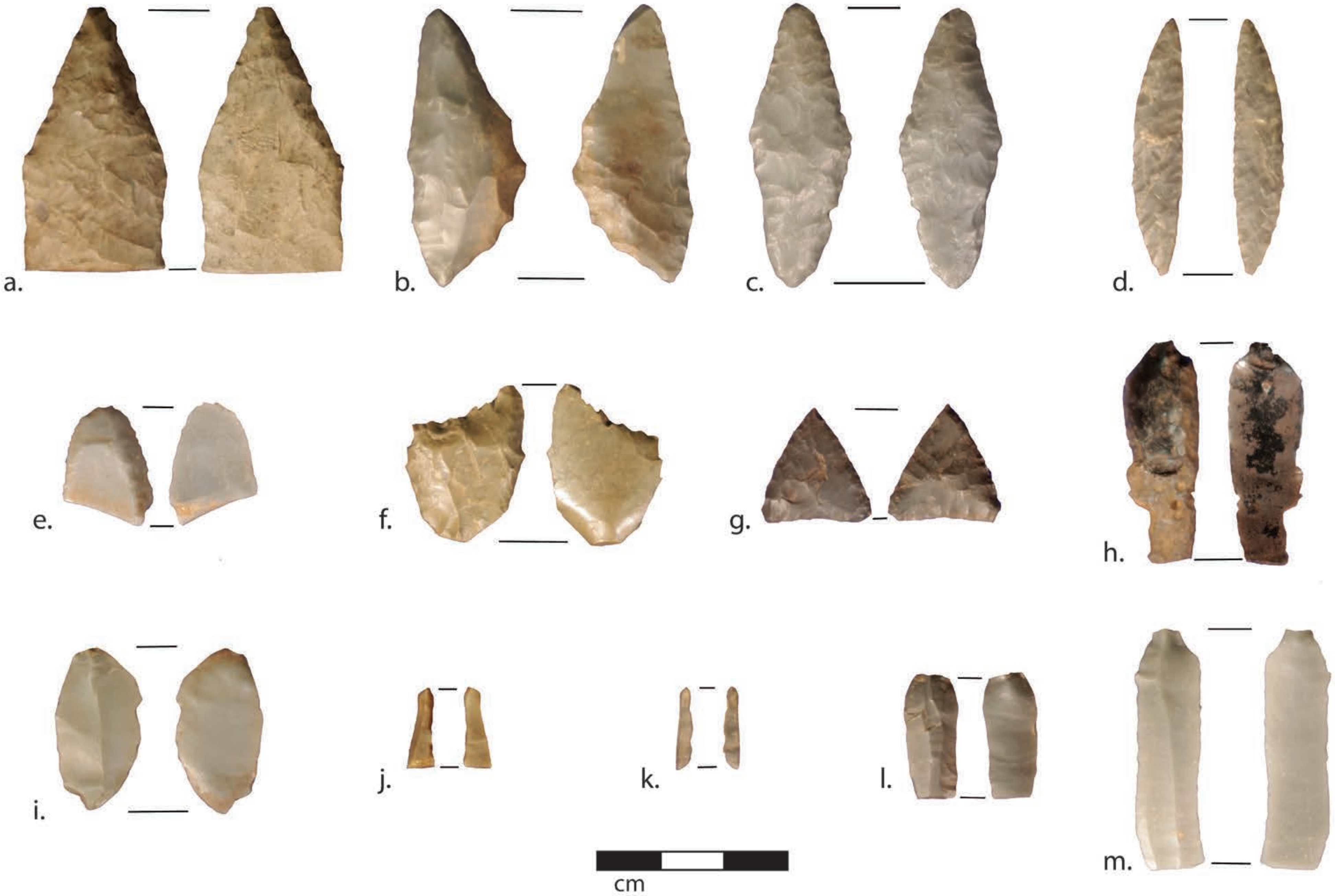
Giddings, J. L. and D. D. Anderson. 1986.
Beach Ridge Archaeology of Cape Krusenstern: Eskimo and Pre-Eskimo Settlements Around Kotzebue Sound, Alaska. Publications in Archaeology 20. National Park Service, U.S. Department of the Interior, Washington, D.C.

Harritt, R. K. 1994.
Eskimo Prehistory on the Seward Peninsula, Alaska. National Park Service Resource/Research Management Report ARORCR/CRR-93/21, Alaska Regional Office.

Powers, W. R. and R. H. Jordan. 1990.
Human biogeography and climate change in Siberia and Arctic North America in the fourth and fifth millennia BP. *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences* 330(1615):665–670.

Schaaf, J. 1988.
Bering Land Bridge National Preserve: An Archaeological Survey, vols. I and II. National Park Service Resource/Research Management Report AR-14. U.S. Department of the Interior, Washington DC.

Tremayne, A. H. 2015.
New evidence for the timing of Arctic small tool tradition coastal settlement in northwest Alaska. *Alaska Journal of Anthropology* 13(1):1-18.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Alaska Native Place Names in Arctic Parks

Rachel Mason and Eileen Devinney,
National Park Service

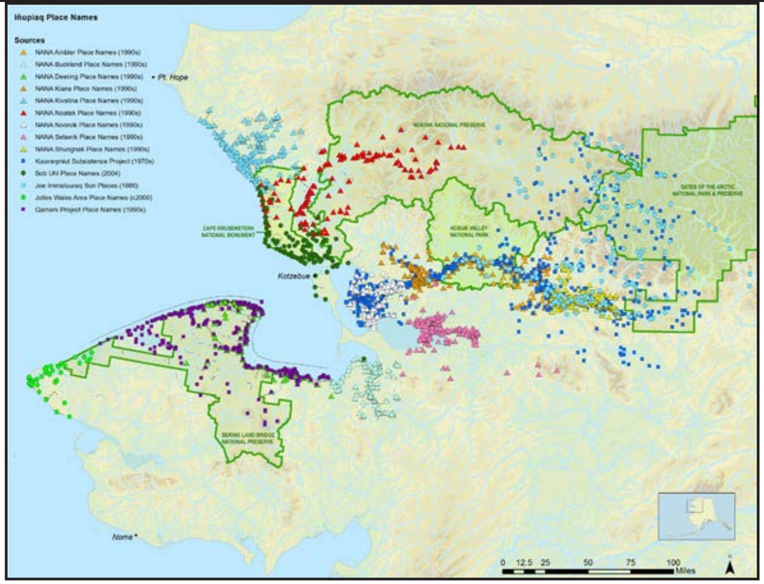
The Iñupiat and Athabaskan people who lived and traveled in the Arctic lands now in Alaska's National Park System had names for natural features such as rivers, mountains, bays; human settlements and trails; and places to hunt, fish, and gather. The indigenous names are rich ethnographic and historical resources. Many of them refer to activities that regularly took place at the site; others tell of historical events that occurred there. Although the names were preserved in oral tradition, they have been replaced with English names on modern maps. Many of the elders who knew the place names and their stories are now gone; it is urgent to document the knowledge of those still living.

Communities and scholars show a growing interest in documenting indigenous place names. Place name research can help archaeologists and historians by tying place names to prehistoric and historic sites. Connecting place names with the broader ethnographic record increases our understanding of how Alaska Natives used the landscape.

Previous National Park Service (NPS) place name projects, such as one supporting the Northwest Arctic Native Association (NANA) Museum of the Arctic, depended on the extensive local knowledge, often from a single person; Joe Immaluraq Sun of Shungnak (1900-1993) was one such person. David Libby interviewed Joe Sun in the early 1980s to record his life history and place names information for the upper Noatak and northwest Alaska. The resulting report, *Place Names on the Upper Noatak and Contiguous Areas*, listed 121 place names.

Qamani: Up the Coast, In My Mind, In My Heart is an unpublished monograph Susan Fair co-authored with Edgar Nunageak Ningeulook for Bering Land Bridge National Preserve in 1995. It includes place names with their stories and histories along the coast near Shishmaref. In 2016, Bering Land Bridge started *Qamani, Volume 2*, a study of place names along the coast near the village of Wales.

Most of the Alaska Native place name projects also include maps. The Iñupiaq Place Names Project, partially funded by the NPS Tribal Grants Program, began in the early 1990s. For a number of years, anthropologist Eileen Devinney and Gates of the Arctic National Park and Preserve staff have consolidated Iñupiaq place names from several projects onto a single map.



Map depicting the extent of select northwest Alaska place names data shared with researchers by Iñupiat communities between 1970 and 2004.

Recently, Gates of the Arctic National Park assisted the Simon Paneak Museum in Anaktuvuk Pass to compile and map local Iñupiaq place names. The park has also documented Nunamiut (inland Iñupiaq) place names in the Killik and Nigu River drainages, recording oral history and stories associated with these places. Working with the Alaska Native Language Center at the University of Alaska Fairbanks, they translated place names on the 1900 George Stoney map of northwestern Alaska, a seminal historic place names map that had not previously been given much linguistic attention.

Yukon-Charley Rivers National Preserve initiated a project in partnership with the Yukon Native Language Centre for Han place names around Eagle Village and the preserve.

Place names may have many levels of meaning, and multiple stories attached to them. The next step is to make information about Alaska Native place names more accessible to Alaska Native communities, park managers, and the public.

◀ Noatak village residents camp on a gravel bar in the Noatak River recording place names and stories in 2004.
NPS photo courtesy of Eileen Devinney

Learning from the Past: Archaeological Results from Cape Krusenstern National Monument

Adam Freeburg, National Park Service

Archaeologists cruised the low-lying, undulating topography of Cape Krusenstern on Kotzebue Sound's north shore (Figure 1). They were looking for remnants of the past; anything that indicated that someone, sometime, stopped here to sharpen a stone tool, build a fire, or even spend a season. From both published descriptions and previous experience, the crew knew what to look for: glimpses under the sparse tundra vegetation of fire-reddened rocks, angular pieces of broken chert, or subtle variations in vegetation in the gravel ridge tops (Figure 2).

At complex archaeological sites, such as the beach ridges of Cape Krusenstern, there are often multiple pasts to discover. People of several different cultures have lived here for more than 4,000 years. In some cases, a more recent past must also be taken into account. In this case, archaeologists were excited when they found items like rusty sardine cans, wooden barrel staves, and a broken shovel handle. These items were clues to previous archaeological research that occurred here in the 1950s and '60s (Figure 3). These clues, in turn, helped the archaeology crew from the University of Washington integrate recent finds with existing documentation. With a better understanding of how new archaeological data overlapped with, and differed from, existing documentation, researchers are able to evaluate new models and interpretations more critically.

◀ **Figure 2.** Testing a possible archaeological feature.
NPS photo courtesy of Adam Freeburg

Figure 1. Location of Cape Krusenstern beach ridges in northwest Alaska.

From 2007 to 2012, researchers from the University of Washington, in a collaborative project with the National Park Service's Western Arctic Parklands, conducted field and laboratory research to identify patterns of dynamic human and environmental interactions within the beach ridge complex of Cape Krusenstern National Monument. To our great benefit, the pioneering work of J. Louis Giddings and Douglas D. Anderson provided a strong framework on which to base renewed archaeological questioning and further archaeological inquiry of Northwest Alaska. To make the most of this existing work, a great deal of time was spent incorporating these "legacy data" into our methods. As described by Anderson and others (2009), information

Figure 3. Documenting whale bones originally excavated in 1960.
NPS photo courtesy of Adam Freeburg

Figure 4. Archaeologists testing the beach ridges; legacy feature 249 (whale vertebra) in foreground.
Photo courtesy of Liz Penttila

from published sources as well as original field and laboratory documentation was recorded and integrated into the project GIS (geographic information system), where the data were used to inform survey areas, sampling locations, analyses, and interpretations. These legacy spatial locations, and their accompanying annotations and feature information, form the basis of the analyses and comparisons that are part of the continuing outcomes of this project.

Overall Legacy Results

A complete legacy database of 688 features was ultimately compiled. This is considered a conservative estimate for the total number of features that Giddings' team noted in their investigation at the beach ridge complex in the 1950s and '60s, but represents the most complete list possible from available sources. Without some idea of spatial location, information about a feature is of little value. In all, over 600 features could at least be attributed to a particular beach ridge or segment. The vast majority of these features could be attributed to annotated points on a digitized and georeferenced photomosaic (see Anderson et al. 2009). There is not a one-to-one ratio of features to points, since some point locations represent multiple features. By loading these locations onto GPS (global positioning system) units, field crews were able to anticipate and investigate the approximate locations of features recorded by Giddings. A large number of features were relocated and determined to be Giddings' features with a relatively high degree of confidence (Figure 4). In some cases, several features were located near the reported location of the legacy feature, so no definitive results could be determined. At other legacy feature locations, there was simply nothing found.

New Impressions of Old Sites, Denbigh Hearths

At Cape Krusenstern, the beach ridges have built up gradually over time, starting as a series of gravel spits extending from the east. The earliest people to occupy these nascent beach ridges were people that used a specific stone tool technology, which in Alaska is known as the Denbigh Flint culture. Originally discovered on Norton Sound (Giddings 1967), this technology was used by people who are recognized as the first to routinely inhabit northern Alaska coastlines. The Denbigh Flint culture is ascribed to the larger Arctic Small Tool tradition, bearers of which continued from Alaska across the Arctic to Canada and Greenland.

No known remains of Denbigh structures have been found at Cape Krusenstern. Instead, the most common indicators of human presence are hearths of campfires, often built with flat stones that contrast with the rounded pea-sized gravels that make up the beach ridges. Giddings and Anderson (1986) interpreted these hearths to be the remains of late-spring or early summer campsites, when Denbigh people would pitch tents of animal skin on the coast and hunt seals. Because these were temporary camps, the resulting archaeological material and features can be difficult to distinguish. Luckily, both the flat stones and the beach gravels are often oxidized from the fire, resulting in a reddish hue that can be noticed between the sparse tundra vegetation (Figure 5). Stone tools, such as microblades, microblade cores, and burins, are sometimes found with the hearths (Figure 6). Hearths were often reported by Giddings and Anderson (1986) as occurring in linear series along a beach ridge. It is unknown if the close proximity of multiple hearths implies contemporaneity, but it is generally assumed that

Figure 5. Hearth feature.
Photo courtesy of Fawn Carter

Figure 6. Chert microblade found in a hearth.
Photo courtesy of Shelby Anderson

Figure 7. Legacy feature 419 in 2008.
NPS photo courtesy of Adam Freeburg

the number of features resulted from a small number of people returning to the beach ridge complex over the course of multiple years.

Legacy feature 419 was one hearth attributed to the Denbigh culture that fell within the survey area investigated by the University of Washington team. This feature serves as an excellent example of the accuracy with which the legacy features were often able to be placed on the photomosaic by Giddings. Within two meters of the derived feature location shown by the photomosaic in GIS, we found a deflated surface lacking vegetation, but containing a concentration of rocks cracked and reddened by fire (Figure 7, Figure 8). Therefore, we confirmed legacy feature 419 to be a previously excavated hearth. Though excavated, a thorough surface search was

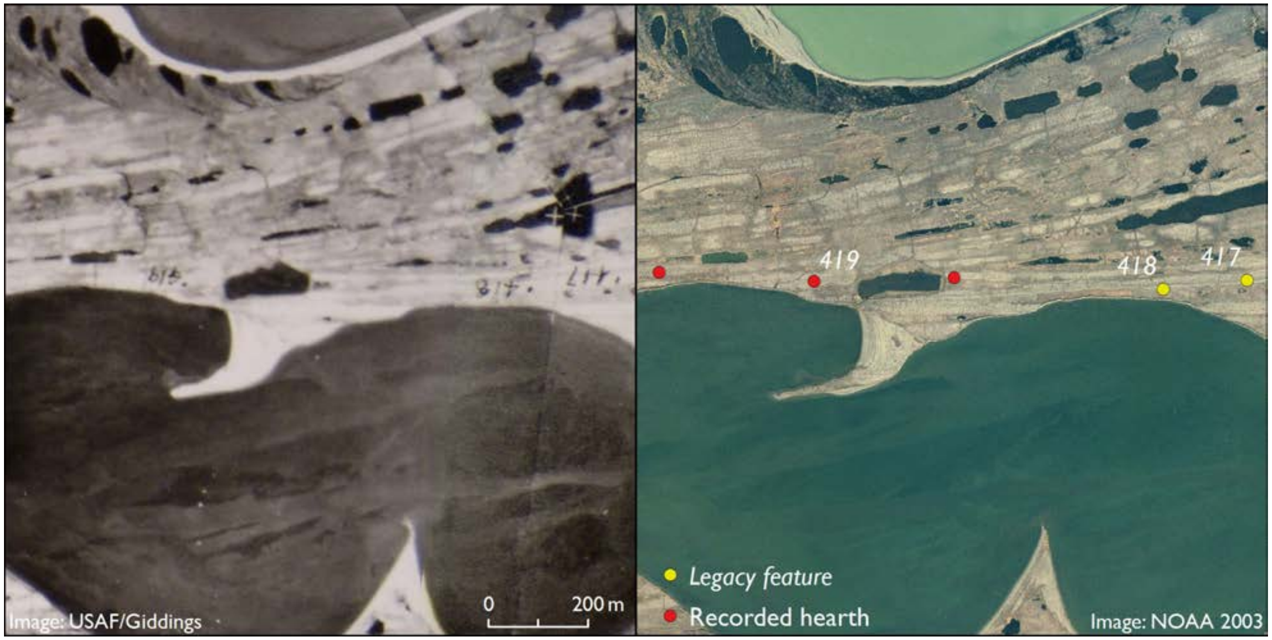


Figure 8. (Left) Giddings' annotated photomosaic showing features 419, 418, and 417 (L-R, numbers are upside down). (Right) Locations of legacy features and newly recorded hearths on recent orthoimagery. Scale is same for each side.

Table 1. Denbigh feature radiocarbon (RC) dating results.

Catalog Number	Material	Description	RC Age	Calibrated Date
CAKR 13580	Charcoal	*Picea*	3760 ± 35	2289 B.C. – 2041 B.C.
CAKR 14011	Charcoal	*Salicacea*, cf. *Salix*	3620 ± 30	2119 B.C. – 1893 B.C.
CAKR 13389	Charcoal	*Picea*	3450 ± 30	1880 B.C. – 1688 B.C.

conducted in and around the area to determine if any artifacts were present, but nothing further was found. Two other hearths (legacy features 417 and 418) were nearby according to Giddings' photomosaic, but their locations fell outside of the new project's survey area, so relocation was not attempted (see Figure 8).

Three additional hearths were recorded by the University of Washington team in the central beach ridge complex, including another known site recorded in the 1980s. In this location, features are generally assigned to the Denbigh culture. None of these hearths appeared to have been previously excavated. Charcoal was found and collected from two of the hearths. An additional charcoal sample associated with a biface fragment was found eroding out of a nearby lakeshore cutbank. Both artifacts were collected, and the charcoal was submitted for dating along with charcoal from the hearths. The dates of each sample falls well within the Denbigh culture period. These are the first absolute dates on Denbigh-period materials from Cape Krusenstern (Table 1).

A Refined Chronological Model

Throughout the project, the scenario described above for locating and confirming legacy features was carried out simultaneously with systematic walking survey and testing. Ultimately, this work not only contributed data for our overall results and interpretations, but also provided a closer look at the data behind past interpretations of the beach ridge complex. The broad strokes of culture history and occupation still stand as determined by Giddings and Anderson (1986), a testament to their pioneering work. Their intra-site interpretations, made possible due to their methods of full-feature excavation and recovery of diagnostic materials, remain the definitive work for the beach complex. We have been able to refine the existing chronological model and provide new detail, however, due to our systematic, intensive survey with a focus on recovery of dateable materials, as well as our use of high-resolution location accuracy.

Giddings' (1966) innovative use of prograding shorelines, such as Cape Krusenstern, as a horizontal stratigraphy was based on the tenet that people would always choose to camp closest to the sea. Mapping and dating of over 2,000 features and artifacts across the beach ridge complex shows use of the entire landscape, with people using all the beaches that existed in their time for a variety of purposes and activities (see Anderson and Freeburg 2013), though Giddings' tenet generally holds for settlements. In addition to the horizontal stratigraphy provided by individual ridges, different depositional and erosional sequences of sediment have formed

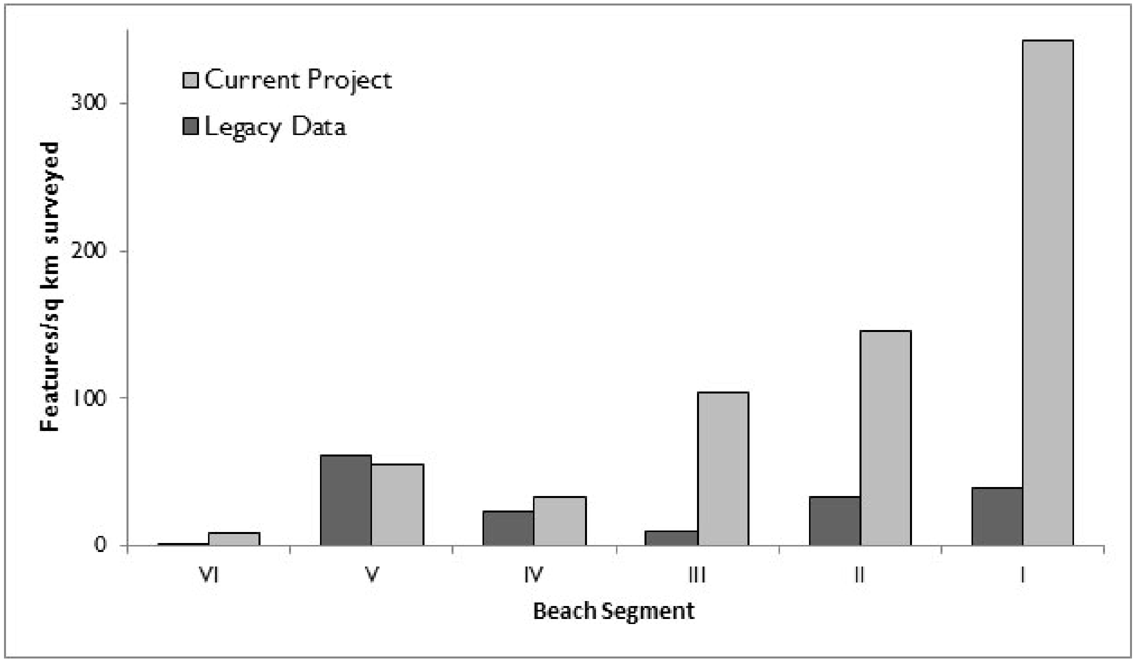


Figure 9. Density of current feature totals and legacy features in 2006-2010 survey areas. "I" for the youngest, closest to the active beach and "VI" for the oldest, closest to the lagoon.

geomorphologically distinct groups of beach ridges that Giddings termed "segments." These segments are useful analytical units with which to compare new and old data, and are identified by roman numerals. A comparison of legacy features and newly recorded features found within the University of Washington's survey area shows marked differences in archaeological feature density (Figure 9). We interpret this to be due to the research methods of the current project, which included systematic survey with tightly spaced transects. While the previous survey work resulting in the legacy data was extensive across the site complex, it was not as systematic or intensive as the recent work. So, while these results support the overall patterns established by Giddings and Anderson (1986), they also indicate much higher population estimates for the site complex (see Anderson and Freeburg 2014). They also indicate a more intensive use of the beaches starting about 2,500 years ago, with an increasing trend. How this changes local and regional archaeological interpretations is the subject of continuing study by the project team.

Conclusions

With such a large geographic extent to cover, archaeologists in Alaska are often covering new ground. Increasingly, however, archaeologists are returning to previously researched sites. At Cape Krusenstern, the work done by Giddings and Anderson provided not only an excellent foundation for renewed archaeological investigation, but also insightful points of comparison in both methods and results. These comparisons highlight the usefulness of legacy data, as well the importance of continued archaeological study, allowing researchers to bring new ideas, new methods, and new perspectives to established ideas of the past.

REFERENCES

Anderson, S. L. and A. K. Freeburg. 2014.
High latitude coastal settlement patterns: Cape Krusenstern, Alaska. *The Journal of Island and Coastal Archaeology* 9(3):295-318.

Anderson, S. L. and A. K. Freeburg. 2013.
A high-resolution chronology for the Cape Krusenstern Site Complex, northwest Alaska. *Arctic Anthropology* 50(1):49-71.

Anderson, S., A. Freeburg, and B. Fitzhugh. 2009.
Cultural vulnerability and resilience in the Arctic: preliminary report on archaeological fieldwork at Cape Krusenstern, northwest Alaska. *Alaska Park Science* 8(2):42-45.

Giddings, J. L. 1966.
Cross-dating the archaeology of northwestern Alaska. *Science* 153(3732):127-135.

Giddings, J. L. 1967.
The Archaeology of Cape Denbigh. Brown University Press. Providence, RI.

Giddings, J. L. and D. D. Anderson. 1986.
Beach ridge archaeology of Cape Krusenstern: Eskimo and pre-Eskimo settlements around Kotzebue Sound, Alaska. *Publications in Archaeology* 20. National Park Service. Washington, D.C.

National Oceanic and Atmospheric Administration (NOAA). 2003.
High-resolution orthorectified imagery for the coastal areas of Bering Land Bridge National Preserve and Cape Krusenstern National Monument. Collaborators: National Park Service Arctic Network Inventory and Monitoring Program, University of Colorado Institute of Arctic and Alpine Research, AeroMap US, Aero-Metric Inc., NOAA National Geodetic Survey.

United States Air Force (USAF).
U.S. Air Force aerial photographs of northwest Alaska. Scale 1:43,000. Acquired 1949-1956. Ink annotations by J. L. Giddings.

A Paleontological Inventory of Arctic Parks

Amanda Lanik and Chad Hults, National Park Service, and Robert B. Blodgett, Consulting Geologist

In July 2012, aquatic ecologist Amy Larsen and pilot Eric Sieh discovered multiple mammoth bones along the edge of a lake in Bering Land Bridge National Preserve. They reported finding at least one tooth and a semi-articulated humerus and ulna (Figure 1). Archaeologist Jeff Rasic, Louise Farquharson (a PhD student at the University of Alaska Fairbanks), and Eric Sieh revisited the site in September, to assess the site's vulnerability to erosion and potential for paleoecological research.

In addition to relocating the mammoth humerus and ulna, they discovered two mammoth vertebra, a mammoth rib fragment, potential mammoth cranial bones, caribou antler fragments, and a moose metapodial (Figure 2). They found the majority of the mammoth bones clustered together, indicating they likely originated from a single individual. Finds of multiple mammoth bones from the same skeleton are relatively uncommon in Alaska, making this one of the more complete mammoth skeletons known.

While exciting and valuable, fossil finds of this nature are not uncommon from within the Arctic parks. Pleistocene (0.01–2.6 Ma [million years ago]) mammal fossils, such as the mammoth bones from Bering Land Bridge, can be found eroding out surficial deposits throughout the parks (Figure 3). Furthermore, many of the Paleozoic (252–541 Ma), and to a lesser extent Mesozoic (66-252 Ma) rocks that form the characteristically majestic landscapes of the Arctic parks contain abundant marine fossils, including trilobites, ammonites, brachiopods, gastropods, and many more. These fossils tell the story of how this area has evolved through millions of years, from a time when trilobites swarmed the ocean floors, to when huge Ice Age megafauna traveled freely between Siberia and North America. Without an understanding of this story told through fossils, it would be nearly impossible to understand the geologic history of the Arctic parks, Alaska, and the Earth as a whole.

What is a Fossil?

When most people hear the word "fossil," they typically picture the enormous dinosaur skeletons that are often displayed in museums. As majestic as these striking paleontological specimens are, they make up only a small portion of the wide variety of organisms that have been preserved as fossils. Fossils, strictly speaking, are any evidence of past life that has been preserved in the rock record. This encompasses microscopic 3.5 billion year-old cyanobacteria, 15,000 year-old wooly mammoths, and everything in between. The study of these ancient organisms (paleontology) allows an understanding of

◀ **Figure 1.** Mammoth humerus and ulna from a lake in Bering Land Bridge National Preserve.
NPS photo courtesy of Jeff Rasic

Figure 2. Mammoth vertebra from a lake in Bering Land Bridge National Preserve.
NPS photo courtesy of Jeff Rasic

Figure 3. Bison metapodial from Goodhope Bay in Bering Land Bridge National Preserve.
NPS photo courtesy of Mariana Dryak

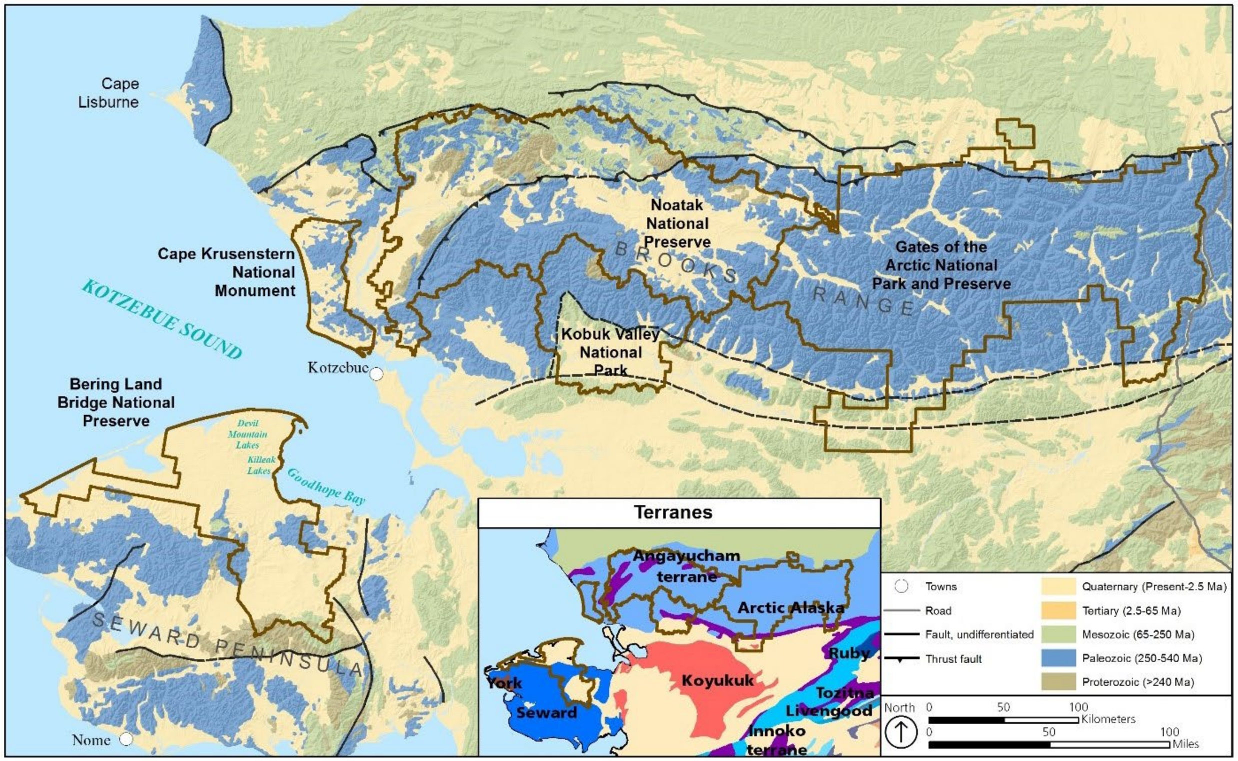


Figure 4. Map of the Arctic parks, generalized geology, and terranes.

how life on Earth has changed through time. Because life is always changing, the fossils in a rock directly reflect the time, place, and environment in which that rock was deposited. This makes the fossil record an invaluable tool not only for studies that focus on how life has changed and evolved through time, but also for any geologic study that could benefit from spatial, temporal, or environmental constraint.

Paleontological Inventory

Fossils can provide geologists a wealth of important information about the rocks in which they are found. When and where were these rocks deposited? What was the environment like then and how has it changed? What other organisms composed this ancient ecosystem? Fossils can answer all of these questions and many more. Because of their inherent value, it is vital to document where fossils have already been found and identify areas of high fossil potential. This information enables park staff to ensure the preservation of these important, non-renewable resources and facilitates further paleontological research. Toward this end, we are compiling a comprehensive report and database of the paleontology of the Arctic parks, which will identify what paleontological resources the parks contain, the condition of these resources, and their potential vulnerability to disturbance.

The following is a brief account of just a portion of the interesting paleontological research that has already been conducted within the Arctic parks, highlighting cases when fossils provided key evidence that enabled scientists to resolve complex geologic questions.

Geologic History

Arctic parks, like most of Alaska, are composed of multiple accreted geologic terranes (Figure 4). A terrane is a fault-bounded package of rocks with a geologic history different from surrounding rocks. Alaska is almost entirely composed of terranes, each with its own history, that have been transported from where they were originally deposited and amalgamated together through tectonic forces.

One of the largest of these terranes is the Arctic Alaska terrane, underlying all of the Arctic parks except Bering Land Bridge National Preserve, which contains rocks of the Seward and York terranes (Silberling et al. 1992). Within the park boundaries these terranes are primarily Paleozoic in age and were deposited on the marine margins of a continent. The biogeographic affinities of the fossils found in the Early Paleozoic rocks indicate that they were deposited in close proximity to Siberia, rather than North America. This Siberian aspect differentiates them from coeval carbonate deposits of the Canadian passive margin, indicating that despite being transported to northern Canada by the end of the Paleozoic, these rocks have an exotic origin with respect to North America.

The Arctic Alaska terrane, along with the terranes of Bering Land Bridge and parts of northeastern-most Russia (notably Chukotka), are interpreted as belonging to a continental block called the Arctic Alaska-Chukotka microplate. The Arctic Alaska-Chukotka microplate has been suggested by some to have rifted away from the Canadian margin during the Mesozoic with the opening of the Canada Basin (Till 2016). This coincides with the beginning of the Brookian orogensis, a mountain-building event caused by the collision of the continental Arctic Alaska terrane and the Koyukuk arc, closing the oceanic Angayucham Ocean (Moore et al. 2015). This collision resulted in the folding and thrusting of the Arctic Alaska terrane, emplacement of the Angayucham terrane onto the Arctic Alaska terrane, and formation the Brooks Range and the Colville basin (Moore et al. 1994). The Arctic parks straddle the Brooks Range, an area of uplift (rather than deposition) during the Mesozoic, and therefore deposits sourced from the uplifted area are not nearly as widespread within the parks as Paleozoic deposits.

In addition to older rocks, the Arctic parks contain a wealth of unconsolidated Pleistocene and Holocene (Present–0.01 Ma) sediments. During these epochs, the Earth went through a series of major glaciations. Ice sheets tied up vast quantities of water on land, causing sea level to drop and the shallow marine platform between Alaska and Siberia to emerge, forming the Bering Land Bridge (Hopkins 1959). The Bering Land Bridge occupied the center of an area known as Beringia that stretched from Siberia to Northern Canada and remained largely unglaciated during the last glacial maximum (LGM; 14,000–28,000 years before present; Hofle et al. 2000). The Arctic parks are located in what was central and eastern Beringia, an arid steppe that hosted large herds of grazing animals such as horses, bison, and mammoths. These deposits preserve the record of how animals and plants interacted through periods of biotic interchange and dramatic climate change at high latitudes (Lenz et al. 2016).

Paleozoic Paleontology

To determine the geographic placement of the Arctic Alaska, York, and Seward terranes during the Early Paleozoic, geologists have relied on the fossilized organisms found within them. Fossils usually reflect the time and place of that rock's deposition. Species that show provincialism (endemic species, meaning that they are restricted to a small geographic region), are especially good for providing geographic constraint. Because of their depositional setting, the Arctic Alaska, Seward, and York terranes contain abundant fossils typically found in Paleozoic carbonate sequences, including trilobites, brachiopods, sponges, corals, mollusks, and conodonts. Some of the macrofauna, and to a lesser extent the macroflora, demonstrate ties to Siberia (Blodgett et al. 2002), while the early Paleozoic conodonts recovered from these terranes display a mixed Siberian and North American affinity (Dumoulin et al. 2002).

There are numerous and varied fossils from Cambrian (485–541 million years ago) to Mississippian (323–359 Ma) strata of the Arctic Alaska terrane that are endemic to Siberia (Figure 5). These include Cambrian trilobites from the eastern and central Brooks Range (Dutro et al. 1984, Palmer et al. 1984), and Mississippian plant macrofossils that were previously only known from Siberia (Blodgett et al. 2002). Numerous Ordovician- (444–485 Ma) to Devonian- (359–419 Ma) aged species of brachiopods recognized from the Arctic Alaska terrane also indicate a depositional environment geographically linked to Siberia (Figure 6; Blodgett et al. 2002). In addition, microfossils demonstrate Paleozoic ties to Siberia; Early Paleozoic conodonts from portions of the Arctic Alaska, York, and Seward terranes are of a mixed Siberian and North American affinity (Dumoulin et al. 2002). These paleontological data indicate that the northern Alaskan terranes were proximal to Siberia from the Cambrian to Devonian, and possibly into the Mississippian (Blodgett et al. 2002).

Figure 5. Late Devonian (Frasnian) Thamnastreid rugose coral from Noatak.
Photo courtesy of Robert B. Blodgett

Quaternary Paleontology

Fossils can be found throughout the Arctic parks, eroding out of surficial Pleistocene and Holocene deposits. These deposits contain a wide variety of fossils, notably the bones and teeth of Ice Age megafauna, but also abundant pollen, insect, ostracod, and plant fossils.

One of the most unique deposits that provides a window into the past environment of Beringia is the 21,570 year-old Kitluk Paleosol, found within the Bering Land Bridge National Preserve. In the area between Devil Mountain and Cape Espenberg, Pleistocene and Holocene volcanism produced ash deposits with at least one of these

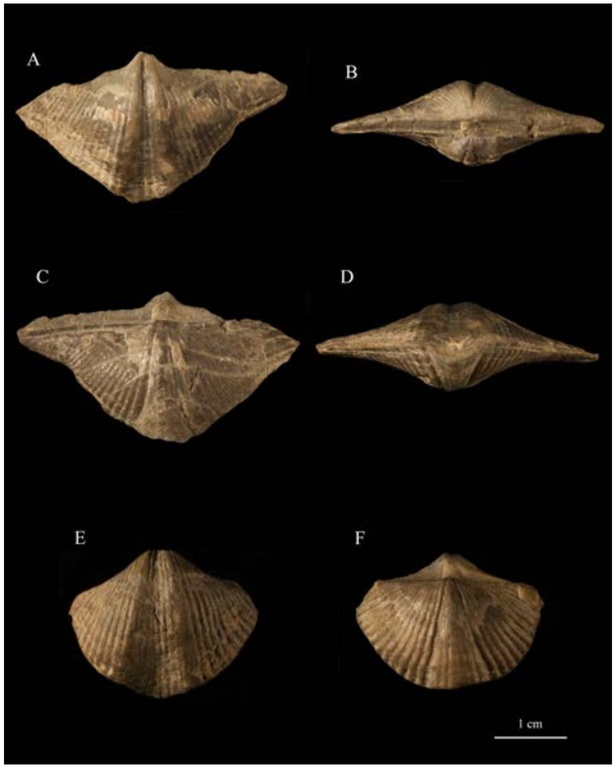


Figure 6. Late Devonian (Frasnian) brachiopods from Noatak that most closely match fauna known from northern Russia. Spiriferid brachiopod (A) ventral view, (B) posterior view, (C) dorsal view, (D) anterior view, Spiriferid brachiopod, (E) ventral view, (F) dorsal view.
Courtesy of Robert B. Blodgett

Figure 7. Caves at Trail Creek in Bering Land Bridge National Preserve. The Trail Creek caves were excavated by a team of NPS scientists in 1985 and 1986 and were found to contain numerous Pleistocene and Holocene mammal and bird fossils, including Pleistocene-aged mammoth and horse remains.
NPS archives; Bering Land Bridge Cultural Resource Inventory, 1985

eruptions producing an ash layer that buried an area of approximately 750 km^2 (289 square miles). The deposition of this ash caused the permafrost to advance upward rapidly and essentially froze the soil in place (Hofle and Ping 1996). This exquisitely preserved fossilized soil, named the Kitluk Paleosol, is now exposed along the perimeters of the many thermokarst lakes on the Seward Peninsula (Kuzmina et al. 2008). During the summers of 1993, 1994, and 1995, a multi-disciplinary team of scientists excavated the Kitluk Paleosol, collecting insect fossils, arachnid fossils (Kuzmina et al. 2008), and plant macrofossils (Goetcheus and Birks 2001). These fossils, along with the other characteristics of the ancient soil, allowed scientists to reconstruct the past environment of a large portion of central Beringia at a single point in time. When integrated with studies from Alaska, Siberia, and Canada, we begin to get a picture of this glacial refuge that enabled the survival and dispersal of various Ice-Aged plants and animals, including the first humans of North America.

During the Pleistocene, Beringia was home to variety of large, cold-adapted mammals. Some of the most commonly found remains include those belonging to wooly mammoth (*Mammuthus primigenius*), horse (*Equus* sp.), steppe bison (*Bison priscus*), caribou (*Rangifer tarandus*), muskox (*Ovibos moschatus*), and grizzly bear (*Ursus arctos*; Figure 7). These fossils can be found eroding out of stream banks and coastal bluffs in the Arctic parks and provide excellent material to study the megafauna that inhabited Beringia, their subsequent extinction, and the circumstances surrounding it (Rivals et al. 2010). The majority of scientists agree that climate change and the loss of habitat were the main factors behind the decline of the Ice Age megafauna, however, some have argued that the migration of humans into North America also played a role.

During the Pleistocene and Holocene, sea-level oscillations caused the sea level to drop as much as 100–150 meters (328-492 feet) and rise at least 20 meters (65 feet) above present position (Hopkins 1967, Hopkins 1988, Kaufman and Brigham-Grette 1993, Brigham-Gette and Hopkins 1995, Muhs et al. 2003). During times of high sea level, marine fossils were deposited in flooded areas that are presently above sea level. The majority of these marine deposits are obscured by overlying terrestrial sediment, however, we can find marine mollusk shells in areas along the coast of Bering Land Bridge National Preserve and Cape Krusenstern National Monument (Brigham-Grette and Hopkins 1995). Interestingly, the Devil Mountain Lakes, two maar lakes located on the northern portion of the Seward Peninsula, are ringed by rocks containing marine mollusk shells. The Devil Mountain maars were formed 7,100 and 17,000 years ago, when the interaction of magma and groundwater caused violent volcanic eruptions. The marine mollusk shells are found in volcanic ejecta that was brought up from the subsurface during these eruptions, indicating that Pleistocene marine deposits extend at least as far inland as these lakes (Hopkins 1988). Times of high sea level are important to understand, because while the flooding of the Bering Land Bridge restricted the migration of terrestrial life between North America and Asia, the opening of the Bering Strait altered ocean circulation and allowed for the exchange of Arctic and Pacific marine organisms.

Virtual Paleontological Specimens

As part of our inventory of Arctic paleontology, we are creating a database to provide park staff with easy access to paleontological data and highlight opportunities for future research and outreach. One project idea that stemmed out of the database is the creation of three-dimensional models of park fossils. Three-dimensional models are an especially exciting new tool in paleontology because they allow anyone the opportunity to observe and interact with fossils. To create the models, fossils are photographed from multiple angles and the images are stitched together in a process known as Structure from Motion (photogrammetry; Figure 8). We've created three-dimensional models of some of the key park fossils, including the mammoth tooth collected from Bering Land Bridge National Preserve. This provides the opportunity for researchers everywhere to study and appreciate the vast paleontological resources Alaska's parks have to offer.

Figure 8. Taking pictures of the mammoth tooth from Bering Land Bridge National Preserve to create a 3D model.

Link to the mammoth tooth model: https://skfb.ly/QRIR

NPS photo courtesy of Amanda Lanik

Acknowledgements

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REFERENCES

Blodgett, R. B., D. M. Rohr, and A. J. Boucot. 2002. Paleozoic links among some Alaskan accreted terranes and Siberia based on megafossils. Pages 273-290 in E. L. Miller, A. Grantz, and S. L. Klemperer, eds. Tectonic Evolution of the Bering Shelf—Chukchi Sea—Arctic Margin and Adjacent Landmasses. Geological Society of America Special Paper 360. The Geological Society of America, Boulder, Colorado.

Brigham-Grette, J. and D.M. Hopkins, 1995. Emergent marine record and paleoclimate of the Last Interglaciation along the northwest Alaskan coast. *Quaternary Research* 43:159-173.

Dumoulin, J. A., A. G. Harris, M. Gagiev, D. C. Bradley, and J. E. Rapetski. 2002. Lithostratigraphic, conodont, and other faunal links between lower Paleozoic strata in northern and central Alaska and northeastern Russia. Pages 291-312 in E. L. Miller, A. Grantz, and S. L. Klemperer, eds. Tectonic Evolution of the Bering Shelf—Chukchi Sea—Arctic Margin and Adjacent Landmasses. Geological Society of America Special Paper 360. The Geological Society of America, Boulder, Colorado.

Dutro, J.T., A.R. Palmer, J.E. Repetski, and W.P. Brosgé. 1984. Middle Cambrian fossils from the Doonerak anticlinorium, central Brooks Range, northern Alaska. *Journal of Paleontology* 58(6):1364-1371.

Goetcheus, V. G. and H. H. Birks. 2001. Full-glacial upland tundra vegetation preserved under tephra in the Beringia National Park, Seward Peninsula, Alaska. *Quaternary Science Reviews* 20:135-147.

Kaufman, D. S. and J. Brigham-Grette. 1993. Aminostratigraphic correlations and paleotemperature implications, Pliocene-Pleistocene high-sea-level deposits, northwestern Alaska. *Quaternary Science Reviews* 12:21-33.

Hopkins, D. M. 1959.
Cenozoic History of the Bering Land Bridge. *Science* 129:1519-1528.

Hopkins, D. M. 1967.
Quaternary Marine Transgressions in Alaska. Pages 47-90 in D. M. Hopkins, ed. The Bering Land Bridge. Stanford University Press, Stanford, California.

Hopkins, D. M. 1988.
The Espenberg Maars: A record of explosive volcanic activity in the Devil-Mountain-Cape Espenberg area, Seward Peninsula, Alaska. Pages 262-321 in J. Schaaf, ed. The Bering Land Bridge National Preserve: an Archeological Survey 1. National Park Service – Alaska Region. Research/Resources Management Report AR-14, Anchorage, Alaska.

Hofle, C. and C. L. Ping. 1996.
Properties and soil development of late-Pleistocene paleosols from Seward Peninsula, northwest Alaska. *Geoderma* 71:219-243.

Hofle, C., M. E. Edwards, D. M. Hopkins, D. H. Mann, and C. L. Ping. 2000.
The full-glacial environment of the northern Seward Peninsula, Alaska, reconstructed from the 21,500-year-old Kitluk paleosol. *Quaternary Research* 53:143-153.

Kuzmina, S., S. Elias, P. Matheus, J. E. Storer, and A. Sher. 2008.
Paleoenvironmental reconstruction of the Last Glacial Maximum, inferred from insect fossils from a tephra buried soil at Tempest Lake, Seward Peninsula, Alaska. *Palaeogeography, Palaeoclimatology, Palaeoecology* 267:245-255.

Lenz J., G. Grosse, B. M. Jones, K. M. Walter Anothony, A. A. Bobrov, S. Wulf, and S. Wetterich. 2016.
Mid-Wisconsin to Holocene permafrost and landscape dynamics based on a drained lake basin core from the northern Seward Peninsula, northwest Alaska. *Permafrost and Periglacial Processes* 27:56-75.

Moore, T. E., W. K. Wallace, K. J. Bird, S. M. Karl, C. G. Mull, and J. T. Dillon. 1994.
Geology of northern Alaska. Pages 49-140 in G. Plafker and H. C. Berg, eds. The geology of Alaska. Geological Society of America, Boulder, Colorado.

Moore, T. E., P. B. O'Sullivan, C. J. Potter, and R. A. Donelick. 2015.
Provenance and detrital zircon geochronologic evolution of lower Brookian foreland basin deposits of the western Brook Range, Alaska, and implications for early Brookian tectonism. *Geosphere* 11(1):1-30.

Muhs, D. R., J. F. Wehmiller, K. R. Simmons, and L. L. York. 2003.
Quaternary sea-level history of the United States. *Development in Quaternary Science* 1:147-183.

Palmer, A. R., J. T. Dillon, and J. T. Dutro. 1984.
Middle Cambrian trilobites with Siberian affinities from the central Brooks Range, northern Alaska. *Geological Society of America Abstracts with Programs* 16(5): 327.

Rivals, F., M. C. Mihlbachler, N. Solounias, D. Mol, G. M. Semprebon, J. deVos, and D. C. Kalthoff. 2010.
Palaeoecology of the Mammoth Steppe fauna from the late Pleistocene of the North Sea and Alaska: Separating species preferences from geographic influences in paleoecological dental wear analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology* 286:42-54.

Silberling, N. J., D. L. Jones, J. W. H. Monger, and P. J. Coney. 1992.
Lithotectonic terrane map of the North American Cordillera. U.S. Geological Survey, Miscellaneous Investigations Series 1-2176.

Till, A. B. 2016.
A synthesis of Jurassic and Early Cretaceous crustal evolution along the southern margin of the Arctic Alaska–Chukotka microplate and implications for defining tectonic boundaries active during opening of Arctic Ocean basins. *Lithosphere* 8(3):219-237.

Sedimentary rocks of the Arctic Alaska terrane, Primus Creek, Noatak National Preserve. ▶
NPS photo courtesy of Jared Hughey

Applying Wilderness Character Monitoring in the Arctic

Nyssa Landres, National Park Service

The primary mandate given by the Wilderness Act of 1964 is to preserve wilderness character. Wilderness character is the essence of the landscape—a holistic concept based on the interaction of (1) biophysical environments primarily free from modern human manipulation and impact; (2) personal experiences in natural environments relatively free from the encumbrances and signs of modern society; and (3) symbolic meanings of humility, restraint, and interdependence that inspire human connection with nature. Taken together, these tangible and intangible values define wilderness character and distinguish wilderness from all other lands (Landres et al. 2015).

To help land managers fulfill this mandate, a framework for monitoring wilderness character was developed and is in the process of being implemented across the U.S. This framework applies to Arctic Alaska in the same way it does to the rest of the country; it uses the same protocols to describe and monitor wilderness character, and provides the same benefits to wilderness stewardship and management efficacy.

Using this framework, the Noatak Wilderness in the western Brooks Range of Arctic Alaska recently completed a Wilderness Character Narrative that describes the area's holistic and often intangible wilderness character. A Wilderness Character Monitoring Baseline Assessment was also completed that describes how we will monitor wilderness character for the Noatak Wilderness. These management documents acknowledge the exceptional setting of Arctic wilderness, helping managers to more fully understand and effectively preserve the area's unique wilderness character.

When applying the wilderness character framework to the Noatak Wilderness, managers made several special considerations, including three primary factors that need to be addressed when monitoring Arctic wildernesses. First, the vast cultural significance and resources of these places, many of which continue to be used to this day, must be acknowledged as an integral part of wilderness character. To do this, the Noatak Wilderness incorporated "Iñupiat Homeland" as a quality of wilderness character to recognize the tangible and intangible cultural values of the Noatak's wilderness character. Second, wilderness character monitoring must address the provisions provided in the Alaska National Interest Lands Conservation Act of 1980 (ANILCA) and how they work in conjunction with the Wilderness Act. For instance, it is important to understand how motorized uses allowed under ANILCA (such as fixed-wing aircraft and motorboats, among others) negatively affect wilderness character, while recognizing that these uses will continue to occur in wilderness. The Noatak Wilderness addressed these provisions by devising strategies to monitor legal motorized uses, thereby allowing managers to better understand their patterns of use and tailor management actions accordingly. Third, creative solutions must be found to account for gaps in the quantifiable data by which wilderness character monitoring is typically conducted. We generally avoid duplicating monitoring and research efforts by using data collected by other programs, but many existing datasets do not include the Arctic. To address these difficulties with data acquisition, Noatak staff worked to identify measures that would accommodate the use of short-term datasets and isolated research projects. For example, some measures provided guidelines for using professional judgement to assess specific wilderness resources in lieu of the long-term data that are typically available for other wilderness areas.

Managers who are tracking change in wilderness character in the Arctic face many challenges, and this monitoring framework is flexible enough to overcome these challenges to meet stewardship needs. Ultimately, the Noatak's Wilderness Character Narrative and Wilderness Character Monitoring Baseline Assessment provide a comprehensive depiction of the area's wilderness character, allowing managers to more effectively meet the stewardship needs of the Noatak Wilderness into the future.

◀ Tundra near Feniak Lake in Noatak Wilderness.
NPS photo courtesy of Nyssa Landres

REFERENCE

Landres, P., C. Barns, S. Boutcher, T. Devine, P. Dratch, A. Lindholm, L. Merigliano, N. Roeper, and E. Simpson. 2015. Keeping it Wild 2: An Updated Interagency Strategy to Monitor Trends in Wilderness Character Across the National Wilderness Preservation System. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-340, Fort Collins, CO.

The Fate of Permafrost

Santosh K. Panda, Vladimir E. Romanovsky, and Sergey S. Marchenko, Geophysical Institute, University of Alaska Fairbanks and David K. Swanson, National Park Service

A skeleton is to a human body
what permafrost is to Arctic land.

Permafrost is ground that remains frozen year-round due to a cold climate; the active layer is the ground above the permafrost that thaws and re-freezes each year. Nearly 40 million acres of National Park Service (NPS) land in Alaska, similar to the size of Florida, lie within the zone of continuous or discontinuous permafrost. Permafrost can be classified as continuous (>90% of land area underlain by permafrost), discontinuous (90%-50%), sporadic (50%-10%), or isolated (<10%; Ferrians 1965). Permafrost is most vulnerable to climatic warming when its temperature is within a few degrees of thawing. Large-scale permafrost thawing would lead to a major reconfiguration of the landscape through the development of thermokarst (irregular topography resulting from ground ice melting).

In the last half century, an increase in ground temperature and profusion of thermokarst landforms throughout Alaska confirm thawing and degradation of permafrost in response to a warming climate. As a result, the ecosystem, landscape, and wildlife habitat in permafrost-affected land are in rapid transition, with both environmental implications and management challenges. Thawing permafrost has many consequences, such as drying lakes, new pond creation, soil erosion, ground slumps, increased sediment loads and siltation of streams and lakes, release of greenhouse gasses, and changes in soil wetness and nutrient cycling. Thawing permafrost is the second most important disturbance to boreal forests after wildfires (Jorgenson and Osterkamp 2005). Because of its indispensable role in maintaining northern ecosystems' health and vitality, permafrost is monitored in Alaska's parks (MacCluskie and Oakley 2005, Lawler et al. 2009).

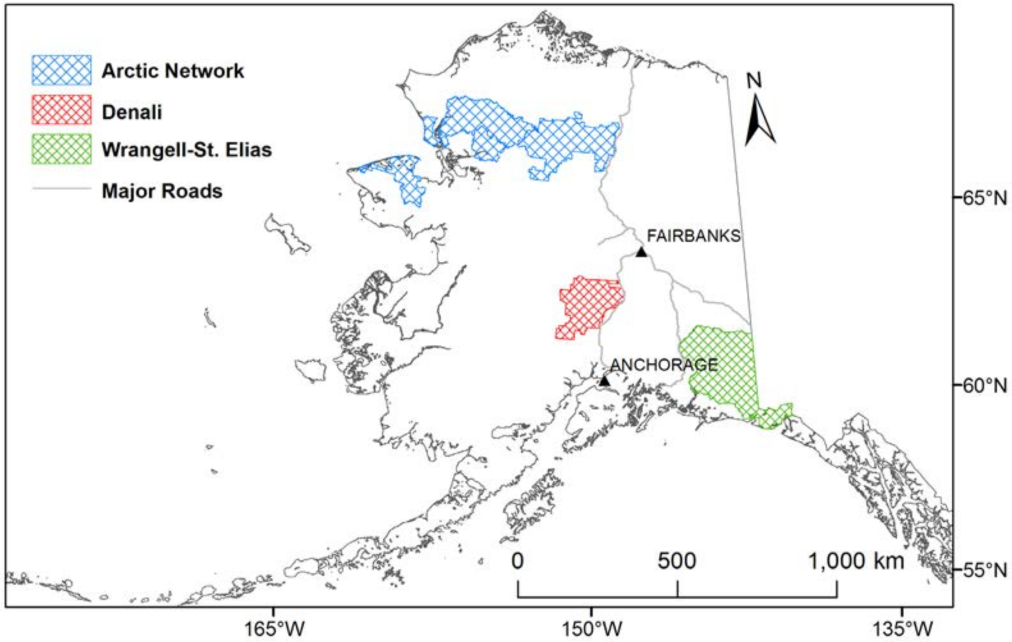


Figure 1. Location of seven permafrost-affected parks in Alaska. The Arctic parks consist of Gates of the Arctic National Park and Preserve, Noatak National Preserve, Kobuk Valley National Park, Cape Krusenstern National Monument, and Bering Land Bridge National Preserve. The Interior Alaska parks consist of Denali and Wrangell-St. Elias national parks and preserves.

Using Models to Map Permafrost

Because it is located under the surface, permafrost is difficult to observe and map directly. Existing knowledge of the distribution and temperature of permafrost in parks is very limited due to the paucity of borehole observations (direct measurements of temperature from boreholes drilled into the Earth's crust) and temperature monitoring sites required to evaluate permafrost health. With sufficient soil, environmental, and climate data, however, the current distribution and temperature of near-surface permafrost can be reliably predicted. By using projected climate data and scenarios, the same models used to predict the current distribution of permafrost can also predict its future distribution.

In recent work, we created improved and higher-resolution maps of permafrost

◀ Massive ice wedges dating to the late Pleistocene are visible in this thermokarst thaw in Noatak National Preserve.
NPS photo courtesy of David Swanson

distribution, temperature, and active-layer thickness for parks (Figure 1) under recent past, present, and future climate conditions. We used a permafrost model called GIPL 1.0 (Geophysical Institute Permafrost Laboratory 1.0) to assess the effect of a changing climate on permafrost. Using the GIPL 1.0 model, Marchenko and colleagues (2008) mapped permafrost distribution for the State of Alaska (at 1 kilometer scale). Using vegetation, soil, and temperature data for all the park units (Stevens et al. 2001, Clark and Duffy 2006, Stumpf 2007, Jorgenson et al. 2008a) with past and projected climate data from global climate datasets, we created 30 meter-resolution maps of near-surface permafrost distribution, temperature, and active-layer thickness for the recent past (the 1950s and 2000s decades) and the future (2050s decade).

We used historical (1901-2009) monthly average air temperature (°C) and total precipitation (millimeters; mm; CRU TS 3.1 from the University of East Anglia, UK, Climatic Research Unit) downscaled to 771 meters by the Scenario Network for Alaska and Arctic Planning (SNAP) for past climate forcing (the amount of energy we receive from the sun, and the amount of energy we radiate back into space; SNAP 2012), and used projected (2001-2100) monthly average air temperature (°C) and total precipitation (mm) data from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) Global Climate Models (GCM) under a moderate greenhouse gas emission scenario for the future climate forcing (Walsh et al. 2008). We also used field observations of permafrost presence/absence, summer thaw depths, and ground temperature records from NPS monitoring stations to assess the accuracy of the modeled permafrost maps.

We created maps of near-surface permafrost dynamics including permafrost distribution, temperature, and active layer thickness for five parks in Arctic Alaska (Bering Land Bridge, Cape Krusenstern, Gates of the Arctic, Kobuk Valley, and Noatak) and two in interior Alaska (Denali and Wrangell-St. Elias). These are an immense improvement over the existing permafrost maps, whether produced through the spatially explicit thermal modeling of ground temperatures or by visual interpretation of satellite images and aerial photos using indirect surface evidence of permafrost, or by compilation of information from detailed field soil, geology, or ecotype surveys.

Arctic Parks' Permafrost at Risk

In the Arctic parks, we found the distribution of near-surface permafrost—permafrost immediately below the active layer—could decrease from the current 99% of the total area to 91% by 2060 with little or no change in the distribution of deeper permafrost. Thermokarst landforms will continue to alter the land as a result of deepening active layers and melting ground ice; after 2060, widespread permafrost loss is likely.

We analyzed data across five Arctic parks (Figure 1). The average decadal air temperature was -5.2 ± 1.9 °C for the 2000s and the modeled average decadal permafrost temperature was -4.0 ± 1.8 °C (Table 1). Near-surface permafrost was mapped under 99% of these parks in the 2000-09 decade. The decadal average air temperature for 2050s is projected to be 2.1 °C warmer than for the 2000s; under these conditions, the model predicted a 1.4 °C increase in average permafrost temperature by the 2050s, and near-surface permafrost under 91% for these parks (Figure 2).

While this may or may not seem like a big loss depending on one's perspective, the area of most vulnerable permafrost—permafrost within one degree of thawing—is predicted to increase from 4% in 2000s to 15% in 2050s. In other words, the loss of near-surface permafrost could be three times higher than predicted by our model if the climate warms a degree more than what current climate models suggest. According to the global climate models, the Arctic climate will continue to warm and the average decadal air temperature will increase by another 2.4 °C by the 2090s, for a total of 4.5 °C increase in the air temperature between the 2000s and 2090s. This will undoubtedly cause further increase in ground temperature and dramatic loss of near-surface permafrost. By the end of this century, only half of the Arctic parks are predicted to be underlain by near-surface permafrost (within the top 3 m of the ground surface), most of which will be in the northern half of Noatak and Gates of the Arctic (Panda et al. 2016).

NPS began collecting ground temperature data at twenty-one sites within Arctic parks in 2011. According to Swanson (2016), the air and soil temperatures at the newly installed monitoring stations have increased by 3-4 °C during the monitoring period from 2011-2015. Comparing modeled ground temperature for the 2000s with recorded temperatures (2011-2015), we found the modeled ground temperatures are 0.2-4.2 °C colder at fourteen sites and 0.4 °C warmer at two sites. In light of Swanson's (2016) observations, the modeled ground temperature for the 2000s would be very close to the actual ground temperature of the modeled time period (2000-2009). We found 100% agreement between the modeled permafrost map for 2000s and field observations of permafrost presence at 575 sites.

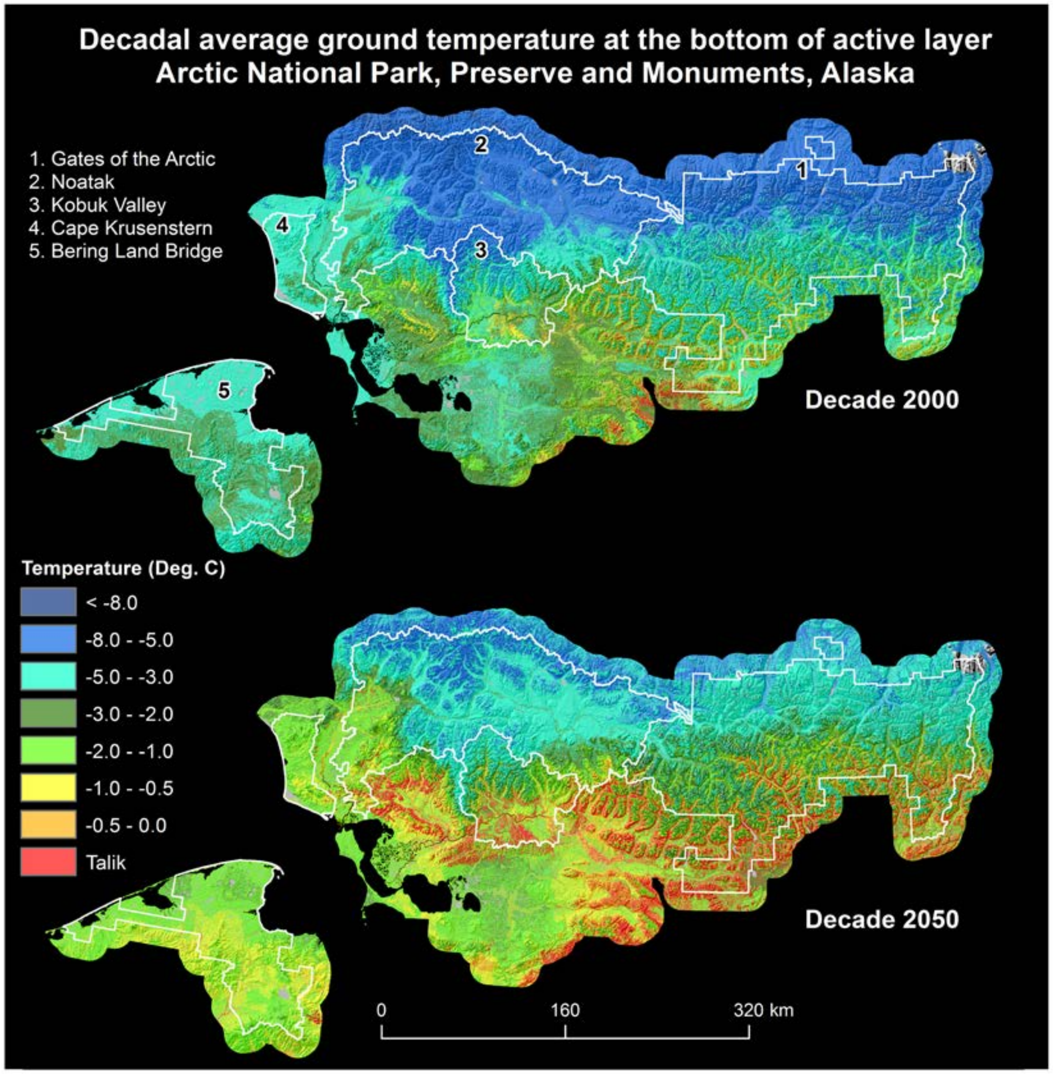


Figure 2. Comparison of modeled ground temperature maps (CRU forcing: 2000s; 5-GCM forcing: 2050s) of Arctic parks at 30 meter spatial resolution. The temperature values indicate presence of near-surface stable permafrost and its mean temperature. The red color identifies areas with Talik (i.e., unfrozen ground above permafrost). The maps are draped over a hillshade model for 3D perspective. The outlines of Gates of the Arctic National Park and Preserve, Noatak National Preserve, Kobuk Valley National Park, Cape Krusenstern National Monument, and Bering Land Bridge National Preserve are shown as white polygons. Note: near-surface permafrost is permafrost that lies immediately below the active layer.

Interior Alaska Likely to Experience Severe Permafrost Loss

For the interior Alaskan parks, the loss of near-surface permafrost will be severe—in Denali the distribution of near-surface permafrost is expected to decrease from the current 51% to 6%, and in Wrangell-St. Elias from the current 51% to 30% by 2060. Taliks (unfrozen ground above the permafrost) will replace the ground previously occupied by permafrost.

Denali National Park and Preserve

Our model predicted near-surface permafrost under 51% of Denali's total area for the 2000s and 6% in the 2050s (Table 1 and Figure 3). If the climate continues to warm as the current global climate models suggest, Denali will experience a dramatic loss of near-surface permafrost in the next half century. Only tiny areas on the north-facing slopes of high mountains are expected to have near-surface permafrost in the 2050s (Panda et al. 2014a).

Only three climate stations within Denali have some recorded ground temperature data. We found less than 1 °C difference between recorded near-surface ground temperatures (at 0.02 m) and modeled ground surface temperatures at these stations. Also, we found 86% agreement between the modeled permafrost map for 2000s and field observations of permafrost presence/absence at 1,375 sites.

Wrangell-St. Elias National Park and Preserve

Our model predicted near-surface permafrost under 51% of Wrangell-St. Elias' total area for the 2000s and 30% in the 2050s (Table 1 and Figure 4). If the climate continues to warm as the current global climate models suggest, it will also experience substantial

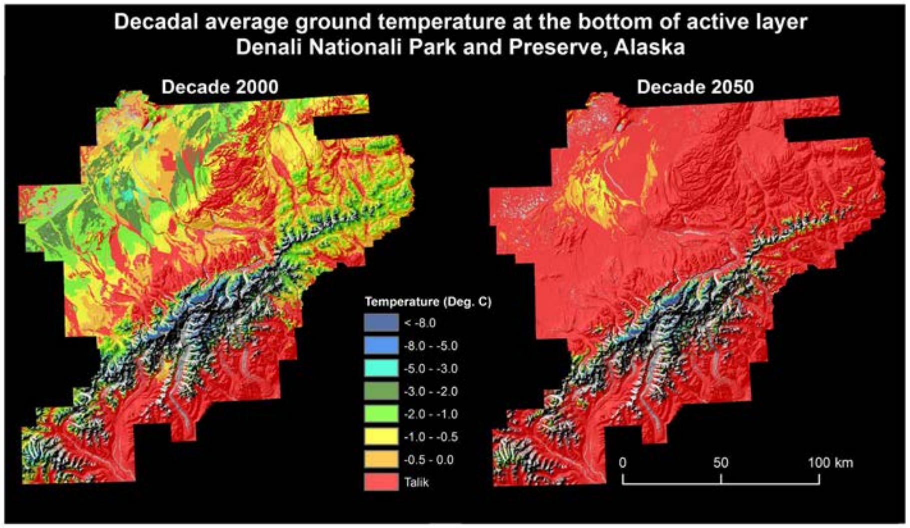


Figure 3. Comparison of modeled ground temperature maps (CRU forcing: 2000s; 5-GCM forcing: 2050s) of Denali National Park and Preserve at 30 meter spatial resolution. The temperature values indicate presence of near-surface permafrost. The red color identifies areas with Talik (i.e., unfrozen ground above permafrost). The maps are draped over a hillshade model for 3-Dimensional perspective.

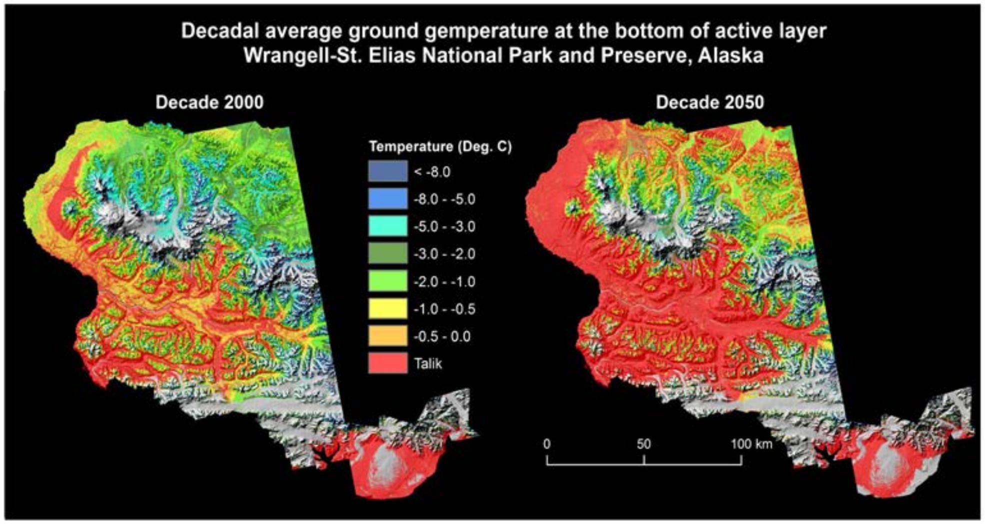


Figure 4. Comparison of modeled ground temperature maps (CRU forcing: 2000s; 5-GCM forcing: 2050s) of Wrangell-St. Elias National Park and Preserve at 30 meter spatial resolution. The temperature values indicate presence of near-surface permafrost. The red color identifies areas with Talik (i.e., unfrozen ground above permafrost). The maps are draped over a hillshade model for 3D perspective.

loss of near-surface permafrost in the next half century (Panda et al. 2014b).

Only two climate stations within Wrangell-St. Elias have useful recorded ground temperature data. The difference between recorded near-surface ground temperatures (at 0.05 m) and modeled ground surface temperatures were less than 1°C at Chicken Creek and 2.0 °C at Gates Glacier. Also, we found a 91% agreement between modeled permafrost map for the 2000s and field observations of permafrost presence/absence at 430 sites.

Warmer Temperatures and Other Factors will Continue to Accelerate Permafrost Loss

At present, permafrost is continuous in Arctic parks, and discontinuous in Denali and Wrangell St.-Elias (Jorgenson et al. 2008b). We expect the distribution of permafrost will still be continuous in Arctic parks by the 2050s; however, it is very likely that the distribution of permafrost in Denali and Wrangell-St. Elias will become sporadic by the 2050s. If projections of current global climate models hold true, near-surface permafrost underneath 45% of Denali and 21% of Wrangell-St. Elias could be lost by the 2050s with deeper permafrost loss in many places.

Our modeling results suggest the average temperature of near-surface permafrost increased by 1.5 °C in Arctic parks, by 1 °C in Denali, and by 0.3 °C in Wrangell-St. Elias in 50 years between the 1950s and 2000s. This warming of permafrost is primarily responsible for the landscape reconfiguration that is ongoing in the parks today. Degradation of ice-rich permafrost is resulting in thermokarst, ponding of low-lying areas, lake drainage, and ground failures such as active layer detachment slides, retrogressive thaw slumps, and gully erosion. Jorgenson and colleagues (2008c) reported a 3.5% to 8% increase in thermokarst-affected areas over the past 50 years in Alaska. Swanson (2013, 2014) reported occurrence of numerous thaw slumps in Arctic parks. Balser and colleagues (2009) reported a two-fold increase in the number of thermokarst features over the total surface area of affected landscape in the Feniak Lake region of Noatak National Preserve over 25 years (1981-2006). The current global climate models suggest another 1.4-2.1 °C of warming by the end of the 2050s under moderate greenhouse gas emission scenario (SNAP 2012). This magnitude of future warming will lead to substantial loss of permafrost in parks and consequent

Table 1. Summary statistics of climate and modeled permafrost characteristics in the Arctic network, Denali National Park and Preserve, and Wrangell-St. Elias National Park and Preserve. Climate data for 1950s and 2000s are from CRU dataset and for 2050s is from 5-GCM composite dataset. The permafrost statistics are from the output of GIPL 1.0 model runs.

Arctic Network Parks	**1950-1959**	**2000-2009**	**2051-2060**
Mean decadal air temperature (°C)	-7.0 ± 2.0	-5.2 ± 1.9	-3.1 ± 1.9
Mean decadal precipitation (mm)	455	472	499
Mean decadal permafrost temperature (°C)	-5.5 ± 1.7	-4.0 ± 1.8	-2.6 ± 1.6
Permafrost distribution (% of total area)	100	99	91
Permafrost warmer than -1 °C (% of total area)	0	4	15
Mean decadal active-layer thickness (ALT)(m)[1]	0.62 ± 0.20	0.67 ± 0.26	0.74 ± 0.31

Denali National Park and Preserve	**1950-1959**	**2000-2009**	**2051-2060**
Mean decadal air temperature (°C)	-3.5 ± 1.5	-1.6 ± 1.5	-0.2 ± 1.5
Mean decadal precipitation (mm)	679	651	845
Mean decadal permafrost temperature (°C)	-2.1 ± 1.2	-1.1 ± 1.2	-1.3 ± 2.2
Permafrost distribution (% of total area)	75	51	6
Permafrost warmer than -1 °C (% of total area)	8.5	30	4
Mean decadal ALT (m)[1]	1.1 ± 0.3	1.1 ± 0.3	1.1 ± 0.4

Wrangell-St. Elias National Park and Preserve	**1950-1959**	**2000-2009**	**2051-2060**
Mean decadal air temperature (°C)	-3.0 ± 2.5	-2.4 ± 2.4	-0.9 ± 2.4
Mean decadal precipitation (mm)	1144	1110	1505
Mean decadal permafrost temperature (°C)	-2.2 ± 1.7	-1.9 ± 1.5	-1.5 ± 1.4
Permafrost distribution (% of total area)	74	51	30
Permafrost warmer than -1 °C (% of total area)	22	22	18
Mean decadal ALT (m)[1]	1.2 ± 0.6	1.2 ± 0.5	1.31 ± 0.6

[1] The active-layer thickness (ALT) statistics does not include ALT for areas with talik above the permafrost table.

proliferation of permafrost-thaw effects like those that occurred due to the pre-2000 warming.

The model that we used assesses the effect of a changing climate on permafrost, but is limited in its ability to incorporate associated changes in vegetation over time, which could also affect near-surface permafrost dynamics. As we used past and projected climate data for modeling, the output permafrost maps show the impact of a changing climate on near-surface permafrost temperature and its distribution. Though we assumed no change in vegetation dynamics for our modeling time periods, the natural disturbances from wildfire and flooding will likely alter the vegetation structure and composition, and consequently, the model's prediction accuracy at those sites in the future.

How to Use this Information

We hope these permafrost maps help people understand the widespread changes to the Arctic's skeleton and park mangers understand the current status of near-surface permafrost within parks and how it may evolve in the future with a changing climate. These results can be used to identify vulnerable sites and landscapes at higher risk of permafrost thawing, with concurrent changes to wildlife habitats and ecosystem function. This can inform critical management decisions on the use of park resources and public access, and evaluate the impacts of climate change on parks' infrastructure, ecosystems, and wildlife habitat.

REFERENCES

Balser, A. W., M. N. Gooseff, J. B. Jones, and W. B. Bowden. 2009.
Thermokarst distribution and relationship to landscape characteristics in the Feniak Lake region, Noatak National Preserve, Alaska. National Park Service Report, Pages: 12.

Clark, M. H. and M. S. Duffy. 2006.
Soil survey of Denali National Park area, Alaska. National Cooperative Soil Survey, 822 p.

Ferrians, O. J., Jr. 1965.
Permafrost map of Alaska. United States Geological Survey Miscellaneous Investigation, Map I-445, scale 1:2,500,000.

Jorgenson, M. T. and T. E. Osterkamp. 2005.
Response of boreal ecosystems to varying modes of permafrost degradation. *Canadian Journal of Forest Research* 35:2100–2111.

Jorgenson, M. T., J. E. Roth, P. F. Loomis, E. R. Pullman, T. C. Cater, M. S. Duffy, W. A. Davis, and M. J. Macander. 2008a.
An ecological survey for landcover mapping of Wrangell-St. Elias National Park and Preserve. Natural Resource Technical Report NPS/WRST/NRTR—2008/094. National Park Service, Natural Resource Program Center, Fort Collins, CO.

Jorgenson, M. T., K. Yoshikawa, M. Kanevskiy, and Y. Shur. 2008b.
Permafrost characteristics of Alaska. Institute of Northern Engineering, University of Alaska Fairbanks, 1 Sheet, Scale 1: 7,200,000.

Jorgenson, M. T., Y. Shur, and T. E. Osterkamp. 2008c.
Thermokarst in Alaska. In the proceedings of Ninth International Conference on Permafrost, June 2008, Vol. 1: 869-876.

Lawler, J. P., S. D. Miller, D. M. Sanzone, J. Ver Hoef, and S. B. Young. 2009.
Arctic network vital signs monitoring plan. Natural Resource Report NPS/ARCN/NRR—2009/088. U.S. Department of the Interior, National Park Service, Natural Resource Program Center, Ft. Collins, CO.

MacCluskie, M., and K. Oakley. 2005.
Vital signs monitoring plan, Central Alaska Network. U.S. Department of the Interior, National Park Service, Fairbanks, AK.

Marchenko, S. S., V. E. Romanovsky, and G. Tipenko. 2008.
Numerical modeling of spatial permafrost dynamics in Alaska. In the Proceedings of Ninth International Conference on Permafrost, June 2008, Vol. 2: 1125–1130.

Panda, S. K., S. S. Marchenko, and V. E. Romanovsky. 2014a.
High-resolution permafrost modeling in Denali National Park and Preserve. Natural Resource Technical Report NPS/CAKN/NRTR—2014/858. National Park Service, Fort Collins, Colorado.

Panda, S. K., S. S. Marchenko, and V. E. Romanovsky. 2014b.
High-resolution permafrost modeling in Wrangell-St. Elias National Park and Preserve. Natural Resource Technical Report NPS/CAKN/NRTR—2014/861. National Park Service, Fort Collins, Colorado.

Panda, S. K., V. E. Romanovsky, and S. S. Marchenko. 2016.
High-resolution permafrost modeling in Arctic national parks of Alaska. Natural Resource Technical Report NPS/ARCN/NRTR—2016/xxx. National Park Service, Fort Collins, Colorado. (In preparation)

Scenarios Network for Alaska and Arctic Planning (SNAP). 2012.
Tools and Data, Data. Available at: http://www.snap.uaf.edu/data.php (accessed March 28, 2016).

Stevens, J. L., K. Boggs, A. Garibaldi, J. Grunblatt, and T. Helt. 2001.
Denali National Park and Preserve landcover mapping project Volume 1: Remote sensing data, procedures and results. Natural Resource Technical Report NPS/DENA/NRTR—2001/001. National Park Service, Fort Collins, CO.

Stumpf, K. 2007.
Wrangell-St. Elias National Park and Preserve landcover mapping project. Natural Resource Technical Report NPS/WRST/NRTR—2008/095. National Park Service, Fort Collins, CO.

Swanson, D. K. 2013.
Monitoring of Retrogressive Thaw Slumps in the Arctic Network, 2012. Natural Resource Data Series NPS/ARCN/NRDS—2013/591. Fort Collins, Colorado: National Park Service.

Swanson, D. K. 2014.
Mapping of Erosion Features Related to Thaw of Permafrost in the NPS Arctic Inventory and Monitoring Network, Alaska. Natural Resource Technical Report NPS/ARCN/NRTR—2014/912. Fort Collins (CO): National Park Service. https://irma.nps.gov/App/Reference/Profile/2216465.

Swanson, D.K. 2016.
Soil temperatures in Alaska's Arctic National Parks, 2011-2015, and implications for permafrost stability. Natural Resource Report NPS/ARCN/NRR—2016/1109. National Park Service, Fort Collins, Colorado.

Walsh, J. E., W. L. Chapma, V. E. Romanovsky, J. H. Christensen, and M. Stendel. 2008.
Global climate model performance over Alaska and Greenland. *America Meteorological Society* 21:6156–6174.

A large permafrost thaw slump on the Noatak River in the Noatak National Preserve. Thaw slumps such as this one are likely to become more common as permafrost thaw continues. ▶

NPS photo courtesy of Rory Nichols

Potential Effects of Permafrost Thaw on Arctic River Ecosystems

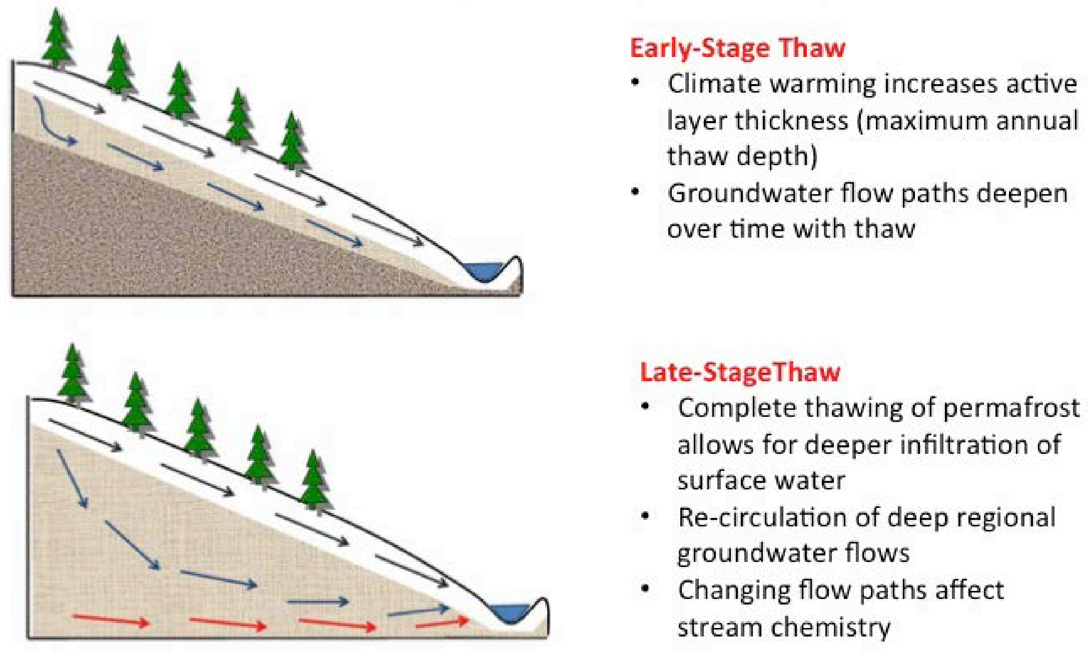
Jonathan A. O'Donnell, National Park Service and Christian E. Zimmerman, Michael P. Carey, and Joshua C. Koch, U.S. Geological Survey, Alaska Science Center

How will fish populations in Arctic streams respond to climate change and permafrost thaw?

While it is relatively easy to pose this question, detecting the effects of permafrost thaw on river ecosystems is complicated. Permafrost thaw in Arctic watersheds presents a complex problem requiring expertise in geophysics, hydrology, chemistry, and biology.

Physical Effects of Permafrost Thaw on Rivers

Permafrost is ground that remains frozen year-round, and occurs in cold climates at high latitudes and altitudes. Recent warming in the Arctic is driving widespread thawing of permafrost, which can have a profound impact on watershed hydrology (Figure 1). Thawing of ground ice may alter stream and river discharge (Walvoord and Kurylyk 2016) and the location and magnitude of stream inflows (Koch et al. 2013). Permafrost thaw in ice-rich terrain can cause the formation of thermokarst features, or depressions associated with melting of ground ice and subsidence of the ground surface. In many cases, thermokarst can lead to erosion of soils from terrestrial uplands followed by deposition into rivers and lakes. These effects of permafrost thaw can alter the physical structure of streams and rivers, which can improve or deteriorate habitat for fish and other aquatic organisms.



Early-Stage Thaw

- Climate warming increases active layer thickness (maximum annual thaw depth)
- Groundwater flow paths deepen over time with thaw

Late-StageThaw

- Complete thawing of permafrost allows for deeper infiltration of surface water
- Re-circulation of deep regional groundwater flows
- Changing flow paths affect stream chemistry

Figure 1. Conceptual diagram of watershed hydrology during early and late stages of permafrost thaw.

◀ Agashashok watershed, Noatak National Preserve.
NPS photo courtesy of Ken Hill

Effects of Permafrost Thaw on Water Quality

Permafrost thaw also plays an important role in water quality in rivers and lakes. Soils in the northern permafrost region store large amounts of organic carbon – nearly twice the amount currently stored in the atmosphere (Hugelius et al. 2014). Much of this carbon has been locked away for thousands of years in the permafrost, which essentially functions like a freezer for carbon. When permafrost thaws, a fraction of this old carbon can be released to the atmosphere as carbon dioxide or methane gas, accelerating climate warming. A smaller fraction of this thawed, old carbon can also be released to aquatic ecosystems as dissolved or particulate organic matter (O'Donnell et al. 2014), affecting water clarity, acidity, and trace metal transport (such as mercury) to streams. Permafrost soils also store large amounts of nitrogen (Harden et al. 2012) and other nutrients. Following thaw, this nitrogen can act to "fertilize" ecosystems, creating bigger, greener plants and more algae in streams.

Effects of Permafrost Thaw on Freshwater Fish

Changing hydrology and stream chemistry associated with permafrost thaw will likely impact fish in Arctic rivers. While climate change may directly affect fish by increasing stream temperature, permafrost thaw will likely affect fish indirectly by altering different components of the stream food web. For instance, the slow release of nutrients from thawing permafrost can increase algal growth on sediments, influence stream invertebrate (e.g., insect larvae) composition and productivity, and fish size (Slavik et al. 2004). Thermokarst (irregular topography resulting from ground ice melting) can also increase the amount of solids transported in stream flow, which can negatively impact stream invertebrates (Chin et al. 2016), an important food source for many fish. Despite these and other recent advances in our understanding of thaw effects on aquatic ecosystems (Vonk et al. 2015), gaps remain in our understanding of the potential effects of permafrost thaw on fish habitat, behavior, and productivity.

Figure 2. Dolly Varden sampled in the Agashashok Watershed, August 2015.
NPS photo courtesy of Jonathan O'Donnell

The Hydro-Ecology of Arctic Thaw (HEAT) Project

In the summer of 2015, we began a five-year project aimed at understanding the effects of permafrost thaw on aquatic ecosystems and fish that we call the HEAT (Hydro-Ecology of Arctic Thaw) project. This project is a collaboration between the NPS Arctic Inventory and Monitoring Network and U.S. Geological Survey (USGS) Changing Arctic Ecosystems Initiative, an effort to better understand biotic response to a warming climate (Van Hemert et al. 2015). An important goal of the HEAT project is to document linkages among hydrology, water chemistry, and fish ecology in a landscape undergoing dramatic change.

We established study sites in the Agashashok River basin, a large tributary of the Noatak River in northwest Alaska. The Agashashok River is situated in the Arctic-boreal transition zone, a region undergoing rapid landscape change associated with a warming climate and thawing permafrost (Panda et al. 2017). We sampled 12 small headwater streams, where terrestrial ecosystems most strongly influence aquatic ecosystems. These streams drain watersheds that vary according to permafrost characteristics (ground ice, soil temperature) and vegetation (boreal forest or tundra).

We collected a broad range of samples and measurements in the field to understand hydrology, water quality, and food-web dynamics across this changing landscape. We collected water samples from all streams and analyzed for carbon, nutrient, and other mineral solute concentrations. We measured stream discharge across the hydrograph to quantify the magnitude and seasonality of stream flow. We scraped algae off rocks on streambeds to measure chlorophyll content of primary producers. We also collected stream invertebrates from sediments to quantify the abundance and diversity of invertebrates in our study streams. We sampled Arctic Grayling (*Thymallus arcticus*) and Dolly Varden (*Salvelinus malma*; Figure 2) throughout the drainage, although their abundance and distribution varied across study streams. We are also using stable isotopes and radiocarbon isotopes to understand food-web dynamics in these streams. Radiocarbon measurements can be used to detect the incorporation of old carbon released from thawing permafrost into the aquatic food web.

We will integrate these field observations with hydrologic and a fish energetics models to better understand possible changes in the abundance and distribution of Arctic fish under future climatic conditions. Forecasting in this way will help researchers to assess the vulnerability of aquatic resources under future warming scenarios, and findings may be used to guide watershed management decisions.

Acknowledgements

This work was part of the USGS Changing Arctic Ecosystem Initiative and was supported by the Wildlife Program of the USGS Ecosystems Mission Area. Additional support was provided by the NPS Arctic Inventory and Monitoring Network, and by the Terrestrial Ecosystem Observing Network of the U.S. Fish and Wildlife Service Arctic Land Conservation Cooperative. We thank John Pearce and Grant Hilderbrand for comments that improved this manuscript.

REFERENCES

Chin, K. S., J. Lento, J. M. Culp, D. Lacelle, and S. V. Kokelj. 2016.
Permafrost thaw and intense thermokarst activity decreases abundance of stream benthic macroinvertebrates. *Global Change Biology*, doi:10.1111/gcb.13225.

Harden, J. W., C. D. Koven, C. L. Ping, G. Hugelius, A. D. McGuire, P. Camill, T. Jorgenson, P. Kuhry, G. J. Michaelson, J. A. O'Donnell, E. A. G. Schuur, C. Tarnocai, K. Johnson, and G. Grosse. 2012.
Field information links permafrost carbon to physical vulnerabilities of thawing. *Geophysical Research Letters* 39, doi:10.1029/2012GL051958.

Hugelius, G., J. Strauss, S. Zubrzycki, J. W. Harden, E. A. G. Schuur, C. L. Ping, L. Schirrmeister, G. Grosse, G. J. Michaelson, C. Koven, J. A. O'Donnell, B. Elberling, U. Mishra, P. Camill, Z. Yu, J. Palmtag, and P. Kuhry. 2014.
Estimated stocks of circumpolar permafrost carbon with quantified uncertainty ranges and identified data gaps. *Biogeosciences* 11:6573-6593, doi:10.5194/bg-11-6573-2014.

Koch, J. C., S. A. Ewing, R. Striegl, and D. M. McKnight. 2013.
Rapid runoff via shallow throughflow and deeper preferential flow in a boreal catchment underlain by frozen silt (Alaska, USA). *Hydrogeology Journal* 21(1):93-106.

O'Donnell, J. A., G. R. Aiken, M. A. Walvoord, P. A. Raymond, K. D. Butler, M. M. Dornblaser, and K. Heckman. 2014.
Using dissolved organic matter composition and age to detect permafrost thaw in boreal streams of interior Alaska. *Journal of Geophysical Research – Biogeochemistry* 119, doi:10.1002/2014JG002695.

Panda, S. K., V. E. Romanovsky, S. S. Marchenko, and D. K. Swanson. 2017.
The fate of permafrost. *Alaska Park Science* 16(1):39-45.

Slavik, K., B. J. Peterson, L. A. Deegan, W. B. Bowden, A. E. Hershey, and J. E. Hobbie. 2004.
Long-term responses of the Kuparuk River ecosystem to phosphorus fertilization. *Ecology* 85:939-954.

Van Hemert, C. R., P. L. Flint, M. S. Udevitz, J. C. Koch, T. C. Atwood, K. L. Oakley, and J. M. Pearce. 2015.
Forecasting wildlife response to rapid warming in the Alaskan Arctic. *BioScience* 65:718-728, doi:10.1093/biosci/biv069

Vonk, J. E., S. E. Tank, W. B. Bowden, I. Laurion, W. F. Vincent, P. Alekseychik, M. Amyot, M. F. Billet, J. Canario, R. M. Cory, B. N. Deshpande, M. Helbig, M. Jammet, J. Karlsson, J. Larouche, G. MacMillan, M. Rautio, K. M. Walter Anthony, and K. P. Wickland. 2015.
Review and synthesis: effects of permafrost thaw on Arctic aquatic ecosystems. *Biogeosciences* 12:7129-7167, doi:10.5194/bg-12-7129-2015.

Walvoord, M. A., and B. L. Kurylyk. 2016.
Hydrologic impacts of thawing permafrost – A review. *Vadose Zone Journal* 15, doi:10.2136/vzj2016.01.0010.

Perennial Snowfields of the Central Brooks Range: Valuable Park Resources

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Thousands of years ago, snow and ice in the central Brooks Range of Arctic Alaska might have looked very different than it does today. Glaciers and perennial snowfields (also known as snow patches or ice patches) in what is now Gates of the Arctic National Park and Preserve (Figure 1) were probably much more extensive then than they are now. Perennial snowfields, like glaciers, are masses of snow and ice that persist for many years and form through the accumulation and compaction of snow. However, unlike glaciers, snowfields never grow thick enough to flow with gravity. In modern times, as in the past, caribou herds move to these snowfields in the summer to stay cool and avoid insects (Anderson and Nilssen 1998). Perennial snowfields are also important ecosystems for an array of different bird species (Rosvold 2016). They influence water availability for down-slope vegetation (Lewkowicz and Young 1990) and alter geology (Berrisford 1991) and permafrost (Luetschg et al. 2004).

Perennial snowfields are an important component of Arctic parks in Alaska, but with pronounced warming (Johannessen et al. 2004, Hinzman et al. 2005), the Arctic is shifting rapidly, and these snowfields are retreating. Snowfields are relatively small and sensitive to climate change (Figure 2), and reductions in year-round ice extent have been evident in the Brooks Range during the late 20th century (Evison et al. 1996). Their loss also has the potential to reveal well-preserved archaeological artifacts or ancient animal remains with significant cultural value. Such discoveries have been made in the last decade in snowfields in the southern Yukon (Alix et al. 2012, Hare et al. 2012) and Northwest Territories (Meulendyk et al. 2012) of Canada, and in Wrangell-St. Elias National Park and Preserve (Dixon et al. 2005). Archaeologists think that ancient caribou herds used snowfields in a manner similar to modern herds for insect relief, where ancient hunters tracked them, and sometimes left behind weapons and other tools that became frozen in ice.

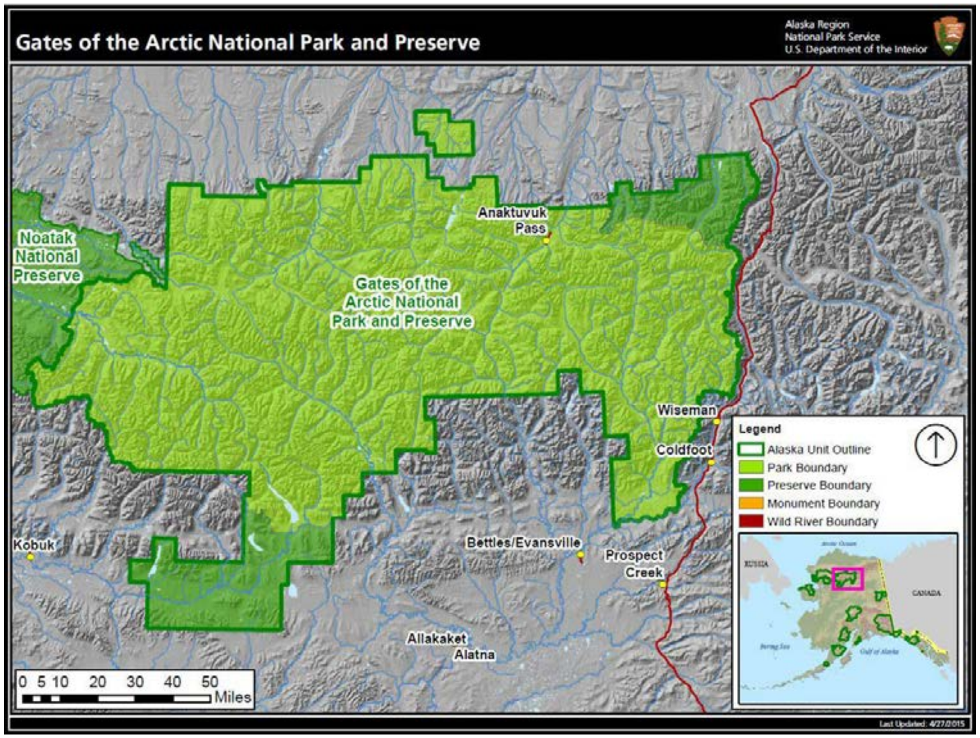

Figure 1. Gates of the Arctic National Park and Preserve. (Map courtesy of NPS Alaska Region GIS Program)

◀ **Figure 2.** Small perennial snowfield in the central Brooks Range, Alaska shows signs of retreat.
Photo courtesy of Rick Swisher

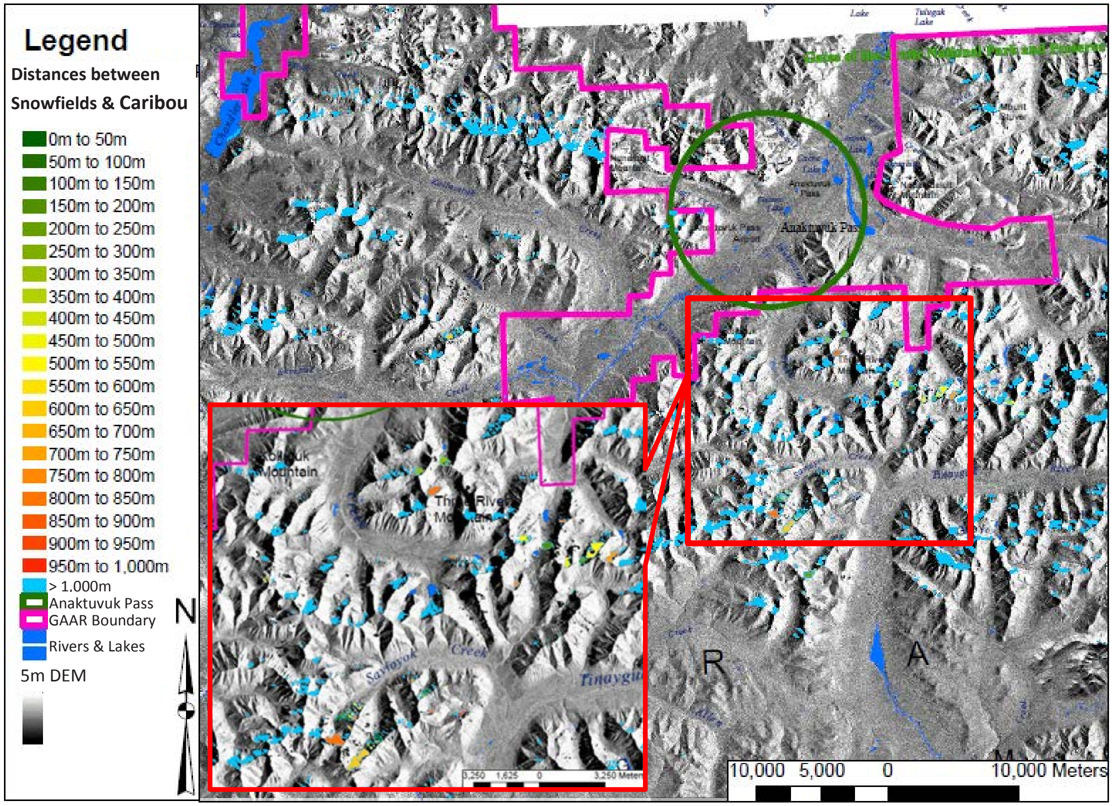

Figure 3. Perennial snowfield extent map derived from Landsat imagery-based data, classified by proximities to caribou movements.

Figure 4. A helicopter assisted field survey of perennial snowfields in July of 2015 provided a much-needed opportunity to field validate the model.
Photo courtesy of Molly Tedesche

In the summer of 2015, we initiated a project to study the extent of changes to perennial snowfields in order to target archaeological field surveys. NPS researchers began by creating an extent model to map and classify individual snowfields by proximity to caribou, as a proxy for ancient herds (Figure 3). This was done by combining caribou movement data from the Western Arctic Caribou Herd with a map of snow persistence based on Landsat satellite imagery for Northwest Alaska (Macander et al. 2015). Snowfields in close proximity to places frequented by caribou were then prioritized for field survey based on factors contributing to possible ease of access by ancient hunters, such as gentle slope angles of snowfields and the surrounding terrain.

Ground-based and aerial surveys were then conducted to look for artifacts and investigate locations and extents of the snowfields (Figure 4). Seventeen snowfields and three glaciers were surveyed for geometry on foot using a GPS with high spatial resolution. Each site was characterized using snow test pits, ice auger bore holes, snow crystal structure and layering, and melt-water chemistry parameters. We surveyed 160 snowfields by helicopter, and conducted visual evaluations for archaeological potential, and location agreement with the extent model. We collected hydrological and biological samples, including water samples, bird remains, and caribou bones and dung. Results of the fieldwork indicate agreement between modeled and surveyed locations of snowfields.

During the 2015 study, no archaeological artifacts were discovered; however, we identified well-preserved animal remains (including soft tissue, skin and feathers) dating to up to 200 years ago. These materials can help reconstruct a record of ecological and biological change that provides context for understanding recently observed changes in the environment. Snow test pits and ice auger bore holes indicated that several of the perennial snowfields surveyed were between 0.74 and 2.23 meters deep, while several others were much deeper than the ice auger could bore or test pits could reasonably be dug. Chemistry indicated that the melt-water pH was neutral to quite acidic. These results establish a baseline for future perennial snowfield monitoring.

The nature of change in perennial snowfields in the central Brooks Range is one of rapid decline, and these changes are of increased significance to the high alpine hydrology and ecology of Gates of the Arctic. Ongoing work will build on the 2015 findings to quantify past perennial snowfield extent and create a snowfield taxonomy that categorizes snowfields with similar physical, topographic, and microclimatic characteristics to predict projected rates of change. Results of this research will help archaeologists continue to target field survey areas, as well as address the impacts that these changes are having on park resources, such as hydrology, vegetation, and wildlife.

Acknowledgements

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REFERENCES

Alix, C., P. G. Hare, T. D. Andrews, and G. MacKay. 2012.
A thousand years of lost hunting arrows: Wood analysis of ice patch remains in northwestern Canada. *Arctic* 95-117.

Anderson, J. R. and A. C. Nilssen. 1998.
Do reindeer aggregate on snow patches to reduce harassment by parasitic flies or to thermoregulate? *Rangifer* 18(1):3-17.

Berrisford, M. S. 1991.
Evidence for enhanced mechanical weathering associated with seasonally late-lying and perennial snow patches, Jotunheimen, Norway. *Permafrost and Periglacial Processes* 2:331-340.

Dixon, E. J., W. F. Manley, and C. M. Lee. 2005.
The emerging archaeology of glaciers and ice patches: Examples from Alaska's Wrangell-St. Elias National Park and Preserve. *American Antiquity* 129-143.

Evison, L. H., P. E. Calkin, and J. M. Ellis. 1996.
Late-Holocene glaciation and twentieth-century retreat, northeastern Brooks Range, Alaska. *The Holocene* 6(1):17-24.

Hare, P. G., C. D. Thomas, T. N. Topper, and R. M. Gotthardt. 2012.
The archaeology of Yukon ice patches: New artifacts, observations, and insights. *Arctic* 118-135.

Hinzman, L. D., N. D. Bettez, W. R. Bolton, F. S. Chapin, M. B. Dyurgerov, C. L. Fastie, and K. Yoshikawa. 2005.
Evidence and implications of recent climate change in northern Alaska and other arctic regions. *Climatic Change* 72(3):251-298.

Johannessen, O. M., L. Bengtsson, M. W. Miles, S. I. Kuzmina, V. A. Semenov, G. V. Alekseev, and H. P. Cattle. 2004.
Arctic climate change: Observed and modelled temperature and sea-ice variability. *Tellus A* 56(4):328-341.

Lewkowicz, A. G. and K. L. Young. 1990.
Hydrology of a perennial snowbank in the continuous permafrost zone, Melville Island, Canada. *GeografiskaAnnaler. Series A. Physical Geography* 13-21.

Luetschg, M., V. Stoeckli, M. Lehning, W. Haeberli, and W. Ammann. 2004.
Temperatures in two boreholes at Flüela Pass, Eastern Swiss Alps: the effect of snow redistribution on permafrost distribution patterns in high mountain areas. *Permafrost Periglac. Processes* 15:283-297.

Macander, M. J., C. S. Swingley, K. Joly, and M. K. Raynolds. 2015.
Landsat-based snow persistence map for northwest Alaska. *Remote Sensing of Environment* 163:23-31.

Meulendyk, T., B. J. Moorman, T. D. Andrews, and G. MacKay. 2012.
Morphology and development of ice patches in Northwest Territories, Canada. *Arctic* 43-58.

Rosvold, J. 2016.
Perennial ice and snow-covered land as important ecosystems for birds and mammals. *Journal of Biogeography* 43(1):3-12.

Caribou: Nomads of the North

Kyle Joly, National Park Service

Caribou (*Rangifer tarandus*) are an iconic Arctic species. With a circumpolar distribution ranging from the temperate rain forest to polar deserts, the species is highly adaptable both physiologically and behaviorally. Yet, caribou populations face many challenges, such as climate change and industrial development, and are in decline in many portions of their range.

Numbering nearly 500,000 caribou in 2003, the Western Arctic Herd (WAH) was the largest herd in Alaska and one of the largest on the planet. By 2016, the herd had declined to 201,000 (ADFG 2016). Habitat, climate, predation, human influences, population density-dependent factors, insects, parasites, diseases, competition with other species, and other factors can influence caribou populations (Joly and Klein 2011). It remains unclear which of these drivers is most important in the decade-long decline of the WAH; particularly difficult winters may have contributed. Population crashes and irruptions in the WAH have been linked to a long-lasting, large-scale climate cycle known as the Pacific Decadal Oscillation (PDO; Joly et al. 2011). Declines are associated with the "negative" phase of the PDO (colder years), while increase with the "positive" phase (warmer years; Figure 1).

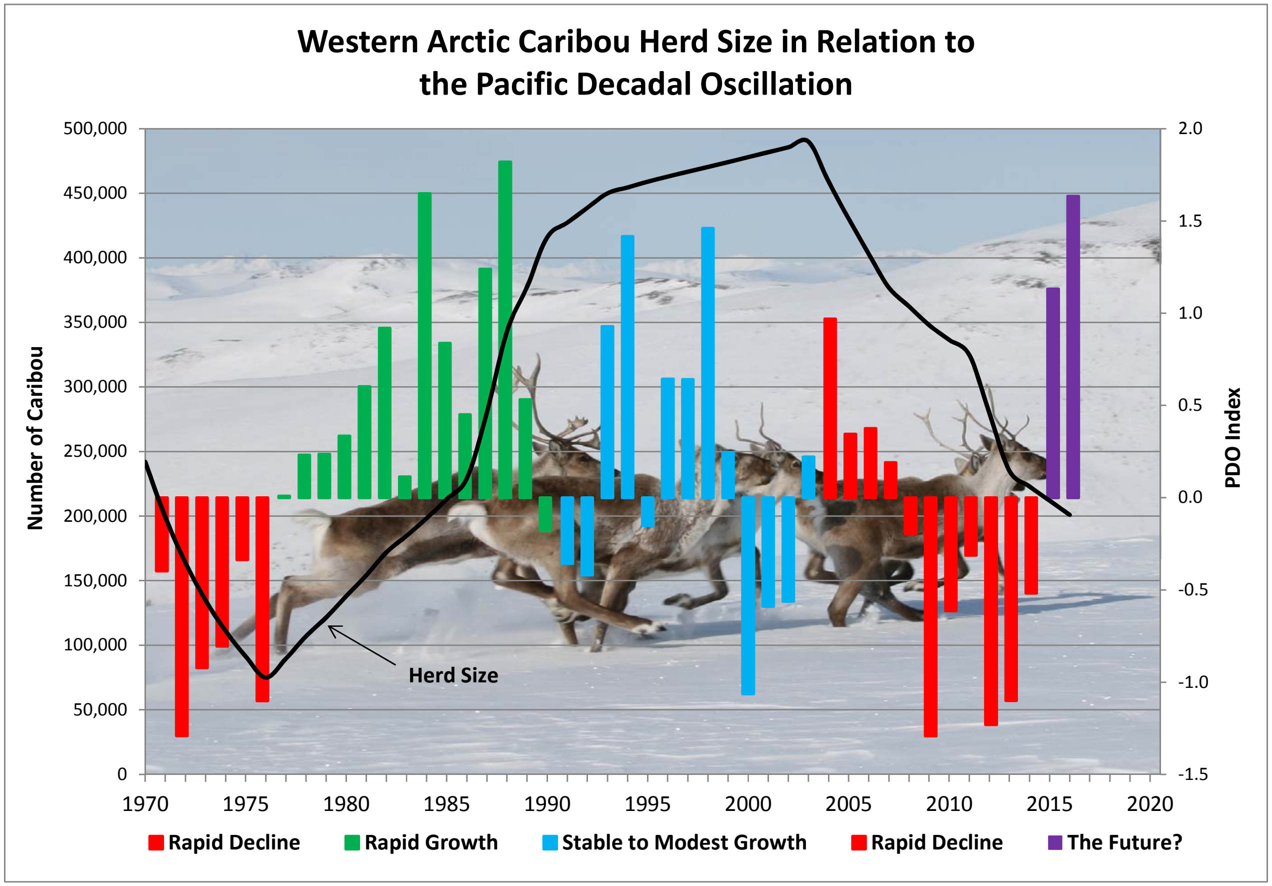


Figure 1. Population size (from Alaska Department of Fish and Game) of the Western Arctic Herd (black line) for 1970-2013 and the strength of the Pacific Decadal Oscillation (PDO, colored bars). Large declines in the herd have coincided with negative ("cold") phases of the PDO and rapid growth with the positive ("warm") phase.

Caribou are known to have the longest terrestrial migrations on the planet. WAH caribou are no exception, with individuals traveling up to 2,737 miles (4,404 km) per year

◀ Caribou, such as these two bulls in Kobuk Valley National Park, are excellent swimmers.
NPS photo courtesy of Kyle Joly

(Joly and Cameron 2015). As the herd has declined, its home range (roughly the size of Montana) has also shrunk. This phenomenon has been documented in other herds as well (e.g., Messier et al. 1988). Despite having a smaller home range, travel by individual caribou increased during the population decline (Joly and Cameron 2015). One possible explanation is that the quality of the herd's range has declined.

Harvest of WAH caribou is dominated (>90%) by subsistence hunters that live within the range of the herd. Hunting likely had limited impact on the herd when it numbered 500,000 caribou, however, as the herd continues to decline, its influence has increased. High numbers of harvested cows could accelerate the herd's decline. Cautious management of the harvest is essential until the trajectory of the herd reverses.

The WAH faces an uncertain future. Will the decade-long decline continue, causing hardship across this vast and wild region? Is the strong positive PDO of the past couple of years (Figure 1) a harbinger of herd recovery? Caribou populations are known to naturally oscillate at the decadal scale (Gunn 2003, Joly et al. 2011), however, climate change and rapid industrial development may hinder the natural recovery of the WAH and other herds around the Arctic.

While tolerant of an extreme range of temperature, climate change could negatively impact caribou in myriad of ways. Warmer temperatures could lead to more wildfires, reducing the abundance of lichens, the primary winter forage of caribou (Joly et al. 2012). Warmer temperatures combined with early successional habitats promoted by increased fire may also allow for more shrubs and moose (*Alces alces*), and thus predators such as wolves (*Canis lupus*), which could affect caribou populations (Joly et al. 2012). These conditions may also enhance insect populations that torment caribou during the short Arctic summer. Not all

Caribou often form large aggregations in July, seen here in Noatak National Preserve, in response to intense insect harassment.
NPS photo courtesy of Kyle Joly

impacts of climate change may be detrimental to caribou. Warming temperatures could lengthen the growing season in the Arctic and increase the abundance of summer forage.

Industrial development continues to expand across the Arctic and the pace of that development is predicted to increase as warming renders the region more accessible. Currently, the only major development in the range of the WAH is the Red Dog Mine, which includes the mine itself, a port and related facilities, and an industrial road connecting the two. Initial anecdotal evidence suggested that the impacts of the operation were limited; however, more contemporary, quantitative studies have revealed otherwise. Dust trailing behind ore-hauling trucks is carried by the wind, affecting habitat for miles, including into Noatak National Preserve (Hasselbach et al. 2004). Disturbance associated with the road has also been implicated in altering the migratory patterns of the WAH. Substantial numbers of WAH caribou can be delayed for more than a month on their fall migration south when they encounter this lone, well-controlled road (Wilson et al. 2016). These effects need to be considered as agencies analyze a proposal by the State of Alaska to construct a 200-mile-long road through Gates of the Arctic National Park and Preserve from the existing contiguous road system into northwest Alaska, one of the world's largest remaining roadless areas, to mine prospects in the Ambler region. Long-distance migrations are imperiled globally, therefore protecting the migratory corridors for the WAH is critical. What does the future hold for the WAH? As the millennia-old Inuit saying goes...

"No one knows the way of the wind and the caribou"

REFERENCES

Alaska Department of Fish and Game (ADFG). September 2016.
Alaska Fish and Wildlife News: Western Arctic Caribou Herd Update. Available at: http://www.adfg.alaska.gov/index.cfm?adfg=wildlifenews.view_article&articles_id=794 (accessed November 18, 2016)

Gunn, A. 2003.
Voles, lemmings and caribou – population cycles revisited? *Rangifer Special Issue* 14:105-111.

Hasselbach, L., J. M. Ver Hoef, J. Ford, P. Neitlich, E. Crecelius, S. Berryman, B. Wolk, and T. Bohle. 2004.
Spatial patterns of cadmium and lead deposition on and adjacent to National Park Service lands near Red Dog Mine, Alaska: NPS Final Report. National Park Service Technical Report NRTR-2004-45. 59 pp.

Joly, K. and M. D. Cameron. 2015.
Caribou vital sign annual report for the Arctic Network Inventory and Monitoring Program: September 2014-August 2015. Natural Resource Report NPS/ARCN/NRR—2015/1090. National Park Service, Fort Collins, Colorado. 25 pp.

Joly, K., P. A. Duffy, and T. S. Rupp. 2012.
Simulating the effects of climate change on fire regimes in Arctic biomes: implications for caribou and moose habitat. *Ecosphere* 3(5):1-18. Article 36.

Joly, K. and D. R. Klein. 2011.
Complexity of caribou population dynamics in a changing climate. *Alaska Park Science* 10(1):26-31.

Joly, K., D. R. Klein, D. L. Verbyla, T. S. Rupp and F. S. Chapin III. 2011.
Linkages between large-scale climate patterns and the dynamics of Alaska caribou populations. *Ecography* 34(2):345-352.

Messier, F., J. Huot, D. le Henaff, and S. Luttich. 1988.
Demography of the George River Caribou Herd: Evidence of Population Regulation by Forage Exploitation and Range Expansion. *Arctic* 41:279-287.

Wilson, R. R., L. S. Parrett, K. Joly, and J. R. Dau. 2016.
Effects of roads on individual caribou movements during migration. *Biological Conservation* 195:2-8.

Lichens of the Arctic

James Walton, National Park Service

Lichens are a conspicuous and colorful component of Alaska's vegetation and one of the most species-rich groups of organisms to inhabit the Arctic. A lichen is a composite organism consisting of a fungus and an alga and/or cyanobacteria growing together in a symbiotic partnership. Together they are intimately connected to their environment. Lichens are highly sensitive to environmental conditions including airborne contaminants, substrate chemistry, and climate and are good indicators of environmental change. They can be found in all types of ecosystems, from intertidal zones to the tops of mountains—even on nunataks (the exposed rock outcrops of icefields). They grow on soil, rock, bark, wood, barnacles, and buildings. Lichens are ecologically important as food, shelter, and nesting material for wildlife; and play important roles in hydrological and mineral cycles, notably nitrogen fixation.

Recent inventories conducted in Arctic Alaska parks have revealed high lichen diversity. Across the Western Arctic Parklands, over 500 lichen species have been discovered, including at least 16 that are newly described in Alaska or North America and three that are newly described to science (Holt and Neitlich 2010, Nelson et al. 2015). Many of these species are circumpolar and also distributed outside the Arctic, though the majority are confined to arctic-alpine habitats.

Lichen species are an important component of the many biological communities across Arctic Alaska. Recently, patterns in Arctic lichen community composition have received attention in response to expanding shrub communities and increasing fire frequency and extent, both of which are linked to declines in lichen abundance. Because lichens are often a major component of forage consumed by caribou, the consequences of lichen habitat decline could be substantial for the ecosystem and local subsistence communities (Joly et al. 2010).

Because certain lichen species are both abundant and sensitive to changes in the environment, they can serve as useful indicators for detecting long-term trends in the larger ecological community, including the effects of changing air quality. Lichens lack roots and largely rely upon the atmosphere for their water and nutrients. Because they do not have an outer epidermal layer, they cannot discriminate between nutrients and pollutants, and absorb both. When exposed to even low levels of certain pollutants, particularly sensitive species will decline or die, making lichen community composition a good indicator of ecosystem health. In park units such as Cape Krusenstern

The boreal pixie-cup lichen (*Cladonia borealis*) can be found on soil and rock in arctic and alpine regions.

NPS photos courtesy of Nina Chambers

The arctic finger lichen (*Dactylina arctica*) can usually be found in mossy tundra, often in late snowmelt areas.

◀ The common freckle pelt lichen (*Peltigera aphthosa*) is often found over mossy ground, rocks, or under trees.
NPS photo courtesy of James Walton

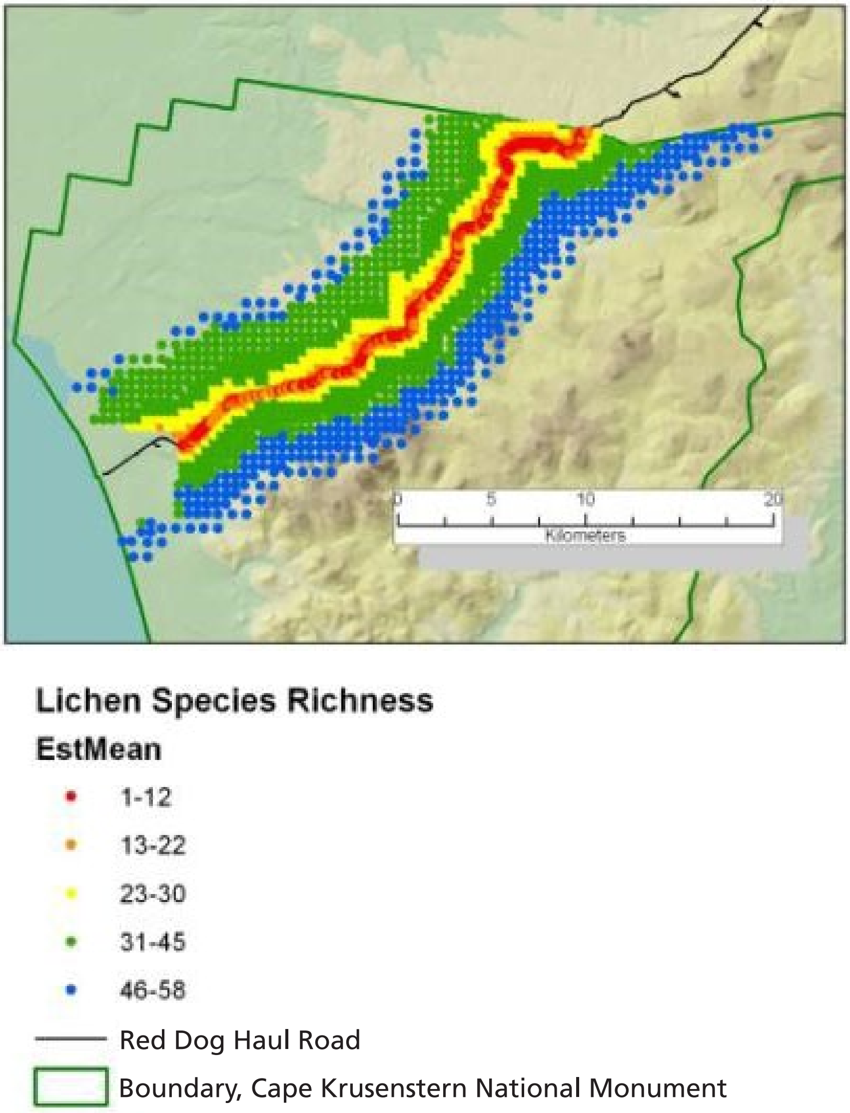


Figure 1. Lichen species richness increases along the Red Dog Haul Road with increasing distance from the road (red to blue in order of increasing richness).

National Monument, lichen communities are being used to monitor mine-related and fugitive dust-borne heavy metals along the Red Dog Mine Haul Road. Recent findings confirm that lichen species richness decreases the closer they are to the Haul Road (Figure 1; Neitlich et al. 2017).

You can learn more about lichens and other non-vascular plants in Alaska's national parks by reading the recent article: *Moving beyond the Minimum: The addition of nonvascular plant inventories to vegetation research in Alaska's national parks* (http://nature.nps.gov/parkscience/index.cfm?ArticleID=673).

REFERENCES

Holt, E. A. and P. N. Neitlich. 2010.
Arctic Network Lichen Inventory Dataset. Geospatial Dataset—2166259. Available at: http://irma.nps.gov/App/Reference/Profile/2166259.

Joly, K., F. S. Chapin III, and D. R. Klein. 2010.
Winter habitat selection by caribou in relation to lichen abundance, wildfires, grazing, and landscape characteristics in northwest Alaska. *Ecoscience* 17(3):321–333.

Neitlich, P. N., J. Ver Hoef, S. B. Berryman, A. Mines, and L. Geiser. 2017.
Effects of heavy metal–enriched road dust from the Red Dog Mine haul road on tundra vegetation in Cape Krusenstern National Monument, Alaska. NPS Natural Resource Technical Report. In preparation.

Nelson, P. R., B. McCune, and D. K. Swanson. 2015.
Lichen traits and species as indicators of vegetation and environment. *The Bryologist* 118(3):252-263.

Quill cladonia (*Cladonia amaurocraea*).

Two species of reindeer lichen: *Cladonia arbuscula* (above) and *Cladonia mitis* (below).

Curled snow lichen (*Flavocetraria cucullata*).

Thorn cladonia (*Cladonia uncialis*).

These species are common and widespread across the Arctic and are important winter food sources for caribou.

Crinkled snow lichen (*Flavocetraria nivalis*).

All photos courtesy of James Walton, NPS

Muskox: An Iconic Arctic Species, Then and Now

Hillary Robison, National Park Service

With their helmet-like, sharply upturned horns and stocky long-haired bodies, muskoxen (*Ovibos moschatus*) conjure up in one's mind images of a prehistoric world. Muskoxen are an iconic species in northwest Alaska whose closest relatives are the gorals (*Naemorhedus* spp.) and serows (*Capricornis* spp.) of Asia (Yang et al. 2013). Once common in Alaska, muskoxen were heavily hunted and extirpated by the mid- to late-1800s (Lent 1988, Allen 1912).

Muskox were reintroduced to Alaska in 1935; 34 animals were captured in eastern Greenland and translocated to Nunivak Island (Gunn and Forchhammer 2008, ADFG 2016) where they thrived. In 1970 and 1981, 36 and 35 muskoxen, respectively, were introduced into the Seward Peninsula from Nunivak Island. Additionally, between 1970 and 1977, 70 muskoxen were reintroduced from Nunivak Island to Cape Thompson (Gunn and Forchhammer 2008, ADFG 2016). As a result of these reintroductions, muskoxen populations now occur on the Seward Peninsula, including Bering Land Bridge National Preserve, and in Noatak National Preserve and Cape Krusenstern National Monument.

The National Park Service (NPS) and Alaska Department of Fish and Game (ADFG) collaborate on muskox population estimation and composition surveys of these populations of muskoxen. To do a population survey, pilots fly planes in long straight lines (transect lines) with biologists who observe and count muskoxen. Composition surveys use a helicopter to land biologists close enough to observe muskox groups without disturbing them. Biologists then determine the number of males, females, and yearlings in a group.

On the Seward Peninsula, surveys have been conducted regularly on population abundance (between 1983 and 2015) and composition (between 2002 and 2015; Schmidt and Gorn 2013). The population increased from the time of introduction until it plateaued in 2010 and then decreased at a rate of 14% per year through 2012 (Schmidt and Gorn 2013). One hypothesis for the decline is that the harvest of mature males from the population may have changed the defensive behavior of groups, thereby leaving them more vulnerable to predation (Schmidt and Gorn 2013).

In response to changes in hunting regulations and harvest rates of <2%, the most recent data show that between 2012 and 2015 the population across the Seward Peninsula appeared to stabilize (Gorn 2015). The number of animals within Bering Land Bridge and adjacent areas, however, declined during the same time period. This localized decline poses population management challenges. The 2015 population-level survey found the recruitment rate (the number of young animals born into the population that survive to an age between 1-2 years old) to be low (8% of the population; Gorn 2015). Muskoxen are now found in suitable habitat throughout the Seward Peninsula, however, they appear to be emigrating to areas outside of Bering Land Bridge and expanding their range into the Nulato Hills.

Since 1988, population and composition surveys have been conducted at regular intervals on the Cape Thompson muskoxen population in what is called the "core area" in and adjacent to Cape Krusenstern. The core area comprises an area within 30 km of the shore from the mouth of the Noatak River northwest to Cape Lisburne (Figure 1). Since 2004, the Cape Thompson population has declined in the core area or is shifting eastward into what has been called the "expanded area" in Noatak National Preserve (Schmidt and Westing 2011).

In 2011, the suspected shift in the Cape Thompson muskoxen population distribution prompted the NPS and ADFG to survey and generate a population estimate for the core and expanded areas. The results showed that at least half of the Cape Thompson population resided in the expanded area.

◀ Conducting muskox population surveys in Cape Krusenstern National Monument.
NPS photo courtesy of Hillary Robison

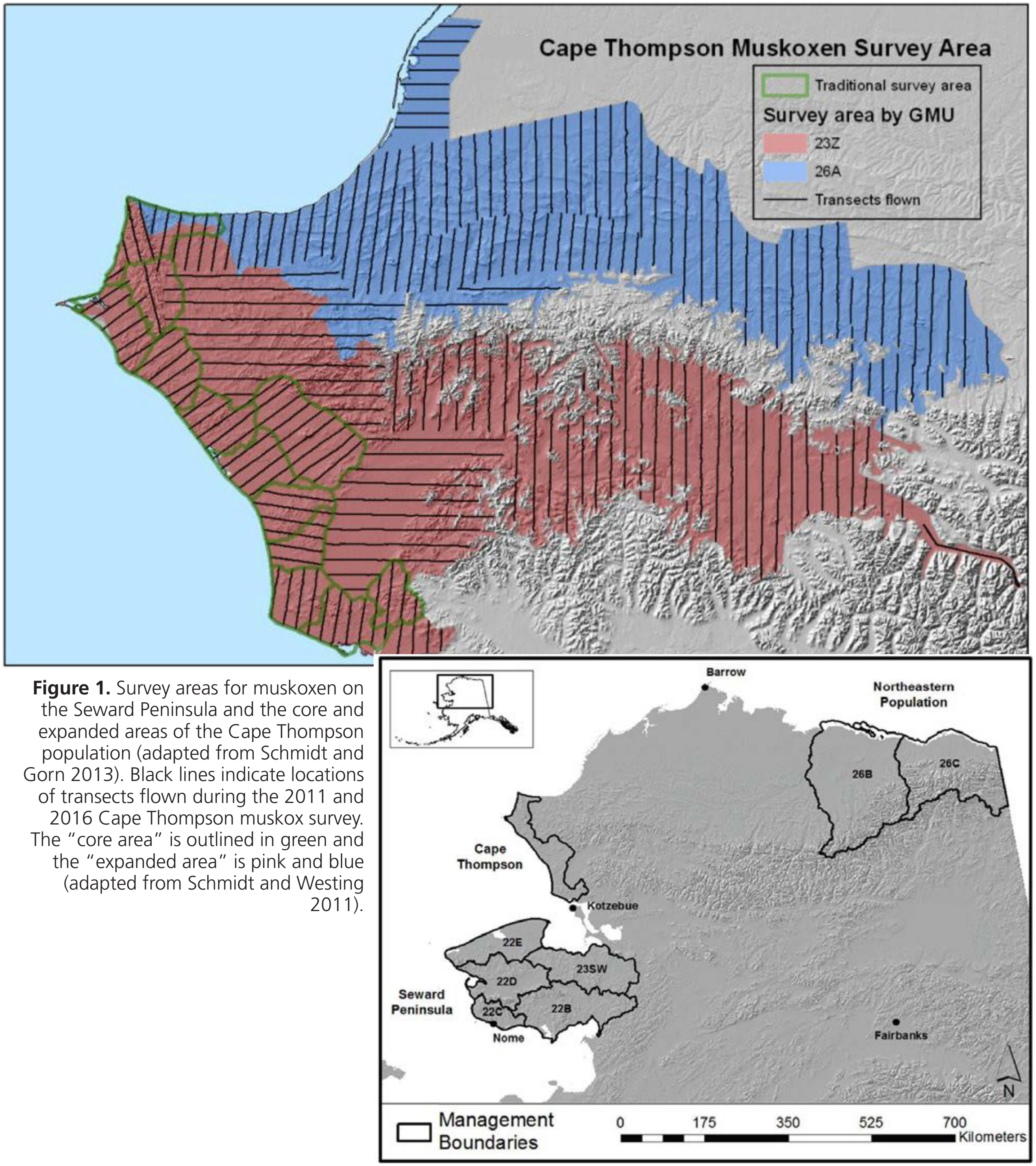


Figure 1. Survey areas for muskoxen on the Seward Peninsula and the core and expanded areas of the Cape Thompson population (adapted from Schmidt and Gorn 2013). Black lines indicate locations of transects flown during the 2011 and 2016 Cape Thompson muskox survey. The "core area" is outlined in green and the "expanded area" is pink and blue (adapted from Schmidt and Westing 2011).

There has been increased interest to expand subsistence hunting opportunity in the Cape Thompson population. Also, recent concern about the overharvest of adult bulls and subsequent declines in muskoxen populations (Schmidt and Gorn 2013) has led to the need for more frequent and precise estimates of abundance and sex and age composition of the population.

To this end, the expanded survey was repeated in March 2016. Comparison of the 2011 and 2016 estimates for the whole population residing in the core and expanded areas indicated that the number of animals did not change over the five-year interval between surveys (Schmidt et al. 2016). From 1988 to present, it appears the population residing in the core area declined from a high of about 370 animals in 2005 to around 220-230 animals in 2011 and has stabilized at that level. The proportion of adult males to females within the core population decreased between 2011 and 2016, which gives managers pause for thought on managing muskoxen harvest in this area. Muskoxen are now found in suitable habitat in areas within and adjacent to Cape Krusenstern, Noatak, and north of the Brooks Range.

REFERENCES

Alaska Department of Fish and Game (ADFG). 2016.
Muskox (*Ovibos moschatus*) species profile. Available at: http://www.adfg.alaska.gov/index.cfm?adfg=muskox.main (accessed March 4, 2016)

Allen, J. A. 1912.
The probable recent extinction of the muskox in Alaska. *Science* 36:720-722.

Gorn, T. S. 2015.
Alaska Department of Fish and Game Division of Wildlife Conservation memorandum: 2015 muskox survey results. May 6, 2015. Alaska Department of Fish and Game Division of Wildlife Conservation, Northwest, Nome, Alaska.

Gunn, A. and M. Forchhammer. 2008.
Ovibos moschatus. Available at: http://www.iucnredlist.org/details/29684/0 and http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T29684A9526203.en (accessed March 4, 2016)

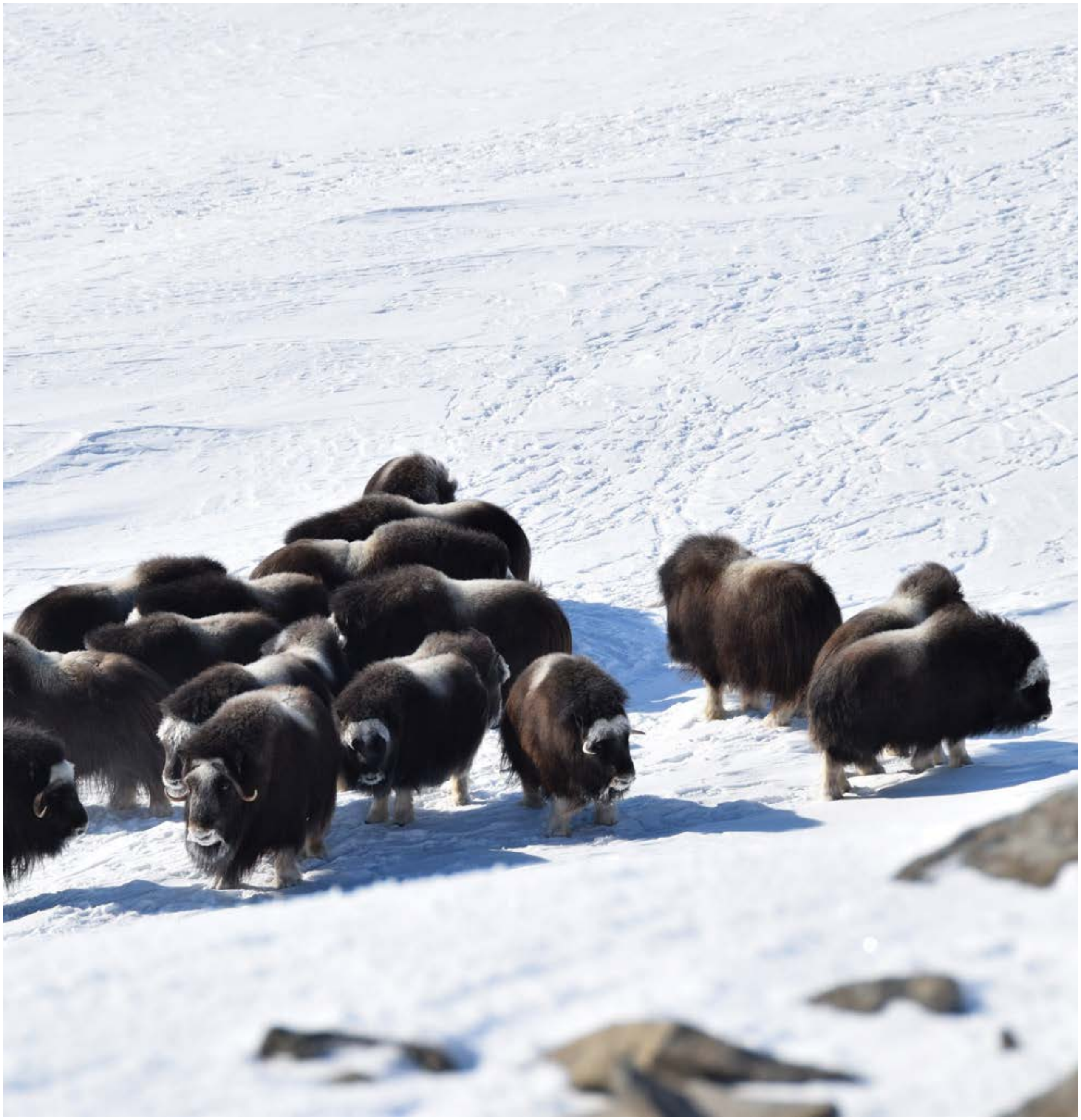
Lent, P. C. 1988.
Ovibos moschatus. *Mammalian Species* 302:1-9.

Schmidt, J. H. and C. W. Westing. 2011.
A range-wide assessment of the Cape Thompson muskox population and implications for future distance sampling surveys. NPS and ADFG Report.

Schmidt, J. H. and T. S. Gorn. 2013.
Possible secondary population-level effects of selective harvest of adult male muskoxen. *Plos One* 8(6): e67493. doi:10.1371/journal.pone.0067493

Schmidt, J. H., H. L. Robison, B. Saito, R. Klimstra, and B. Dunker. 2016.
Assessment of the Cape Thompson Muskox Population 2011-2016. NPS and ADFG Report.

Yang, C., C. Xiang, W. Qi, S. Xia, F. Tu, X. Zhang, T. Moermond, and B. Yue. 2013.
Phylogenetic analyses and improved resolution of the family Bovidae based on complete mitochondrial genomes. *Biochemical Systematics and Ecology* 48:136-143.



A group of muskox cows, yearlings, and young bulls.
NPS photo courtesy of Hillary Robison


Marmot

Declining Sheep Populations in Alaska's Arctic Parks

Kumi Rattenbury and Joshua Schmidt,
National Park Service

Dall's sheep (*Ovis dalli*) populations may be at an all-time low in Noatak National Preserve and Gates of the Arctic National Park and Preserve since the first park-wide surveys were conducted in the early 1980s. These parks were estimated to have ~12,000 sheep (~9,800 adult sheep) in 2010-2011, but severe winter weather in 2013 and 2014 (among other factors) reduced populations by 50-80% in some areas. In particular, lamb numbers were very low in 2013 in multiple mountain ranges in Alaska and Canada following a colder-than-normal winter and record-cold temperatures in May when lambs are born. Whether there were fewer lambs born that year or they did not survive the cold spring, very few were seen in July when most surveys are conducted. Although sheep populations throughout Alaska were impacted, the recent decline appeared to be more pronounced in the north. In Noatak and Gates of the Arctic, the decline affected all age classes and lamb recruitment has been low from 2012-2015.

To monitor sheep populations, biologists with the parks and the Arctic and Central Alaska Inventory and Monitoring Networks conduct aerial distance sampling surveys in Noatak and Gates of the Arctic, as well as Denali, Lake Clark, and Wrangell-St. Elias national parks and preserves (Schmidt et al. 2012, Schmidt and Rattenbury 2013). Pilot-observer teams fly transect lines that follow mountain contours and collect data about sheep groups on the uphill side of the aircraft. These data are analyzed using Bayesian statistical models to estimate total abundance, sex and age composition of the population, and survival rates of lambs, ewes and rams.

We surveyed Noatak and adjacent habitat in 2011 and again in 2014 with the Alaska Department of Fish and Game, including two subareas in the western Baird Mountains and central De Long Mountains, which we surveyed again in 2015 (Bairds only) and 2016 (Figure 1). We estimated there were 784 adult sheep (583-1,080 at 95% Bayesian credible intervals [CI]) in Noatak in 2014, down 65% since 2011. The 2015 and 2016 surveys indicated continued decline of all age classes, with 67% fewer adult sheep in the western Baird Mountains in 2016 compared with the average of 20 surveys from 1988 to 2015 (Figure 2; Shults 2004). In the Trail Creek-Kugururok River portion of the central De Long Mountains, the 2016 estimates were similar to numbers observed during a previous crash in the 1990s (Dau 2002).

Surveys were also conducted across Gates of the Arctic and adjacent habitat in 2009, 2010, and 2015, in the Itkillik subarea annually from 2009-2016, and in the Anaktuvuk subarea in 2009, 2010, and 2014-2016 (Figure 1). We estimated there were 5,526 adult sheep (4,910-6,244 at 95% CI) in Gates of the Arctic in 2015, down 25% since 2010, but the decline was more obvious in the north (over 50% fewer sheep in the Itkillik and Anaktuvuk subareas) compared with more stable numbers in the southwestern portion of the park (Game Management Unit [GMU] 23/Alatna River West subarea). Although the ratio of lambs to ewes was higher in 2015 than in 2013 and 2014, the 2016 survey results indicate recruitment of those lambs was not substantial in the Itkillik and Anaktuvuk subareas. Recovery of sheep populations in Gates of the Arctic and Noatak will be slowed by the multi-year lag in lamb recruitment.

Dall's sheep are an important subsistence species for local residents, particularly when caribou are scarce, and they are highly valued by sport hunters and wildlife enthusiasts. Noatak has been closed to sheep hunting since 2014 due to the decline, but closures are not new to the region. In 1991, when adult sheep dropped 50% in the western Baird Mountains following two high-snowfall winters, state and federal hunts were closed across Noatak for several years then reopened under limited quotas (Shults 2004). The population returned to pre-1991 levels by 2009 following milder winters, but has been in decline since (Figure 2). Federal hunting regulations have become more restrictive in southern

◀ NPS ecologist, Kumi Rattenbury, collects Dall's sheep fecal pellets for a diet study in Gates of the Arctic National Park and Preserve.
NPS photo courtesy of Stacia Backensto

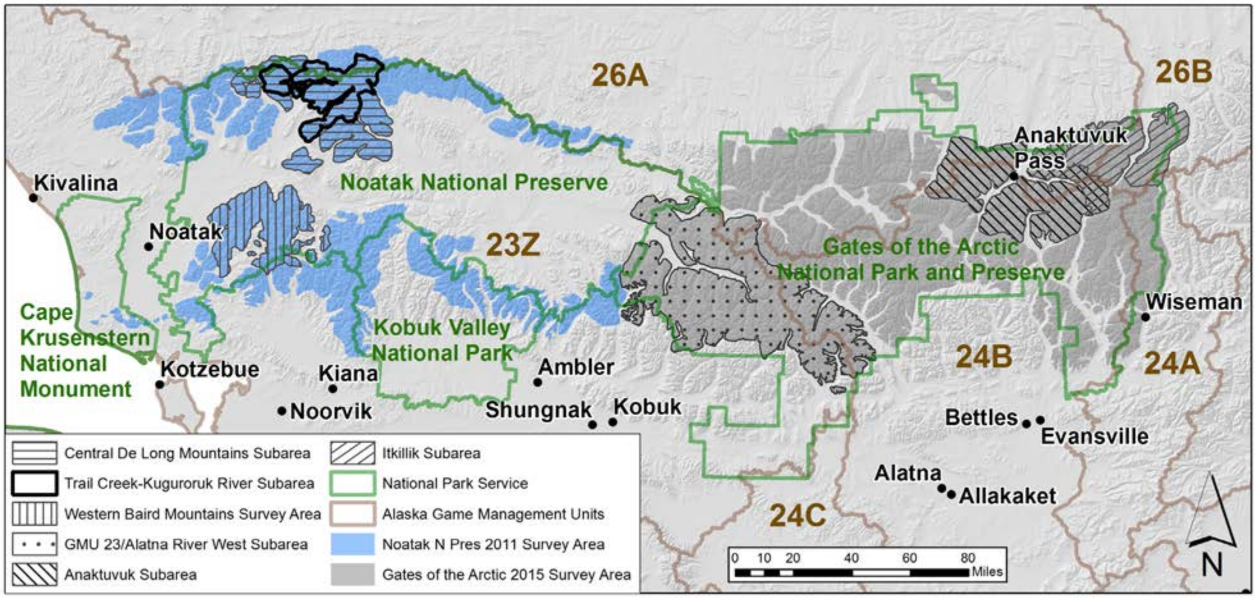


Figure 1. Dall's sheep survey areas in Noatak National Preserve and Gates of the Arctic National Park and Preserve, 2011-2016.

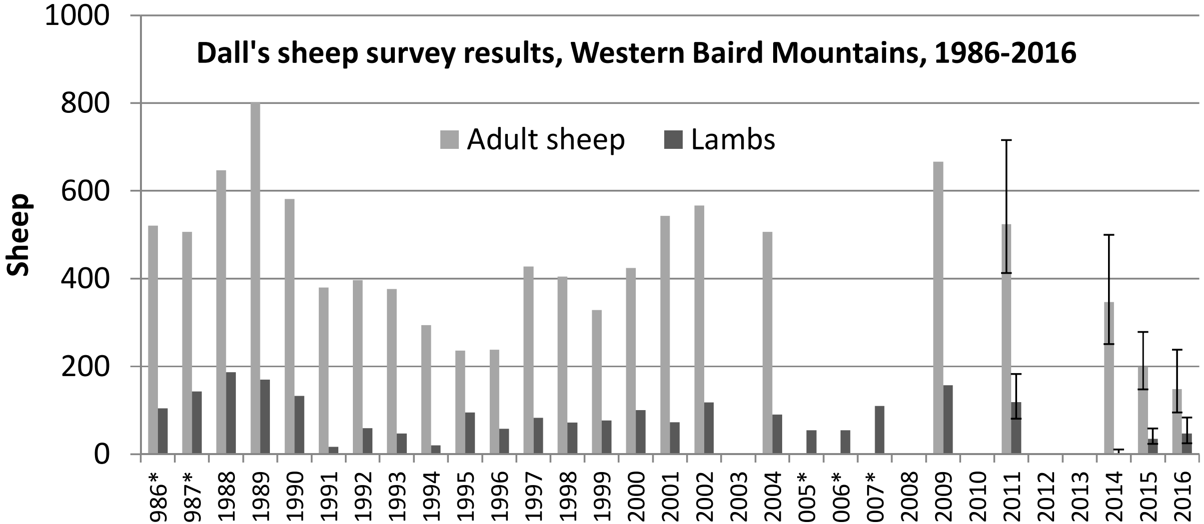


Figure 2. Dall's sheep survey results for the western Baird Mountains in Noatak National Preserve, 1986-2016. Minimum count surveys were conducted from 1988 to 2009 (Shults 2004, NPS unpublished data) and distance sampling surveys (shown as point estimates with 95% Bayesian Credible Intervals) were conducted in 2011, 2014, 2015 and 2016 (Schmidt and Rattenbury 2013, NPS unpublished data). *Partial surveys were completed in 1986, 1987, 2005-2007.

Gates of the Arctic due to the decline, and park staff have been encouraging communities to curb ewe harvest while populations are low.

Populations fluctuate naturally as Dall's sheep are an alpine-adapted and relatively non-migratory species sensitive to environmental change. Multiple factors can affect population dynamics including stochastic weather events, long-term environmental change, nutrition, predation, hunting, development, parasites, and disease. Large-scale declines have been primarily linked to severe winter weather such as deep snow, extreme cold, and icing events, which may reduce access to forage and increase vulnerability to predation (Nichols and Bunnell 1999). Increases in winter weather variability or changes in vegetation phenology and species composition related to climate change may impact sheep populations, particularly in Noatak where the small populations in the Baird and De Long Mountains exist at the northwestern edge of the species range and are relatively isolated from one another and the larger population in Gates of the Arctic.

We will continue annual surveys in Noatak and Gates of the Arctic to track the effects of the recent decline and inform harvest management decisions as well as discussions with local residents and other agencies regarding sheep conservation and management.

REFERENCES

Dau, J. 2002.
Units 23 and 26A. Dall sheep management report. Pages 142-154 in C. Healy, editor. Dall sheep management report of survey and inventory activities 1 July 1998-30 June 2001. Alaska Department Fish and Game. Proj. 6.0. Juneau, Alaska.

Nichols, L. and F. L. Bunnell. 1999.
Natural history of thinhorn sheep. In R. Valdez and P. R. Krausman, eds. Mountain sheep of North America. pp. 23-77. The University of Arizona Press, Tucson.

Schmidt, J. H., K. L. Rattenbury, J. P. Lawler, and M. C. MacCluskie. 2012.
Using distance sampling and hierarchical models to improve estimates of Dall's sheep abundance. *Journal of Wildlife Management* 76:317-327.

Schmidt, J. H. and K. L. Rattenbury. 2013.
Reducing effort while improving inference: Estimating Dall's sheep abundance and composition in small areas. *Journal of Wildlife Management* 77:1048-1058.

Shults, B. 2004.
Abundance survey of Dall's sheep in the western Baird Mountains, Alaska, July 2004. Technical Report NPS/AR/NRTR-2004-46. U.S. Department of the Interior, National Park Service. Anchorage, Alaska.

Ewes and lambs in Noatak National Preserve.
NPS photo courtesy of Marci Johnson

Small Mammals as Indicators of Climate, Biodiversity, and Ecosystem Change

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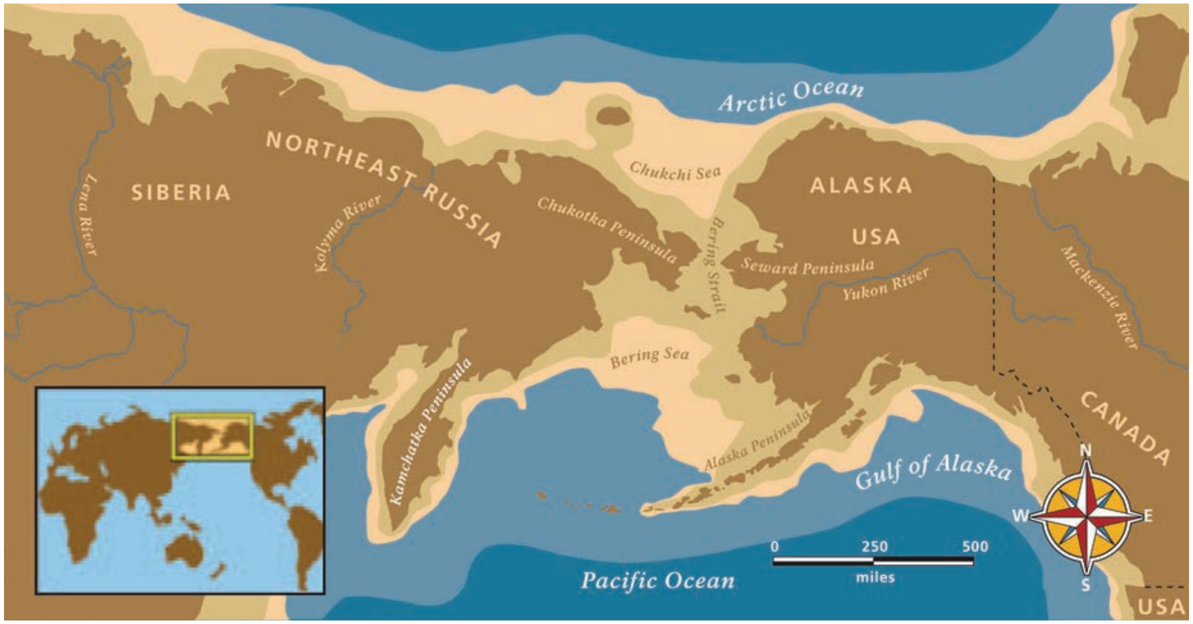

Figure 1. Map of Beringia indicating in shades of brown the extent of land including exposed continental shelf during glacial climate phases. Not shown is the corresponding extent of continental and local ice sheets that covered northwestern Canada and southern Alaska during these times. Map courtesy of NPS.

Climate is a driving evolutionary force for biodiversity in high-latitude Alaska. This region is complex and dynamic with high annual variation in temperature and light. Throughout history, Alaska has experienced major climate extremes over much longer periodicity. For example, the Quaternary Period (the last ~2.5 million years), commonly known as the Ice Age, was punctuated by more than 20 major glacial-interglacial cycles.

During glacial phases, water was locked up in ice sheets that covered much of North America, and the resulting lower sea levels exposed a land connection between Alaska and Siberia, a combined region known as *Beringia* (Figure 1). This isthmus provided vast expanses of land for species to inhabit, provided they could withstand potentially harsh polar conditions. Each extended glacial phase periodically transitioned into a shorter interglacial warm phase. These climate reversals melted continental ice sheets to expose corridors for reinvasion of terrestrial species, particularly those associated with forested habitats further south. Those species that survived at northern latitudes through repeated glacial-interglacial cycles formed the Arctic's tundra communities that persist today.

At present, Alaska supports diverse communities associated with both tundra and forests (Figure 2). These communities often interact with one another across latitudinal and elevational gradients, with tundra species generally found further north or higher in elevation. Alaska's climate is continuing to change today, strongly influencing local environments and the distribution and dynamics of wildlife species.

Methods to Understand Changing Ecosystems

One of the central challenges for the National Park Service (NPS) is to understand how natural resources (particularly biodiversity) are responding to change through time (Marcot et al. 2015). Understanding how species have responded to past episodes of environmental

◀ A red fox about to make a meal of some voles, Noatak National Preserve.
Photo courtesy of Jared Hughey

change provides comparative knowledge for current changes and predictive ability to envision future trends. One way we can access evidence from different temporal scales is by combining knowledge from multiple sources. For instance, we can compare fossil evidence of the extent of ancient distributions with present species' ranges, often suggesting dramatic distributional shifts through time. Field specimen collections spanning multiple decades (Cook et al. 2004), provide valuable samples through time for DNA or isotopic analyses that can highlight changes in regional diversity. Evolutionary histories of species leave predictable signatures within DNA sequences that can indicate how species have responded to changing environments through movement, population size changes, adaptation, or often through complex interactions between species. Ecological modeling and analyses can assess recent changes in populations as they react to current climate.

Monitoring Small Mammals

Small mammals are useful for understanding fine-scale responses to environmental change. Twenty-three years of monitoring in Denali National Park and Preserve yielded critical information on population and community changes (MacCluskie and Oakley 2005). Small mammals in Alaska are diverse for high-latitudes and have evolutionary origins from both Eurasia, further south in North America, including unique populations that are a consequence of local adaptation over multiple glacial phases. Small mammals are also intermediate trophic components of communities because they rely on vegetation, seeds, and arthropods for food, and interact with other wildlife through competition for resources or as a source of prey (Krebs et al. 2014). They have rapid generation times and are often found at exceptionally high abundances, making them relatively easy to locate, capture, and collect, which is particularly valuable considering the many logistic challenges associated with field access and inventory through Alaska. Unlike most birds that migrate

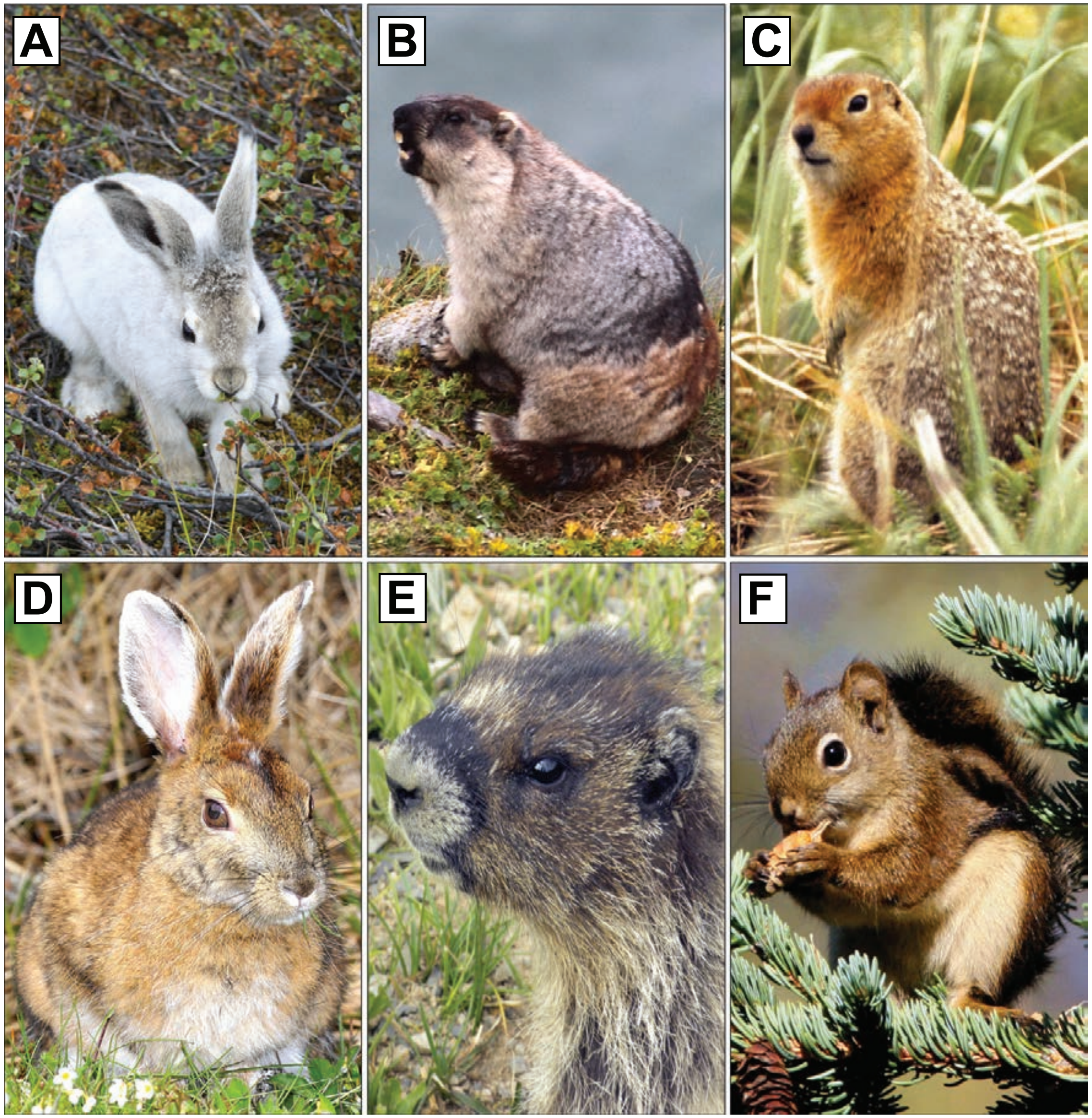

Figure 2. Small mammal ecological counterparts of tundra (top) and forest (bottom) communities within Alaska's national parks. (A) Alaskan hare and (D) snowshoe hare; (B) Alaska marmot and (E) hoary marmot; (C) Arctic ground squirrel and (F) North American red squirrel.
Photos courtesy of Creative Commons (creativecommons.org)

seasonally to compensate for fluctuating climate and food resources, small mammals are resident and most do not hibernate, meaning that they respond and adapt to year-round conditions.

An Integrated Analytical Framework for Community Assessments

A key advantage of monitoring small mammals is the "library" of accumulated specimens archived in museums and associated ecological data resulting from decades of standardized field sampling and analysis. As a consequence of robust field efforts (Cook et al. 2004, 2005), knowledge of the evolutionary and natural history of small mammals in Alaska is relatively comprehensive. We can now begin to interpret how whole communities change through time for a given region.

Analysis of accumulated data is facilitated by new statistical and genetic methods not possible only a decade ago (Hope et al. 2013). To demonstrate, we gathered genetic sequences and locality information from museum databases for over 25 species of small mammals occurring within Alaska, including tundra and boreal forest species, and representing shrews, voles, squirrels, rabbits, and small carnivores. Our results indicate that species associated with forests in Alaska arrived here together through rapid range expansion since the end of the last glacial phase as climate warmed (Hope et al. 2015). Many are still experiencing population growth and continued range expansion. Tundra species, however, exhibited more idiosyncratic responses, whereas some species recently expanded their range, others exhibited stable or declining populations.

Student interns live trapping within Denali National Park for the Central Alaska Inventory and Monitoring Network small mammal monitoring project. (A) Jenna DiFolco and (B) Vida Torres handle specimens of *Microtus oeconomus*, the tundra vole; (C) Heather Stewart sets a Sherman® live trap baited with rolled oats.

Photos courtesy of NPS.

Graduate students Dianna Krejsa and Donavan Jackson working with Alaska specimens archived in the mammal collections of the Museum of Southwestern Biology at the University of New Mexico, Albuquerque, NM.

Sarah Arguello and Robert Nofchissey, working with the Beringian Coevolution Project, process small mammal specimens within a field laboratory.

In addition to interpreting genetic information from museum specimens, we performed ecological analyses of climate data associated with the current distribution of each species. Climate tolerances of species (e.g. temperature or rainfall extremes) for the present time are often a strong predictor of where they occur. We used these climatic "envelopes" to verify the genetic and fossil evidence and better understand how distributions have changed through time, and how they may be expected to change into the future. Future predictions indicate the possible trend (increase or decrease in population size), magnitude, and physical location of species ranges into the next several decades. Finally, by overlaying predictions for multiple species, we mapped changes in small mammal diversity through time, independently for both tundra and forest communities (Figure 3) and with all study species combined (Figure 4).

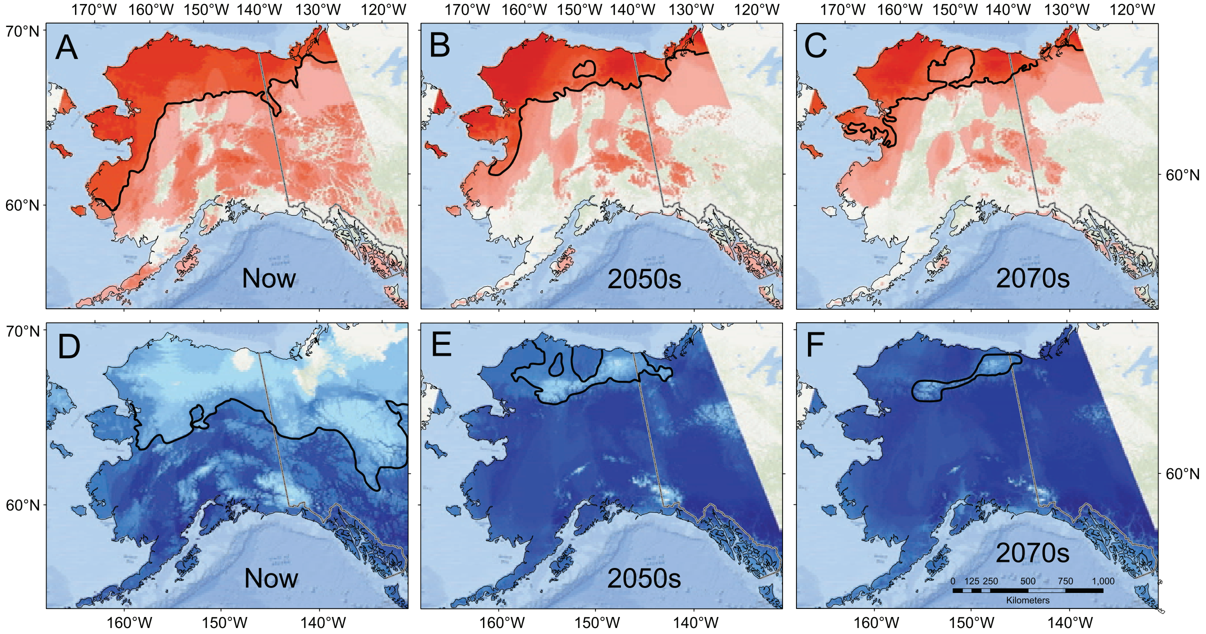

Figure 3. Climate envelope model predictions for tundra taxa (top; red) and forest taxa (bottom; blue) based on (A) and (D) current (now), (B) and (E) 2050s, and (C) and (F) 2070s climate projections. The color gradient reflects areas of low (light) to high (dark) diversity. Distribution of diversity reflects compilation of predictive maps for 12 boreal and 7 tundra/alpine-associated species. Black lines provide a guideline to the extent of ≥50% of the diversity within boreal and tundra biomes respectively during each timeframe.
Adapted from Hope et al. (2015).

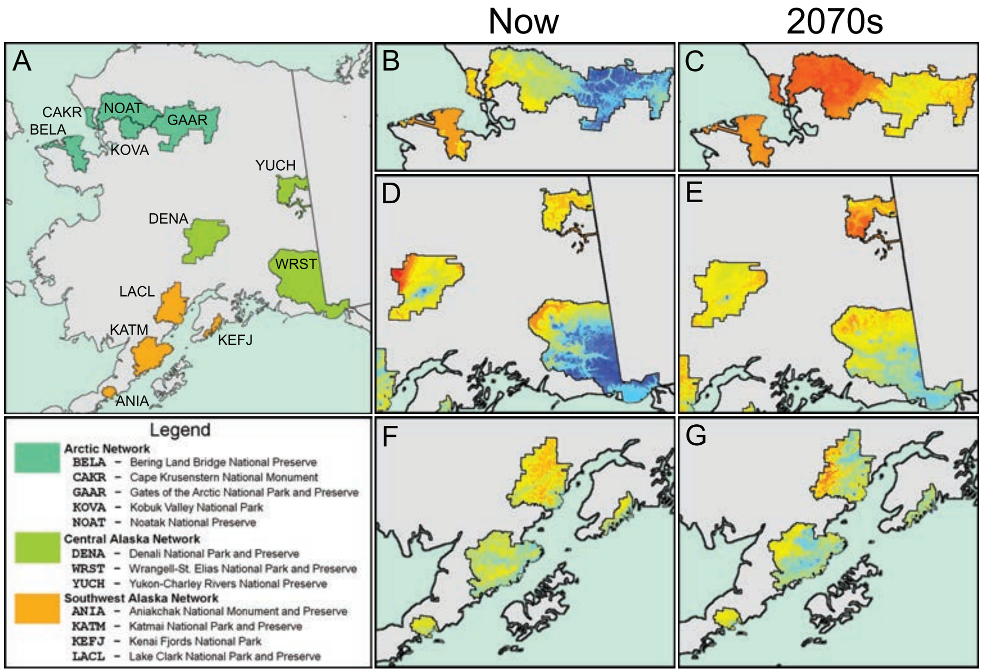

Figure 4. Climate envelope model predictions for all taxa for the current time (now) and the future (2070s) within Alaska parks. The grouping of parks within inventory and monitoring (I&M) networks within Alaska is shown in (A). Diversity change is shown in (B) and (C) the Arctic I&M Network, (D) and (E) the Central Alaska I&M Network, and (F) and (G) the Southwest Alaska I&M Network. The color gradient reflects areas of low (blue) to high (red) richness.
Adapted from Hope et al. (2015).

Trends in Diversity and Community Turnover

Predicted changes for total small mammal diversity into the next century vary across Alaska parks (Figure 4). In the Arctic parks, mammal diversity exhibits a strong longitudinal gradient with more species predicted in the west. Future predictions indicate an overall increase in diversity, although the distribution of diversity will become more even (Figure 5). Increasing diversity is generally considered beneficial; however, this increase is largely due to the rapid northward movement of forest species, whereas tundra species are contracting their range more slowly. Different velocities of change among forest and tundra species (Figure 3) will broaden overlap between these communities through time and increase the complexity of interactions among them. In the central forested region, the total number of species is not predicted to change, although the distribution of this diversity will change as species are predicted to invade higher elevations and so increasing total occupancy in this region. Within Southwest parks, the number of species is predicted to decrease slightly as total diversity shifts along both latitudinal and elevational gradients. It is possible that other species currently occurring further south, such as Keen's deer mouse (*Peromyscus keeni*), may shift north and west, maintaining or increasing the total small mammal diversity through this region. Recent studies have also suggested that climate changes may reduce the extent of boreal forests further south in Alaska, giving way to other novel habitats such as deciduous forest or grassland (e.g., Wolken et al. 2011), and by extension, changes in the associated mammal communities.

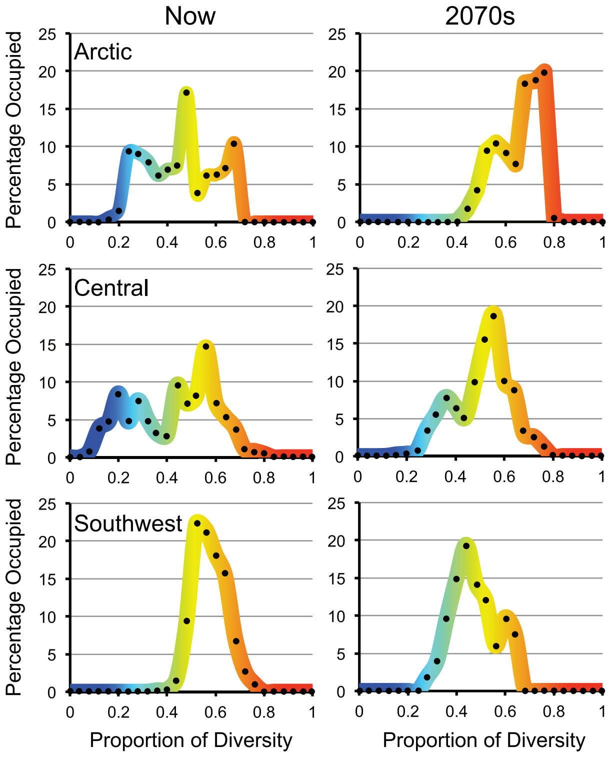

Figure 5. Plots of predicted small mammal community diversity within three networks of Alaska parks analyzed for the current time (left) and future (right) ranging from blue (low) to red (high) where colors reflect climate envelope model predictions of total diversity (Figure 4). Values reflect percentage area (y-axis) of each network's parks predicted to support a given proportion of richness (x-axis). For example, for current predictions within the Arctic I&M Network, almost half of total richness (13 taxa) is predicted to occur across roughly 17% of the management region, whereas peak richness (roughly two thirds of the taxa) is only predicted to occur through roughly 10% of this region. Into the 2070s timeframe, almost four fifths of the species are predicted to occur through 20% of the total area.
Adapted from Hope et al. (2015).

Conclusion

This is a time of rapid environmental changes in Alaska and effective management of natural resources benefits from detailed knowledge of the past and present, and our most informed predictions of future biotic responses to these changes (Barnosky et al. 2012). Species that have evolved within tundra habitats over multiple glacial cycles are not only best adapted to high-latitude and high-elevation environments, but may also respond more slowly to change. This equates to a broadening overlap between distinct communities as forest species advance along environmental gradients faster than tundra species retreat. Less certain is how different communities will interact in regions of overlap, so-called contact zones, such as occurs across latitudinal, longitudinal, and elevational gradients through many Alaska parks. High-latitude and high-elevation areas may constitute future refugial areas for tundra and alpine species respectively and these regions within Alaska parks will likely constitute critical areas for future research to inform resource management. Studies of hybridization, competition, disease, associated species such as parasites, physiological tolerances, phenology, and evolutionary adaptation to novel environments could all be facilitated by focusing on small mammal communities and continuing to build spatially extensive and temporally deep archives from parks.

Preserving our natural resources within Alaska parks will remain a challenge, particularly considering the predicted changes in community dynamics and species distributions. We provide a framework for small mammal fieldwork that can be built on through time; similar effort is needed for other facets of biodiversity.

REFERENCES

Barnosky, A. D., E. A. Hadly, J. Bascompte, E. L. Berlow, J. H. Brown, M. Fortelius, W. M. Getz, J. Harte, A. Hastings, P. A. Marquet, N. D. Martinez, A. Mooers, P. Roopnarine, G. Vermeij, J. W. Williams, R. Gillespie, J. Kitzes, C. Marshall, N. Matzke, D. P. Mindell, E. Revilla, and A. B. Smith. 2012.
Approaching a state shift in Earth's biosphere. *Nature* 486:52-58.

Cook, J., N. Dawson, S. MacDonald, and A. Runck. 2004.
Mammal diversity: Inventories of Alaska National Parks stimulate new perspectives. *Alaska Park Science* 3(2):22-27.

Cook, J. A, E. P. Hoberg, A. Koehler, H. Henttonen, L. Wickström, V. Haukisalmi, K. Galbreath, F. Chernyavski, N. Dokuchaev, A. Lahzuhtkin, S. O. MacDonald, A. Hope, E. Waltari, A. Runck, A. Veitch, R. Popko, E. Jenkins, S. Kutz, and R. Eckerlin. 2005.
Beringia: intercontinental exchange and diversification of high latitude mammals and their parasites during the Pliocene and Quaternary. *Mammal Study* 30:S33-S44.

Hope, A. G., E. Waltari, J. L. Malaney, D. C. Payer, J. A. Cook, and S. L. Talbot. 2015.
Arctic biodiversity: increasing richness accompanies shrinking refugia for a cold-associated tundra fauna. *Ecosphere* 6:article 159.

Hope, A. G., E. Waltari, D. C. Payer, J. A. Cook, and S. L. Talbot. 2013.
Future distribution of tundra refugia in northern Alaska. *Nature Climate Change* 3:931-938.

Krebs, C. J., R. Boonstra, S. Boutin, A.R.E. Sinclair, J. N. M. Smith, B. S. Gilbert, K. Martin, M. O'Donoghue, and R. Turkington. 2014.
Trophic dynamics of the boreal forests of the Kluane region. *Arctic* 67:71-81.

MacCluskie M. and K. Oakley. 2005.
Central Alaska Network Vital Signs Monitoring Plan Phase III Report. National Park Service, Fairbanks, Alaska.

Marcot, B. G., M. T. Jorgenson, J. P. Lawler, C. M. Handel, and A. R. DeGange. 2015.
Projected changes in wildlife habitats in Arctic natural areas of northwest Alaska. *Climatic Change* 130:145-154.

Wolken, J. M., T. N. Hollingsworth, T. S. Rupp, F. S. Chapin III, S. F. Trainor, T. M. Barrett, P. F. Sullivan, A. D. McGuire, E. S. Euskirchen, P. E. Hennon, E. A. Beever, J. S. Conn, L. K. Crone, D. V. D'Amore, N. Fresco, T. A. Hanley, K. Kielland, J. J. Kruse, T. Patterson, E. A. G. Schuur, D. L. Verbyla, and J. Yarie. 2011.
Evidence and implications of recent and projected climate change in Alaska's forest ecosystems. *Ecosphere* 2:article 124.

Alaska marmots in Gates of the Arctic National Park and Preserve. ▶
Photo courtesy of Jared Hughey

Collaborative Conservation of the Rare Alaskan Yellow-billed Loon

Melanie Flamme and Stacia Backensto,
National Park Service

In April, rafts of Yellow-billed Loons (*Gavia adamsii*) float in the Yellow Sea of China feasting on fish, fuel for their migration to Alaska. Considered one of the ten-rarest breeding birds of the mainland U.S. and occurring only in Alaska, the species is of international concern with the global population estimated between 16,650 and 21,000 birds. Of this, approximately 20-25% occur seasonally in Alaska, where the summer breeding population is estimated at less than 5,000 birds. The majority of the birds nest on the Arctic Coastal Plain in the National Petroleum Reserve-Alaska, earmarked for oil and gas development. Approximately 1,500 Yellow-billed Loons are estimated to nest in Bering Land Bridge National Preserve and Cape Krusenstern National Monument, coastal parklands that may offer more protections for the birds and their nesting habitat (Figure 1). Yellow-billed Loons of the Seward Peninsula differ from those of the Coastal Plain in that they frequently use marine habitats for foraging (Schmutz et al. 2014), making them especially vulnerable to exposure to an oil spill with the recent growth in oil exploration and vessel traffic in the region.

Because they use both freshwater and marine environments, Yellow-billed Loons

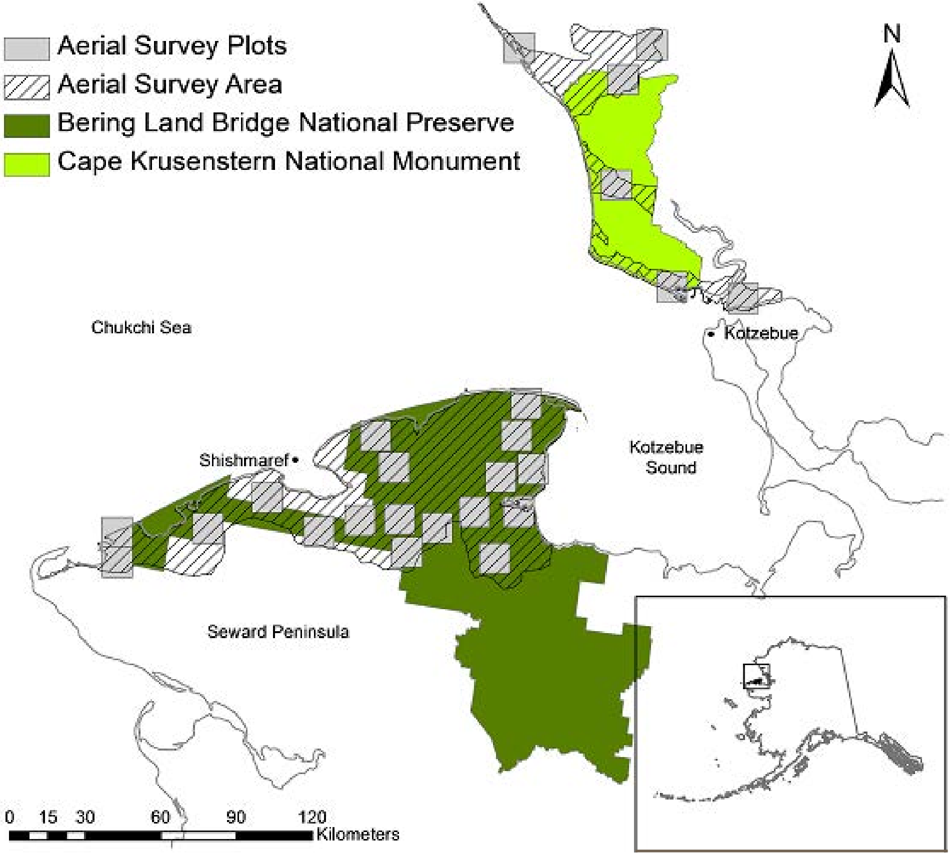

Figure 1. Location of the Yellow-billed Loon aerial survey study area on the in Cape Krusenstern National Monument (light green) and Bering Land Bridge National Preserve (dark green). Squares indicate sample plots and hatched lines indicate the study area boundary.

◀ Yellow-billed Loon.
Photo courtesy of Cameron Rutt, Wildlife Conservation Society

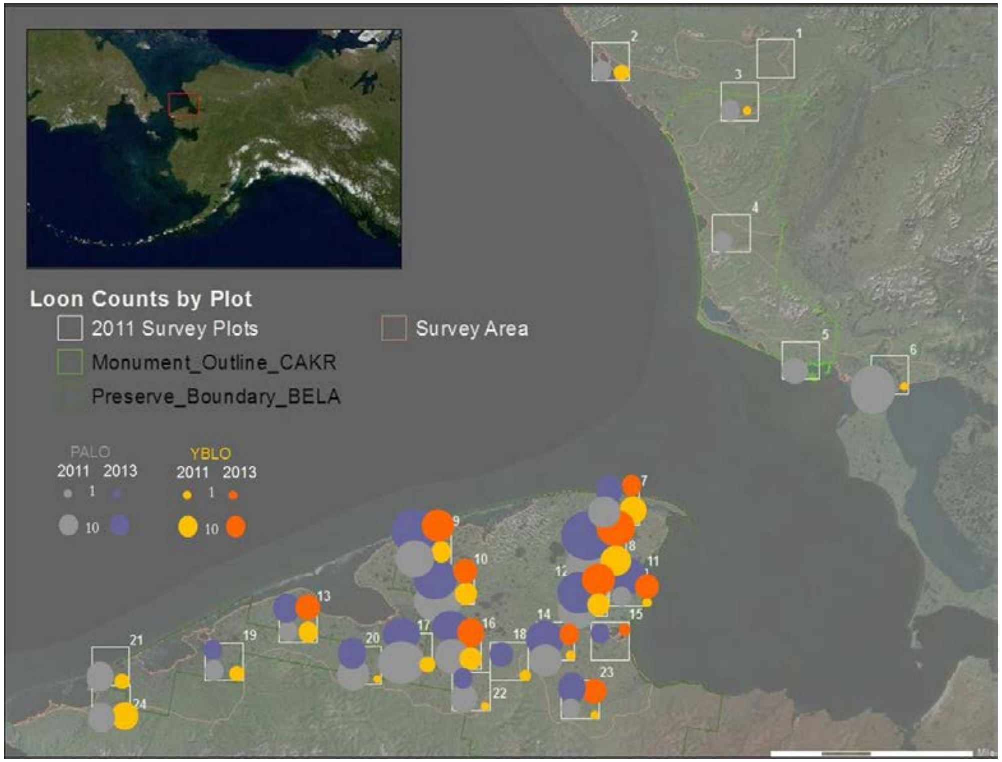

Figure 2. Map of Yellow-billed and Pacific Loon detections and distributions from aerial surveys conducted in 2011 and 2013 in Cape Krusenstern National Monument and Bering Land Bridge National Preserve. Blue hues indicate detections of Pacific Loons (PALO) and golden hues indicate detections of Yellow-billed Loons (YBLO). Lighter shades denote detections in 2011 and darker shades, those from 2013. Boxes represent the 24 aerial surveys plots. Both park units are outlined in green and the survey area is outlined in pink.

are indicators of water quality and provide insight into the movement of marine-derived nutrients and changes in ecological communities in riparian and coastal areas. They are large, long-lived, and top trophic-level predators of fish in lake ecosystems, which makes them vulnerable to contaminants bioaccumulation. This is of particular concern given that some birds winter in the highly contaminated Yellow Sea and are potentially harvested (along with their eggs) by Alaska Natives. All of these life history traits, in addition to their propensity to return to the same breeding sites each year, make Yellow-billed Loons ideal for monitoring long-term population trends in occupancy, density, distribution, and types and levels of contaminants burdens (Lawler et al. 2009).

Looking at the Long-term Picture with Monitoring

Since 2005, we have worked with the U.S. Fish and Wildlife Service (USFWS) to monitor Yellow-billed Loons in Bering Land Bridge and Cape Krusenstern to document long-term population trends. Though the surveys are designed for and focused on detecting Yellow-billed Loons, we collect data on all species of loons observed. To conduct these surveys, we work with experienced loon surveyors, pilot and biologist Nikki Guldager and biologist Tamara Zeller from the USFWS.

Based on aerial surveys conducted in 2011 and 2013 across both parks, Alaska's northwestern breeding population of Yellow-billed Loons is about 2-2.5 times larger than previously thought (Figure 2). The birds nested at 205 lakes and used an additional 207 of 1,291 lakes in the study area (Schmidt et al. 2014). The likelihood these same lakes would be used in subsequent years was high (greater than 70%), suggesting strong nest site fidelity for particular lakes. Similar species, like Pacific Loons (*Gavia pacifica*), often require the same lake habitat for nesting and may compete with Yellow-billed Loons. We found that even though Pacific Loons were more likely to use lakes in the study area, in some cases they were excluded from doing so by Yellow-billed Loons. Competition between these two species occurs to a greater degree on the Coastal Plain (Haynes et al. 2014).

Further, our research shows that Yellow-billed and Pacific loons in both parks are using a broader area of lake habitats during the breeding season for both nesting and foraging than previously thought. More study is needed to understand why these species select specific lakes while protecting a broader area around them. Such information will be an essential consideration for the conservation of these species. Overall, our results suggest that Bering Land Bridge and Cape Krusenstern may support significant populations of both species, warranting additional consideration for conservation.

To evaluate the health of the birds and the aquatic systems they use, we monitor the types and levels of contaminants burdens found in eggs and small prey fish from their nesting lakes. Analysis of eggs provides a signature of contaminants the adults are exposed to when off their breeding grounds. We analyze prey fish to provide information on the types and levels of local contaminants present on the breeding grounds. To conduct this work, we work with researchers Dr. Angela Matz (Chief of the USFWS Ecological Contaminants Program) and Debbie Nigro (Primary Investigator of the Bureau of Land Management's (BLM) Yellow-billed Loon research on the Coastal Plain). Environmental contaminants we analyze include: metals (e.g., mercury), persistent organic pollutants (POPs), organochlorine pesticides, perfluorinated hydrocarbons, polychlorinated biphenyl (PCB) congeners, and polybrominated diphenyl ethers.

Our preliminary results from egg samples suggest that mercury may be approaching levels that could impede reproduction in Yellow-billed Loons nesting in these parks; similar results were detected in eggs from the Coastal Plain (Matz et al. 2006). Currently, we are comparing data from these northwestern Alaska parklands to data collected from birds on the Coastal Plain to assess the types and levels of contaminants burdens present across the entire population of Yellow-billed Loons in Alaska. We will continue to collect data from egg samples and prey fish to get a more thorough understanding of contaminants and their long-term impacts on Yellow-billed Loons.

Swabbing Yellow-billed Loon eggs for genetic samples.
NPS photo courtesy of Melanie Flamme

A View from Above: Remote Sensing Studies Assess Habitat for Fish and Loons

We know very little about what lake characteristics (type, connectivity, depth, and flood regimes) are preferred by Yellow-billed Loons in northwestern Alaska. Freshwater fish distributions in Arctic lakes are an important determinant in nest-site selection for these piscivorous birds, and yet these data also are lacking (Ernst et al. 2006, Haynes et al. 2014). To address these data gaps, we work with Dr. Ben Jones at the U.S. Geological Survey (USGS) and Dr. Chris Arp at the University of Alaska-Fairbanks to identify characteristics of freshwater lakes in Bering Land Bridge that provide important winter habitats for fish. We are using remote sensing and high-resolution satellite imagery, space-borne synthetic aperture radar (ifSAR) imagery, ice-growth models, and weather station data to develop a geospatial database of lake type, connectivity, depth, and flood regimes (Arp et al. 2011, Jones et al. 2013). By analyzing winter and spring ifSAR imagery of hundreds of lakes in the park, we can estimate lake depths to identify areas that remain partially unfrozen throughout the year. These areas may serve as important overwintering areas vital for fish, and thus, are attractive to loons. These data can then be used to develop habitat-selection models for Yellow-billed Loon nesting and direct future sampling of environmental DNA (eDNA) to assess fish distributions in these parklands. This research is currently underway and is slated for completion by late 2017.

Diving Deeper with Genetics Research

Genetic tools can help us understand more about fish distributions and the relatedness of Yellow-billed Loon populations in Bering Land Bridge and Cape Krusenstern to other populations. We collected water samples from Yellow-billed Loon nesting lakes and analyzed them for eDNA (trace fragments of DNA shed from organisms in the lakes that can provide a picture of the lakes' biodiversity). Often, the eDNA samples can be linked to a specific species of fish or loon present in the lake or, more coarsely, to the level of the genus or family.

We also use DNA swabs to collect shed adult epithelial cells and maternal blood (from egg-laying) from the surface of Yellow-billed Loon eggs. Because both parents brood the eggs, this less-invasive method allows us to collect DNA samples from the pair without handling the adult birds. From the DNA extracted from the egg swabs, we developed a suite of over 20 polymorphic microsatellite markers for Yellow-billed Loons that are used to generate specific genotypes of each bird for individual identification. These data can be used not only to develop a DNA fingerprint (specific genotype) for each bird, but can also help us confirm fidelity of pairs returning to the same nest sites each year and explore family relationships, such as paternity.

Collectively, we assess the levels and types of genetic variation present within the population, such as levels of heterozygosity, allelic, and genotypic variation to ascertain degrees of relatedness among different populations of Yellow-billed Loons and the other four species of loons in Alaska: Pacific, Red-throated (*Gavia stellate*), Arctic (*Gavia arctica*), and Common

Sharing the Yellow-billed Loon Story through Youth Engagement

Since 2013, we have recruited five students from urban and rural Alaska to participate in video production at the Alaska Teen Media Institute (ATMI) to learn the craft of video storytelling. Our goal was to have the students tell the story of Yellow-billed Loons from a youth perspective. The students traveled with scientists to Bering Land Bridge, Cape Krusenstern, the village of Inigok in the National Petroleum Reserve, and the Helmrick's homestead on the Colville River to experience the loons in their habitat, learn about scientific studies of loons, and collect video footage. Through partnerships with ATMI, Shishmaref School, West High School, Effie Kokrine Early College Charter School, the Wildlife Conservation Society, USFWS, BLM, and funding from Alaska Geographic and Murie Science and Learning Center grants, the students created three compelling videos about Yellow-billed Loons that resonate with their communities and other youth.

The group produced three videos that are available on Alaska NPS YouTube:

- Alaska's Yellow-billed Loons (2014, http://youtu.be/QwoI-oBX540?list=UUlVsMcv6QD7cmqaZxCwulXg)
- Telling a loon story: An Alaskan youth filming expedition in Bering Land Bridge National Preserve (2013, http://youtu.be/EbRmNLWNvAc)
- Filming Alaska's Yellow Billed Loons: A Youth Experience (2013, https://www.youtube.com/watch?v=zFGpfu2lauo)

Students film their experiences in the field and work with ATMI to produce videos.
NPS photos courtesy of Dev Dharm Khalsa and Stacia Backensto

(*Gavia immer*). We conduct the genetic analyses at the USGS Molecular Ecology Laboratory in collaboration with research geneticist, Dr. Sandy Talbot, and Trey Simmons, NPS aquatic ecologist. Preliminary results indicate Yellow-billed Loons have lower levels of genetic variation than other species of loons, both in allelic variation and levels of heterozygosity (Talbot et al. 2014). Initial analyses of the eDNA samples taken from Yellow-billed Loon nesting lakes have detected the presence of many fish species as well as Yellow-billed Loons (Talbot 2014, pers. comm.). Research for both projects is ongoing. When combined with the ifSAR geodatabase as a guide for future sampling locations, the eDNA could prove to be a powerful tool to assess the presence and distributions of fish and loons in additional waterbodies throughout these parklands.

Conservation: It Takes Collaboration

In combination, these studies (aerial surveys, contaminants analyses, ifSAR geodatabase of fish distribution and lake characteristics, and eDNA and Yellow-billed Loon population genetics) provide missing pieces of information that help us develop a clearer picture of the population status of Yellow-billed Loons in Bering Land Bridge and Cape Krusenstern. Together, through collaborative research with our partners, we are addressing the data gaps outlined in the Status Assessment and Conservation Plan for the Yellow-billed Loon (Ernst 2004) to inform prudent conservation efforts and science-based management of this rare and majestic species across Alaska.

REFERENCES

Arp, C. D., B. M. Jones, F. E. Urban, and G. Grosse. 2011.
Hydrogeomorphic processes of thermokarst lakes with grounded-ice and floating-ice regimes on the Arctic coastal plain, Alaska. *Hydrological Processes* (wileyonlinelibrary.com) doi: 10.1002/hyp.8019

Earnst, S. L. 2004.
Status and Assessment and Conservation Plan for the Yellow-billed Loon (*Gavia adamsii*). U. S. Geological Survey, Scientific Investigations Report 2004-5258. 42pp.

Earnst, S., R. M. Platte, and L. Bond. 2006.
A landscape-scale model of Yellow-billed Loon (*Gavia adamsii*) habitat preferences in northern Alaska. *Hydrobiologia* 567:227-236.

Haynes, T. B., J. A. Schmutz, M. S. Lindberg, K. G. Wright, B. D. Uher-Koch, and A. E. Rosenberger. 2014.
Occupancy of Yellow-billed and Pacific Loons: Evidence for interspecific competition and habitat mediated co-occurrence. *Journal of Avian Biology* doi:10.1111/jav.00394

Jones, B. M, A. Gusmeroli, C. D. Arp, T. Strozzi, G. Grosse, B. V. Gaglioti, and M. S. Whitman. 2013.
Classification of freshwater ice conditions on the Alaskan Arctic Coastal Plain using ground penetrating radar and TerraSAR-X satellite data. *International Journal of Remote Sensing* Vol. 34, No. 23, 8253-8265. http://dx.doi.org/10.1080/2150704X.2013. 834392

Lawler, J. P., J. Ver Hoef, S. B. Young. 2009.
Arctic Network Vital Signs Monitoring Plan. Natural Resource Report NPS/ARCN/NRR-2009/088. National Park Service, Fort Collins, Colorado. 280 pp.

Matz, A., J. Schmutz, D. Nigro. 2006.
FY07 Environmental Contaminants Program, Off-refuge Investigations Sub-Activity: AK-Exposure and Effects of Environmental Contaminants on Yellow-billed Loons. Unpubl. report, U. S. Fish and Wildlife Service. 18pp.

Schmidt, J. M.Flamme, and J. Walker. 2014.
Habitat use and populaton status of Yellow-billed and Pacific Loons in western Alaska. *Condor* 116:483-492. http://www.aoucospubs.org/doi/abs/10.1650/CONDOR-14-28.1

Schmutz, J. A., K. G. Wright, C. R. DeSorbo, J. S. Fair, D. C. Evers, B. D. Uher-Koch, and D. M. Mulcahy. 2014.
Size and retention of breeding territories of Yellow-billed Loons in Alaska and Canada. *Waterbirds* 37(sp1):53-63. doi:10.1675/063.037.sp108.

Talbot, S. L., G. K. Sage, S. A. Sonsthagen, J. Schmutz and M. J. Flamme. 2014.
Preliminary results of the development of polymorphic microsatellite loci for the Yellow-Billed Loon (*Gavia adamsii*). Unpublished USGS Interim Report to the U. S. Fish and Wildlife Service Region 7 and Gates of the Arctic National Park and Preserve and Yukon-Charley Rivers National Preserve. 3 pp.

Eurasian Metal Found in Ancient Alaska

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Excavations at Cape Espenberg on the northwest coast of Alaska between 2009 and 2011 recovered thousands of wood, bone, ivory, antler, lithic, and ceramic artifacts. Six metal or composite metal artifacts were recovered including a bone fishing lure with iron inset eyes; a piece of bone fishing tackle with a copper hook; an eyed copper needle; a small fragment of sheet copper; a copper alloy cylindrical bead; and a fragment of a small copper alloy buckle. The metal finds at Cape Espenberg are significant because the presence of smelted alloys in a prehistoric Inuit context in northwest Alaska is demonstrated here for the first time, indicating the movement of Eurasian metal across the Bering Strait into North America before sustained contact with Europeans.

Energy dispersive-x-ray fluorescence (ED-XRF) was performed on all five copper artifacts. The fish hook, needle, and small sheet fragment were identified as relatively pure copper, but the analysis was unable to determine definitively whether they were native copper (naturally occurring pure copper) or smelted copper (i.e., an industrial product). We identified the cylindrical bead and buckle fragment definitively as industrial smelted alloys, specifically, leaded bronze, an alloy of copper, tin, and lead. By weight, the buckle consists of nearly 45% lead, 20% tin, a few percent arsenic and silver, and 24% copper, while the bead is composed of about 30% lead, 18% tin, and 47% copper.

On the basis of its morphology, the buckle was suspected to have been cast in a mold, which would make it an industrial product and an unprecedented find in Alaskan prehistory. Accordingly, high priority was placed on non-destructive analysis to identify its composition and determine if it could have been made with naturally occurring copper from Alaska or the Canadian Arctic.

The buckle was found with a leather strap still attached, providing an opportunity to obtain a radiocarbon date reflecting when the object was used. Two radiocarbon dates provided ages of AD 1165-1490 and A.D. 1122-1460. Additional research found that the buckle closely resembles horse harness equipment buckles from north-central China dating to the first six centuries BC.

◀ The multi-room Feature 12 structure at KTZ-304 on Cape Espenberg, under excavation in July 2016, viewed to the south. In the foreground is a small room defined by horizontal timbers and corner uprights. In the background is a long, side room with collapsed roof and walls. The tarps (middle and left background) are positioned to cover areas not in excavation to protect them from drying. Engaged in excavation are, from left to right: Juliette Taieb, Edgar Ningeulook and Mike Lorain.
Photo courtesy of Owen Mason


Buckle with leather strap still attached.

The iron eyes in the fish lure were analyzed using a handheld Bruker x-ray fluorescence (XRF) spectrometer to eliminate meteoritic iron as a possible source. Iron meteors may contain several percent nickel (Ni); at a minimum they contain 5%. The iron used to make the eyes was determined to be non-meteoritic iron due to the very small amount of nickel detected (<1%), and therefore an industrial smelted product.

Acknowledgements

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Rust in the Wilderness: The Story of Mining Machines in Yukon-Charley Rivers National Preserve

Chris Allan, National Park Service

> *Gravel mining continues to be a simple process; not the simplicity of a fool, but the simplicity of empirical deduction. It is the growth of experience in overcoming natural obstacles.*
>
> *T. A. Rickard, 1908*

The drama of the Klondike gold rush in the late 1890s and subsequent gold discoveries across Alaska made the region synonymous with glittering gold and overnight wealth, but pulling profit from the earth was never easy. The region has always presented its human inhabitants with natural obstacles like frigid temperatures, rough terrain, and lengthy supply lines. In addition, the mechanical products of the Industrial Revolution, which transformed much of the world, were slow to arrive in the Far North. For much of the gold rush era, sled dogs and foot travel were more common than steamboats or other representatives of industrialism. It was not until gold was discovered in large quantities that the pace of mechanization increased. My new book entitled *Gold, Steel & Ice: A History of Mining Machines in Yukon-Charley Rivers National Preserve* (2015) helps to document the ways in which machines made "gravel mining" possible during the heyday of gold production in the Far North.

Mining in the Klondike began in spectacular fashion with stampeders who entered northwestern Canada to begin pick-and-shovel-style placer gold mining. At first, they used rudimentary tools and simple technology—whatever they could haul on their backs or build from materials on site. Using hand tools, flowing water, sluice boxes, and plenty of hard work, they set about separating small amounts of gold from large amounts of sand and gravel. Although some gold could be captured at the surface with a prospecting pan, most was deep underground in a thin layer just above bedrock. Unlike stampeders in California a half century before, miners at northern latitudes faced an additional challenge: the frozen ground called permafrost that made digging to bedrock and locating the gold difficult, dangerous, and slow. Within a year or two, those miners with money began importing labor-saving machines.

Some of the first machines imported to the Klondike gold fields were powered by steam boilers, which could be used to produce electricity and to drive hoists, water pumps, and sawmills. After an accidental discovery and some trial and error, steam boilers revolutionized placer mining when they were adapted to thaw frozen ground. As the gold rush spilled across the international boundary into Alaska, miners tested other machines in the hopes of striking it rich. In Yukon-Charley Rivers National Preserve, old machines are scattered across the landscape, each one intended to overcome a certain mining challenge. For example, the steam-powered traction engine at Washington Creek was supposed to transport coal over winter trails; coal the miners hoped would fuel a network of steamboats, railroads, and new gold-mining cities. The "donkey engine" at Fourth of July Creek was needed to excavate large amounts of gold-bearing gravel in a remote mining camp. Steam boilers throughout the region were used to melt the frozen earth. Gold dredges ate away at the earth and processed gold on an industrial scale. The prospecting drills at Coal Creek could locate and measure quantities of gold under many feet of earth. And the Caterpillar-style tractors, used throughout the area, proved that one machine could transform the land and revolutionize an industry.

Documenting the history of mining machines is challenging for a number of reasons. Miners, as a rule, did not write about their daily activities or leave detailed descriptions of the tools they used. Why pay attention to a pick, a shovel, or an excavation bucket? Likewise, large machinery received little notice. Oral history recordings rarely describe mining activities, and business records yield information about the economics of mining, but rarely explain how work was carried out. Historical newspapers tend to focus on how much gold was collected while

◀ The 1930s-era gold dredge at the Coal Creek mining camp in the heart of Yukon-Charley Rivers National Preserve, 2014.
NPS photo courtesy of Yasunori Matsui

A self-propelled churn drill for finding gold is accompanied across Coal Creek by a Caterpillar tractor crew, ca. 1938.
University of Alaska Fairbanks, Stanton Patty Family Papers (2012-93-128).

A Caterpillar "Diesel Forty" pulling a Dodge truck on skids to Coal Creek mining camp, ca. 1936.
University of Alaska Fairbanks, Stanton Patty Family Papers (2012-93-80).

ignoring the machines used to do the work. To fill in the gaps, historians must turn to less conventional sources like company catalogs and advertisements, patent drawings, trade journals, and the clues contained in historical photographs. The machines themselves also offer clues about how they were used and when.

Today visitors to Yukon-Charley Rivers National Preserve can explore mining camps that look as if the miners simply dropped their tools, turned off their machines, and walked away. These sites exist as open-air museums in a landscape sculpted by decades of mining. Although at first the machines appear to be mute hunks of rusted steel, each one has a story to tell. They tell about the challenges of placer mining in an unforgiving environment, about the dramatic shift from steam power to the internal combustion engine, about the process of trial and error that made poor ground profitable, and about the inventors and engineers who dreamed of conquering the Far North by machine. Finally, the mining machines of the park unit tell stories about the lives of the intrepid individuals who turned a gold rush into a gold industry and in the process changed the course of Alaska's history.

REFERENCE

Allan, C. 2015.
Gold, Steel & Ice: A History of Mining Machines in Yukon-Charley Rivers National Preserve. National Park Service.

The Best-brand traction engine in Yukon-Charley Rivers National Preserve may be missing parts, but it remains an impressive sight for travelers on the Yukon River today. ▶
NPS photo courtesy of Yasunori Matsui


ZUIDERDAM

Why the National Park Service Cares about Shipping in the Arctic

Scott M. Gende, National Park Service

The Arctic is changing more rapidly than any other place on earth. Warming, increases in storm frequency and severity, permafrost thaw, and loss of sea ice all portend dramatic changes in Arctic ecosystems and biodiversity. These physical changes are also increasing opportunities for human use of the Arctic including hydrocarbon development, tourism, and, importantly, shipping (Reeves et al. 2014). In fact, an increase of up to 500% of ship traffic in the Arctic was recently forecasted over the next decade with the largest increase coming from "destination" shipping, such as tourism and resource extraction (CMTS 2014).

The NPS is actively engaged in efforts to document and forecast these changes because of the potential to impact the large volume and high diversity of park resources and values in the Arctic. The U.S. Coast Guard recently proposed a two-way vessel route through the Bering Strait region. The resulting Port Access Route Study (PARS) would funnel nearly all large ships passing 15-25 nautical miles from the nearly 1,000 miles of coastline of Bering Land Bridge National Preserve and Cape Krusenstern National Monument. This area is subject to strong currents, extreme weather, and dynamic ice flow, yet currently lacks adequate emergency response facilities and is poorly charted, increasing the risk of grounding and catastrophic oil spill. Oil could easily reach the extensive coastal lagoons and sensitive salt marshes of these parks before any sizable response is available.

Pollution from shipping is also a concern because of its potential impacts to air and water quality. Arctic Alaska does not currently fall within the North American Emission Control Areas (ECA) designated for the rest of the U.S. coast (e.g., Fagerholt et al. 2015). Unlike ships operating near Glacier Bay in southeastern Alaska, ships operating in the Arctic can continue to burn lower-quality fuel and, as a result, emit tons of oxides of sulfur, nitrogen, and particulate matter per day. These pollutants can impact air quality in national parks far from where they are emitted (Mölders et al. 2010), and can elevate pollutants even when ships are passing in low density. In fact, studies have demonstrated that concentrations of terrestrial black carbon and oxides of sulfur measured on shore increased by over 70% with the passing of just a few ships (Eckhardt et al. 2013).

Some ships, such as cruise ships, also generate a large volume of wastewater, upwards of 300,000 gallons per day (EPA 2008). While this wastewater must be treated if discharged within three miles of shore, outside this near-coastal area ships may continuously discharge untreated wastewater including raw sewage. Emitted or discharged pollutants are of significant concern for their potential to bioaccumulate in marine mammals and fishes consumed by people. Hunting in the Bering Strait region is critical both nutritionally and culturally, with harvests of marine mammals averaging over 600 pounds per person for 12 communities in the region (Ahmasuk et al. 2008). Even if water is treated and low sulfur fuel is utilized, shipping can disturb marine mammals or marine mammal hunters with significant implications for human health and well-being. As representatives from the Alaska Eskimo Whaling Commission emphasized during an Arctic Marine Safety Taskforce meeting, a single missed opportunity for taking a bowhead whale during the fall migration due to disturbance from shipping, tourism, or other activities can have significant and potentially catastrophic human impact on an entire village.

The NPS has a clear role in efforts related to the management and sustainability of shipping in the Arctic. We work with many partners, including with the Wildlife Conservation Society in efforts to (1) forecast shipping volume and risk, and (2) develop an Arctic Standard of Care for cruise tourism to the area, which will include opportunities for enhanced outreach and education targeting cruise ship passengers. These activities are part of the larger effort to ensure that NPS serves its role in resource stewardship in the rapidly changing Arctic.

◀ A cruise ship approaching harbor seals hauled out on ice in Glacier Bay National Park. While disturbance by ships in Glacier Bay is of fundamental importance for resource stewardships, the implications of disturbance to marine mammals in the Arctic can affect entire communities if it results in reduced hunting success.
NPS photo courtesy of Jamie Womble

REFERENCES

Ahmasuk, A., E. Trigg, J. Magdanz, and B. Robbins. 2008.
Bering Strait Region Local and Traditional Knowledge Pilot Project: A Comprehensive Subsistence Use Study of the Bering Strait Region. North Pacific Research Board Project Final Report Project #643. Kawerak, Inc., Nome, AK.

Committee on the Marine Transportation System (CMTS). 2014.
Ten-year projection study of maritime activity in the U.S. Arctic. Available at: www.cmts.gov (accessed May 9, 2016)

Eckhardt, S., O. Hermansen, H. Grythe, M. Fiebig, K. Stebel, M. Cassiani, A. Baecklung, and A. Stohl. 2013.
The influence of cruise ship emissions on air pollution in Svalbard—a harbinger of a more polluted Arctic? *Atmospheric Chemistry and Physics* 13: 8401-8409.

Environmental Protection Agency (EPA). 2008.
Cruise ship discharge assessment report. EPA842-R-07-005.

Fagerholt, K., N. T. Gausel, J. G. Rakke, and H.N. Psaraftis. 2015.
Maritime routing and speed optimization with emission control areas. *Transportation Research Part C* 52: 57-73.

Mölders, N., S. Porter, C. F. Cahill, and G. A. Grell. 2010.
Influence of ship emissions on air quality and input of contaminants in southern Alaska National Parks and Wilderness areas during the 2006 tourist season. *Atmospheric Envrionment* 44: 1400-1413.

Reeves, R. R., P. J. Ewins, S. Agbayani, M. P. Heide-Jorgensen, K. M. Kovacs, C. Lydersen, R. Suydam, W. Elliott, G. Polet, Y. van Dijk, and R. Blijleven. 2014.
Distribution of endemic cetaceans in relation to hydrocarbon development and commercial shipping in a warming Arctic. *Marine Policy* 44: 375-389.

Emissions from a large cruise ship in the upper fjords of Glacier Bay National Park. Ships can impact air quality by emitting pollutants. The NPS has three decades of ship traffic research, monitoring, and management in Glacier Bay, including development of interpretation and education programs that target cruise ship passengers. This extensive knowledge and experience can be applied to effective stewardship as shipping increases in the Arctic. ▶

NPS photos courtesy of Scott Gende

Synthesis of Coastal Issues and Projects in the Western Arctic National Parklands

Peter Neitlich, Tahzay Jones, and Jim Lawler,
National Park Service and
Trevor Haynes, Wildlife Conservation Society

The vast and shallow lagoons, estuaries, and marshes are ecologically important and vulnerable to human disturbances such as oil spills.
NPS photo courtesy of Shorezone

Bering Land Bridge National Preserve and Cape Krusenstern National Monument have approximately 994 miles (1,600 kilometers) of predominantly soft-sediment Arctic coastlines rich in biological resources. These shorelines include vast, shallow lagoons with fractal-patterned interiors, large estuaries, barrier islands, sandy capes, salt marshes, mudflats, brackish wetlands, and the world's northernmost eelgrass beds. Like those of eastern North America before European contact, the northwest Arctic shorelines are wild, dynamic, productive, and extensive.

With climate change progressing steadily in the Arctic, sea ice has retreated by an average of 1.3 percent per year (NSIDC 2015) since the 1950s. Through 2015, the September Arctic sea ice extent has decreased by 13.4 percent per decade, relative to the 1981-2010 average. The nine lowest September sea ice extents have occurred in the last nine years. In the summer months, the Arctic ice pack is now sufficiently far north to allow for passage of vessels by both the Northern Sea Route (above Siberia) and the Northwest Passage (through the Canadian Archipelago to Greenland). As a result, vessel traffic has increased dramatically through the Bering Strait (Marine Exchange of Alaska, pers. comm. 2014).

The Bering Strait is poised to become an important waterway for commercial traffic. Connecting the Bering Sea to the Chukchi Sea, the Bering Strait is the only connection from the Pacific Ocean into Arctic waters; all Pacific marine traffic to or from the Arctic Ocean must pass through here. The Northern Sea Route shipping lanes to Europe and North America from Asia are now in use by cargo ships and fuel tankers, and there is projected to be as much as a 500% increase in traffic by 2025 from 2015 transit estimates (Azzara et al. 2015). Arctic shipping transits through the Bering Strait are immediately adjacent to Bering Land Bridge and Cape Krusenstern. Arctic, large cruise ship tourism is also emerging as a new enterprise; a 1,100-passenger ship recently completed the trip through the Northwest Passage from Anchorage to New York.

Of course, with increasing vessel traffic comes the increased risk of marine incidents. Given the proximity of emerging shipping to these formerly remote conservation areas, the National Park Service (NPS) has embarked on an ambitious plan to prepare for the potential of oil spills by characterizing the biological and physical properties of these coastlines.

◀ Arctic people depend on bearded seals and other ice seals as an important food resource.
NPS photo courtesy of Peter Neitlich

Erosion is accelerated by the lack of sea ice that normally protects the coast during strong storms as well as thawing of exposed permafrost and ice deposits.
NPS photo courtesy of Peter Neitlich

The marine waters off of the Arctic park coasts are shallow and highly productive, perched atop a barely inundated continental shelf. Pacific walrus (*Odobenus rosmarus divergens*) feed on sea floor invertebrates. Four species of ice seals consume large quantities of fish, and polar bears (*Ursus maritimus*) move south seasonally to hunt them. Several species of whales migrate through these waters annually. An estimated 12 million seabirds nest or forage in the area each year and are joined by as many as 37 species of shorebirds that nest or stage for their annual migration. Numerous species of whitefish move in and out of the extensive and shallow lagoon systems. Chum salmon (*Oncorhynchus keta*) run in tremendous numbers into Kotzebue Sound and its major river systems, the Noatak and Kobuk drainages, and are joined by several other species of salmon and the iconic sheefish (*Stenodus leucichthys*).

Inupiat peoples have made their homes along these coastlines for hundreds of generations. Communities are heavily interconnected with marine and terrestrial mammals, and have a wealth of knowledge about the region, its ecosystems and wildlife. The health of the region's marine and coastal ecosystems is inextricable from the health and welfare of the region's communities. Marine mammals, especially the bearded seal (*Erignathus barbatus*) and other ice seals, represent as much as 68 percent of Bering Strait community residents' diets, with much of the remainder coming from terrestrial mammals (Arctic Council 2009). At oil spill response workshops sponsored by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Coast Guard, local communities have expressed concern that a spill that creates a catastrophic effect on marine mammals would have an equally catastrophic effect on residents and their traditional lifestyles (NOAA and UNH 2012).

The Arctic parks now need to be concerned about issues that once seemed remote. Climate change-induced warming of ocean water has prevented the formation of shore-fast ice until November or December. In the past, the ice froze along the immediate shoreline in October or early November and had protected the coast from strong fall storms. These storms now cause large surges (up to 12 feet) that cause large-scale coastal erosion averaging about 2.95 feet (0.9 meters) per year (Manley and Lestak 2012). The erosion is assisted by the thaw of permafrost and *yedoma* (relict Pleistocene ice deposits) on the immediate coast, which makes the soil more erodible. Recent surveys and reports from communities have shown significant loss of soft-sediment beaches (Shishmaref IRA, pers. comm. 2015). The outside world has also impinged upon Arctic coasts in the form of significant accumulation of marine debris including plastic garbage, derelict fishing gear, rope, tarps, foam, and plastic crates.

Arctic Monitoring

The importance of inventory and monitoring of the coastal resources in the Arctic was recognized early during the development of the NPS Arctic Network Inventory and Monitoring (I&M) Program's monitoring plan (Lawler et al. 2009). Out of a starting list of dozens of potential indicators, six related to coastal resources were ultimately placed on the selected list of 28. They are: coastal erosion, lagoon communities and ecosystems, Yellow-billed Loons, sea ice, fish assemblages, and subsistence resources. Of these, NPS has made the most significant progress studying the former three areas.

Monitoring coastal erosion has produced a detailed rendering of erosion and accretion rates along the entire coastline of Bering Land Bridge and Cape Krusenstern based on comparisons of older and more recent aerial and satellite imagery. While the phenomenon of coastal erosion has long been recognized in low-lying regional communities like Shishmaref and Kivalina, the extent of erosion along the length of the park shores caught park researchers and resource managers by surprise.

Lagoon communities and ecosystems monitoring is being developed in recognition of the important habitats they provide for a diversity of bird and fish species, and for sustaining a vital subsistence fishery for Alaskan villages. Given that most Arctic lagoons are still relatively free of human impacts, they also represent some of the last naturally functioning lagoon systems in the world. Despite the ecological and cultural importance of coastal lagoons, very little research has been conducted on lagoon fish communities in the western Arctic. Local fishermen have observed the loss of "countless numbers" of whitefish in some areas of the western Arctic, emphasizing the need to understand, and if necessary, respond to the factors driving perceived declines.

Lagoon monitoring crew doing field work.
NPS photo courtesy of Tahzay Jones

Yellow-billed Loons (*Gavia adamsii*) are an important species for the area and depend on both marine and fresh water habitats. Considered one of the ten rarest breeding birds of the United States, the species is of international concern with a global population estimated at 16,650-21,000 (Earnst 2004). Approximately 20-25% of this global population occurs seasonally in Alaska, where the summer breeding population is estimated at less than 5,000. As top-level trophic predators, Yellow-billed Loons that migrate annually to the Yellow Sea are susceptible to contaminant bioaccumulation. Because the life history of these birds includes returning to the same nesting grounds each year, they are good subjects for long-term monitoring.

Current Projects

Since 2011, the NPS has placed heightened focus on coastal and lagoon environments. Several recent planning efforts for Northwestern Arctic spill response illustrated large gaps in the biological and physical understanding of coastal systems and a significant deficiency in spill response containment capabilities. Over the past two years, the coastal Arctic parks have begun to address these data gaps with significant project funding for applied coastal research. Of particular note are the following four projects: (1) community integrated response planning, (2) whitefish ecology and seasonal use in lagoons, (3) shorebird census and species of special concern, and (4) marine debris cleanup and education.

Future Projects

A number of funded projects will complement the preparedness agenda the Arctic coastal parks and the Arctic I&M Network have begun. The goal of these projects is increased baseline data acquisition so parks will have information in the event of a spill to better assess and mitigate natural resource damage.

Coastal projects completed or in progress, 2011-2017.

Project	Years Funded	Status
ShoreZone. Gathering a Pre-spill Baseline for Bering Land Bridge and Cape Krusenstern Prior to Potential Oil Spills Using the ShoreZone Protocol: This project mapped the coastline from Wales to Pt. Hope, gathering georeferenced video and still photos (available at www.shorezone.org). Map data layers include dominant invertebrates, vascular plants, wave energy, oil residency indices, and sensitivity. ShoreZone provides much needed support in terms of gross assessment of coastal risks of oil spill, imagery for decision support on spill response, and a photographic baseline.	2012-2013	Complete
Coastal Synthesis Report. Development of an Arctic Parks Coastal Resources Synthesis Report	2013	Pending
Post-breeding Shorebird Use of Coastal Tide Flats in Bering Land Bridge National Preserve, Seward Peninsula, Alaska	2013-2014	Complete
Coastal Avian Synthesis Report. Synthesis of Historical and Contemporary Information on the Avian Fauna of Cape Krusenstern and Bering Land Bridge	2013	In progress
Shorebird Pilot Project. Seasonal Use and Population of Bering Land Bridge Shorebirds at Ikpek Lagoon	2013	Complete
Post-breeding Shorebird Use of Coastal Marsh and Tidal Mudflats at Sisualik Lagoon, Cape Krusenstern National Monument, Alaska	2014	Complete
SAR Imagery for Yellow-billed Loons. Assess Fish Availability for Yellow-billed Loons by Remotely Assessing Lake Freezing in Cape Krusenstern and Bering Land Bridge	2015-2017	In progress
Western Arctic Parklands Waterbird Census and Special Population Surveys. Population Status and Spatial Distribution of Breeding and Post-Breeding Waterbirds	2015-2017	In progress
Marine Debris. Remove Marine Debris from Five Parks and Involve Schools and Local Communities	2015-2016	Ongoing
Community Integrated Coastal Incident Preparedness. This project field truths U.S. Coast Guard and State of Alaska Geographic Response Strategies, develops vessel traffic modelling for the Bering Straits/Southern Chukchi region, and holds incident training in communities	2015-2017	In progress
Whitefish Ecology. Assess Kotzebue Sound Whitefish Ecology and Seasonal Dynamics	2015-2017	In progress
Coastal Interpretation. Interpreting Coastal Science in the Western Arctic National Parklands in the Digital Age, Developing Story Maps and Generating Content for Web Presentation	2015	In progress
Arctic I&M Network Lagoons Vital Sign	Ongoing from 2011	In progress
Arctic I&M Network Yellow-billed Loons Vital Sign. Population and Nest Count of Yellow-billed Loons	Ongoing from 2009	In progress

Coastal projects funded, but not yet started, 2016-2021.

Project	Years Funded
Coastal Environmental Sensitivity Index. Updating Coastal Environmental Sensitivity Indices for Emergency Response Applications	2016-2017
Yellow-billed Loon Genetic Variability. Assess Genetic Variability in Alaskan Yellow-billed Loons in Cape Krusenstern and Bering Land Bridge	2016
Arctic I&M Network Lagoons Vital Sign. Ongoing Measurements of Physical Water Parameters, Chlorophyll A, Benthic Invertebrates, Nearshore Fish, and Pelagic Fish	Ongoing
Arctic I&M Network Yellow-billed Loons Vital Sign. Ongoing Population and Nest Surveys for Yellow-billed Loons	Ongoing
Yellow-billed Loons Contaminants. Assessment of Contaminants Burdens in Alaskan Yellow-billed Loons: Cape Krusenstern and Bering Land Bridge	2018
Geomorphological and Vegetation Classification. Preparing for Oil Spills Through Ecological Classification of the Bering Land Bridge and Cape Krusenstern Coastlines	2018-2019

Conclusions

The Arctic coastal parks are currently facing a new set of threats brought about primarily by climate change and associated economic trends. While the magnitude of future shipping in the Chukchi Sea is not currently known, the likelihood of some type of marine incident grows larger each year with increased vessel traffic. Physical scientists have predicted that the Arctic may be free of summer ice by 2040 (Wang and Overland 2009) or sooner. Vessel traffic modeling based on a retrospective analysis of ship traffic data may help quantify the likelihood of a marine incident.

Remote parks, people, and cultures are finding themselves increasingly in the midst of complex and novel situations. With President Obama's visit to Kotzebue in summer 2015 and the United States assuming leadership of the Arctic Council (2015-2017), we are hopeful that the attention, partnerships, and funding may emerge to bring increased focus on the coastal issues of the northwest Arctic.

REFERENCES

Arctic Council. 2009.
Arctic Marine Shipping Assessment 2009 Report. 5.5. Bering Strait Region Case Study. Arctic Council. Available at: http://www.pame.is/images/03_Projects/AMSA/AMSA_Background_Research_Docs/Scenarios/5.5-Bering-Strait-Region-Case-Study.pdf (accessed December 1, 2016)

Azzara, A., H. Wang, and D. Rutherford. 2015.
A 10-year projection of maritime activity in the U.S. Arctic region. A report to the U.S. Committee on the Marine Transportation System. The International Council on Clean Transportation, Washington D.C. 20005. Contract DTMA91P140125.

Earnst, S. 2004.
Status and Assessment and Conservation Plan for the Yellow-billed Loon (*Gavia adamsii*). Scientific Investigations Report 2004-5258. U.S. Geological Survey.

Lawler, J., S. Miller, D. Sanzone, J. Ver Hoef, and S. Young. 2009.
Arctic Network vital signs monitoring plan. Natural Resource Report NPS/ARCN/NRR—2009/088. National Park Service.

Manley, W. and L. Lestak. 2012.
Protocol for high-resolution geospatial analysis of coastal change in the Arctic Network of Parks. Natural Resource Report NPS/ARCN/NRR—2012/537. National Park Service.

National Snow and Ice Data Center (NSIDC). 2015.
Arctic sea ice news and analysis. Available at: http://nsidc.org/arcticseaicenews/ (accessed December 1, 2016)

NOAA and University of New Hampshire Coastal Response Research Center. 2012.
Northwest Arctic Borough Oil Spill Workshop: Natural Resource Damage Assessment (NRDA) & Environmental Response Management Application (ERMA), May 22-23, 2012.National Oceanic and Atmospheric Administration and Coastal Response Research Center. Available at: http://www.crrc.unh.edu/sites/crrc.unh.edu/files/media/docs/Workshops/nwab_12/NWAB_workshop_report_appendices.pdf (accessed Deccember 1, 2016)

Wang, M. and J. Overland. 2009.
A sea ice free summer Arctic within 30 years? *Geophysical Research Letters* 36: L07502, doi:10.1029/2009GL037820.

National Park Service Participation in the Arctic Council

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The Obama White House established strategic priorities for the Arctic Region, including the need for responsible stewardship to support healthy, sustainable, and resilient ecosystems over the long term. The National Strategy for the Arctic Region (2013) and subsequent Implementation Plan (2014) focus on establishing and institutionalizing an integrated Arctic management framework to sustain nature and the communities that depend on the region's ecosystems and resources. In 2015, Barack Obama became the first sitting president to visit the Arctic, including the coastal community of Kotzebue and an excursion to Kenai Fjords National Park. With the release of Executive Order 13689 Enhancing Coordination of National Efforts in the Arctic (2015), environmental stewardship of the Arctic became recognized as vital to the national interest.

"What happens in the Arctic doesn't stay in the Arctic" has become the tagline for expressing how widespread and far-reaching changes, such as melting sea ice, species range shifts, and increased development, transportation, and tourism, shape not only the Arctic's lands, seas, and peoples, but reverberate across the entire planet. Effective conservation in the face of these changes will require a high level of collaboration and implementation of ecosystem-based management approaches from local to panarctic scales.

Ecosystem-based management recognizes that natural and human systems are interconnected and that functioning ecosystems underpin all life. This approach to management focuses on maintaining the integrity of ecological systems, including all component parts, so that natural systems may continue to provide benefits and services such as biodiversity, reduced risks from extreme events, clean air and water, and food security. Ecosystem-based management approaches are essential to promote resilience in the face of broad-scale stressors, including climate change.

National Parks' Role in a Changing Arctic

When making local resource management decisions, park and other protected-area managers benefit from taking an ecosystem-based management approach and extending their geographic scale of consideration beyond the local unit to include broad-scale resource patterns and trends. By framing park decisions in a large-landscape context, managers are often better able to understand and interpret changing local conditions. Many management initiatives and programs already incorporate this broad-scale perspective, including NPS Inventory and Monitoring Networks, Bureau of Land Management (BLM) Rapid Ecoregional Assessments, Department of the Interior Landscape Conservation Cooperatives, and the North Slope Science Initiative, to name a few.

In Alaska, natural resource managers face unique challenges and opportunities related to the vastness and remoteness of protected areas. The large size and inaccessibility of most Alaskan parks makes it difficult to inventory and monitor natural resource status and trends. Providing a large-landscape context for interpreting data that do exist is another challenge. Ecosystems in the Arctic are generally quite different from those outside the Arctic (meaning there are few, if any, parallel ecosystems in other regions of the United States). We share many commonalities with other Arctic Nations. Therefore, international collaboration, and access to data and information about resource trends from other Arctic nations, is essential for interpreting the status and trend of resources within Alaska's national parks, and for anticipating, adapting to, and managing for change into the future.

Strengthening the capacity to anticipate, understand, and manage for change are primary reasons for NPS involvement with the Arctic Council and its working groups. The following paragraphs introduce several of the Arctic Council initiatives to which the NPS contributes.

◀ The Arctic Council engages member nations in resource management issues that emphasize the interconnectedness between people and the Arctic environment.
Photo courtesy of Jared Hughey

ARCTIC COUNCIL

http://www.arctic-council.org/

The Arctic Council and its Working Groups

An important mechanism for supporting broad-scale conservation in the Arctic region is engagement with the Arctic Council and its working groups. The Council is an intergovernmental forum that promotes cooperation, coordination, and interaction among Arctic nations, Arctic indigenous peoples, and other interested parties. NPS Alaska has engaged in several Arctic Council activities with the goal of furthering the mission of the NPS by protecting natural resources, serving the public, and engaging internationally.

The Arctic Council was established in 1996 to address issues critical to the Arctic Region and its peoples. Membership includes all eight Arctic nations: the United States, Canada, Iceland, Norway, Sweden, Kingdom of Denmark (on behalf of Greenland and the Faroe Islands), Finland, and the Russian Federation. In addition, six organizations representing Arctic indigenous peoples have Permanent Participant status, including the Aleut International Association, Arctic Athabaskan Council, Gwich'in Council International, Inuit Circumpolar Council, Russian Association of Indigenous Peoples of the North, and the Saami Council. Lastly, Observer status is open to non-Arctic nations and non-governmental organizations to engage in the various Arctic Council working groups. Importantly, the function of the Arctic Council is primarily advisory; the Council does not enforce its guidelines, assessments, or recommendations.

The work of the Council is primarily carried out in six working groups: Arctic Contaminants Action Program (ACAP); Arctic Monitoring and Assessment Program (AMAP); Conservation of Arctic Flora and Fauna (CAFF); Emergency Prevention, Preparedness and Response (EPPR); Protection of the Arctic Marine Environment (PAME); and Sustainable Development Working Group (SDWG).

The chairmanship of the Arctic Council rotates every two years among Arctic nations. The first country to chair the Arctic Council was Canada (1996-1998). In April 2015, the United States assumed chairmanship for the second time led by the Secretary of State, John Kerry. Priorities for this U.S. chairmanship include: improving economic and living conditions for Arctic communities; Arctic Ocean safety, security, and stewardship; and addressing the impacts of climate change. In 2017, the chair will rotate to Finland.

CAFF
Conservation of Arctic Flora and Fauna

The Circumpolar Biodiversity Monitoring Program

The Conservation of Arctic Flora and Fauna (CAFF) working group focuses on the conservation of Arctic biodiversity and promotes sustainability of the Arctic's living resources. The United States will assume chairmanship of the CAFF working group in May 2017; priorities for this chairmanship are being developed now and NPS Alaska is contributing to their development.

CIRCUMPOLAR BIODIVERSITY
MONITORING PROGRAM

The CAFF working group established the Circumpolar Biodiversity Monitoring Program (CBMP) in 2004 to address the need for broad-scale biodiversity and ecosystem information in a timely manner for policy-makers, managers, scientists, and communities within the Arctic and globally. The CBMP is an international network of scientists, managers, conservation organizations, government agencies, and Arctic community experts and leaders that collaborate to develop and implement comprehensive plans for monitoring status and trend in four Arctic systems, which serve as subgroups for the CBMP: (1) marine, (2) coastal, (3) terrestrial, and (4) freshwater ecosystems and species. The CBMP works as a "network of networks," attempting to harmonize monitoring efforts and data from many sources and across scales, disciplines, and jurisdictional boundaries.

The United States has been involved with the CBMP since 2010 and currently plays a number of key leadership roles. Scientists and resource specialists from NPS, BLM, U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS), and the National Oceanic and Atmospheric Administration (NOAA) participate in various efforts.

NPS Alaska Regional Office and BLM Alaska, in cooperation with the North Slope Science Initiative, co-lead the overall CBMP for the U.S. with the Kingdom of Demark. In addition, the NPS and USGS co-lead development of the

CBMP coastal monitoring plan with Canada. Importantly, the coastal plan will include perspectives and approaches based in multiple knowledge systems, including western science and traditional knowledge. Lessons learned from this process will advance our understanding of how to integrate different knowledge systems to support resource management needs.

In addition, staff from the NPS Arctic Inventory and Monitoring (I&M) Network are providing metadata records relevant to implementation of the terrestrial monitoring plan. These data records will be integrated with similar records from across the circumpolar Arctic to report on global status and trend of key Arctic resources. The conceptual process upon which I&M vital sign monitoring targets were selected (i.e., an ecosystem-based approach that is management relevant, model driven, and multidisciplinary in nature) has contributed to the framework used in CBMP terrestrial and coastal plans. Further, protocols developed to collect I&M data in the Arctic (e.g., remote sensing, permafrost, and coastal erosion), have been made available to the panarctic monitoring program.

Overall, the active engagement by multiple Department of the Interior bureaus in the CBMP helps ensure that Alaska's resource managers can leverage panarctic efforts to better understand changes to inform their decisions.

The Arctic Migratory Bird Initiative

Over 75% of bird species that breed in Alaska leave the state in the fall (Kessel and Gibson 1978). Migration to and from the Arctic requires many species to perform impressive flights that take them across the globe connecting Alaska to the rest of the planet. Alaska's national parks provide migratory birds with tens of millions of acres of protected breeding habitat. The breadth and diversity of movements exhibited by migratory birds pose one of the most complex conservation challenges facing NPS resource managers—conserving breeding, migratory stop-over, and wintering habitats for birds that nest in the parks. This is an important example of the need for ecosystem-based management approaches that go beyond the boundaries of any individual protected area.

The Red Knot is an imperiled Arctic migratory bird.
Photo courtesy of Lucas DeCicco, U.S. Fish and Wildlife Service

The CAFF working group created the Arctic Migratory Bird Initiative (AMBI) to improve the conservation status and secure the long-term sustainability of declining Arctic-breeding migratory bird populations (Johnston et al. 2015). The NPS participates in AMBI to further conservation of migratory birds, especially those that rely on habitats within Alaska's parks for breeding or refueling during migration.

AMBI has outlined priority conservation actions for several species of imperiled Arctic birds, including Yellow-billed Loons (*Gavia adamsii*) and Red Knots (*Calidris canutus*). AMBI's focus includes the four main flyways of the world: East Asian-Australasian, African-Eurasian, Americas, and Circumpolar. Alaska's unique geographic position in the far north as the northwestern extremity of the North American continent, the northern boundary of the Pacific Ocean, and the fact that it encompasses much of Beringia, makes it an important land area for all of the main flyways except the African-Eurasian (Kessel and Gibson 1978).

To showcase the importance of the Arctic conservation to other parts of the planet, two

Arctic Council working groups held a joint session at the World Conservation Congress in Honolulu, Hawaii in September 2016. AMBI was one of two case studies used to demonstrate how the Arctic affects the rest of the world. The Congress, held every four years, is the flagship event of the International Union for the Conservation of Nature and attracts conservation professionals and leaders from all continents and regions. The session, *From Policy to Implementation in the Arctic: Protected Area Networks as Tools for Conservation and Adaptation to Transformational Change*, focused attention on enhancing stewardship and well-being for the region, its residents, and the globe. The session was co-chaired by NPS and NOAA, representing the CAFF and PAME working groups of the Arctic Council. Outcomes focused on actions and recommendations to strengthen partnerships and coalitions and will inform the work plans for the two working groups.

Participation in AMBI provides the broader context necessary for park resource managers and scientists to understand how their efforts are important to conservation on a larger scale and enables professionals to communicate and share strategies and approaches. This is ecosystem-based management in practice! This panarctic-scale engagement yields critical information to NPS managers and others seeking to protect resources within the national parks of Alaska by enhancing understanding of how local- to regional-scale decisions affect lands, waters, and resources in other parts of the planet.

Protection of the Arctic Marine Environment

Marine resources in the Arctic provide a critical foundation for both natural and cultural heritage in the region, serving as key ecosystem components and significant subsistence resources. Both ecosystem integrity and subsistence are specified within the enabling legislation of parks in the Arctic region, including Bering Land Bridge National Preserve and Cape Krusenstern National Monument. These parks include nearly 1,000 miles (1,600 km) of shoreline and 115,157 acres (466 km^2) of marine ecosystems, and they protect fishes, migratory birds, marine mammals, and other wildlife and provide for subsistence opportunities. Managing these parks for the conservation of cultural and ecological integrity also makes them important marine protected areas (MPAs)—areas designated in the marine environment where special natural and cultural resources are recognized, studied, and protected.

A U.S. chairmanship priority for the Arctic Council's Protection of the Arctic Marine Environment (PAME) working group is to facilitate a panarctic network of MPAs. The network proposes a common vision for international cooperation in establishment and management of MPAs by the Arctic nations, promotes best practices, and is consistent with other Arctic Council initiatives, such as an ecosystem-based approach to management.

The NPS is also providing recommendations to the MPA Federal Advisory Committee to strengthen and connect MPAs and MPA programs in U.S. waters in support of a framework for panarctic MPAs. Further, the NPS supports a PAME and CAFF joint project on Arctic Marine Protected and Important Areas that consists of three phases, each building upon the other, over a three-year period (2015-2017). The goal is to integrate and harmonize existing data on the Arctic's

Marine ecosystems are ecologically and culturally important resources. Arctic people depend on marine resources for subsistence.
NPS photo courtesy of Ken Hill

marine protected areas and other important conservation areas; identify gaps and priorities in the Arctic's network of protected areas; present science-based suggestions for next steps; and inform and guide policy and decision making.

Conclusion

The pace of change in the Arctic is rapid and the challenges associated with managing the land, water, and other resources are many. Parks and other protected areas in this region play a critical role. The parks' relatively intact ecosystems are not only valuable within their own right, they contribute many societal benefits, including subsistence use for Alaska Natives, unsurpassed opportunities for recreation and solitude, conservation of biodiversity, resilience to natural hazards, carbon storage, clean water, and a host of other ecosystem services. Further, large, intact protected areas such as Alaska's parks, provide vital habitat for migratory species experiencing stressors in other parts of their ranges. These areas also allow species to respond to a rapidly changing climate by shifting their ranges, leading to development of new biotic communities.

The Arctic Council and its working groups provide a forum through which NPS scientists and managers can share information and learn from a wide array of colleagues and Arctic residents that are coping with similar challenges. The NPS and other U.S. participants in Arctic Council activities have much to offer and much to gain from engagement with this international community. Ultimately, involvement with the Arctic Council and its working groups will support informed, defensible decision making at multiple scales through enhanced integration of global science with local management needs. Such an approach is essential for meeting emerging management challenges in the Arctic and beyond.

REFERENCES

Johnston, V., E. Syroechkovskiy, N. Crockford, R. B. Lanctot, S. Millington, R. Clay, G. Donaldson, M. Ekker, G. Gilchrist, A. Black and R. Crawford. 2015.
Arctic Migratory Birds Initiative (AMBI): Workplan 2015-2019. CAFF Strategies Series No. 6. Conservation of Arctic Flora and Fauna, Akureyri, Iceland. ISBN: 978-9935 431-40-0.

Kessel, B. and D. D. Gibson. 1978.
Status and distribution of Alaska birds. Studies in Avian Biology, No. 1. Cooper Ornithological Society (Allen Press), Lawrence, Kansas.

The United States, Office of the President. January 21, 2015.
Executive Order 13689 Enhancing Coordination of National Efforts in the Arctic. Available at: https://www.whitehouse.gov/the-press-office/2015/01/21/executive-order-enhancing-coordination-national-efforts-arctic (accessed September 15, 2016)

The United States, Office of the President. 2014.
Implementation Plan for the National Strategy for the Arctic Region. Available at: https://www.whitehouse.gov/sites/default/files/docs/implementation_plan_for_the_national_strategy_for_the_arctic_region_-_fi....pdf (accessed September 15, 2016)

The United States, Office of the President. 2013.
National Strategy for the Arctic Region. Available at: https://www.whitehouse.gov/sites/default/files/docs/nat_arctic_strategy.pdf (accessed September 15, 2016)

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◀ Arctic fox, changing coats.
Photo courtesy of Jared Hughey

Back cover: Caribou in the snow-covered tundra. ▶
NPS photo courtesy of Kyle Joly

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