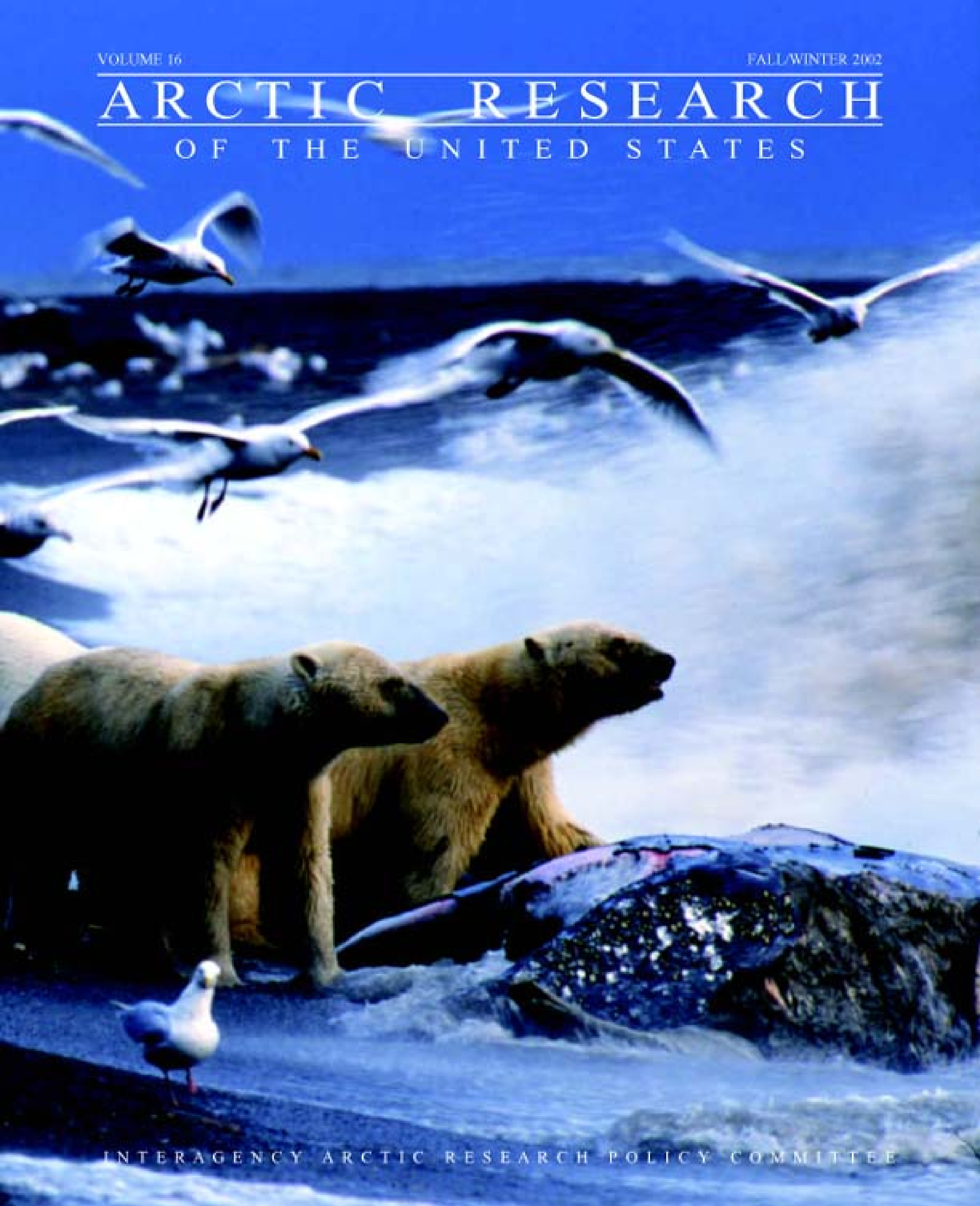
VOLUME 16 FALL/WINTER 2002

ARCTIC RESEARCH
OF THE UNITED STATES



INTERAGENCY ARCTIC RESEARCH POLICY COMMITTEE

About the Journal

The journal *Arctic Research of the United States* is for people and organizations interested in learning about U.S. Government-financed Arctic research activities. It is published semi-annually (spring and fall) by the National Science Foundation on behalf of the Interagency Arctic Research Policy Committee (IARPC) and the Arctic Research Commission (ARC). Both the Interagency Committee and the Commission were authorized under the Arctic Research and Policy Act (ARPA) of 1984 (PL 98-373) and established by Executive Order 12501 (January 28, 1985). Publication of the journal has been approved by the Office of Management and Budget.

Arctic Research contains

- Reports on current and planned U.S. Government-sponsored research in the Arctic;
- Reports of ARC and IARPC meetings; and
- Summaries of other current and planned Arctic research, including that of the State of Alaska, local governments, the private sector, and other nations.

Arctic Research is aimed at national and international audiences of government officials, scientists, engineers, educators, private and public groups, and residents of the Arctic. The emphasis is on summary and survey articles covering U.S. Government-sponsored or -funded research rather than on technical reports, and the articles are intended to be comprehensible to a nontechnical audience. Although the articles go through the normal editorial process, manuscripts are not refereed for scientific content or merit since the journal is not intended as a means of reporting scientific research. Articles are generally invited and are reviewed by agency staffs and others as appropriate.

As indicated in the U.S. Arctic Research Plan, research is defined differently by different agencies. It may include basic and applied research, monitoring efforts, and other information-gathering activities. The definition of Arctic according to the ARPA is "all United States and foreign territory north of the Arctic Circle and all United States territory north and west of the boundary formed by the Porcupine, Yukon, and Kuskokwim Rivers; all contiguous seas, including the Arctic Ocean and the Beaufort, Bering, and Chukchi Seas; and the Aleutian chain." Areas outside of the boundary are discussed in the journal when considered relevant to the broader scope of Arctic research.

Issues of the journal will report on Arctic topics and activities. Included will be reports of conferences and workshops, university-based research and activities of state and local governments and public, private and resident organizations. Unsolicited nontechnical reports on research and related activities are welcome.

Address correspondence to Editor, *Arctic Research*, Arctic Research and Policy Staff, Office of Polar Programs, National Science Foundation, 4201 Wilson Boulevard, Arlington, VA 22230.

Cover

A mixed group of polar bears, including an adult male, at least one adult female, and other sub-adults, yearlings, and two-year-old cubs, feed on a gray whale carcass killed perhaps a week earlier by killer whales. Glaucous gull wait their turn to feed on the carcass. In the background are the skulls of whales harvested in past years for subsistence use. The photo was taken at Point Barrow, Alaska, in September 2002.

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Editing and production: Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

To Our Readers

This special issue of *Arctic Research of the United States* focuses on wildlife research in Alaska, and we offer free copies to visitors to national parks, wildlife refuges, and other Federal lands in Alaska.

Federal lands cover approximately 60% of Alaska, managed by more than a dozen Federal agencies. Much of this land is preserved as parks, wildlife refuges, and wilderness areas for the use and enjoyment of all.

Management of these lands is a major challenge. Scientific research and study provides much of the information needed to manage these Alaska lands and resources. Dedicated scientists work to ensure that resources currently enjoyed by Alaskans and visitors to Alaska will be available for the enjoyment and use of future generations. Our objective in producing this issue of *Arctic Research of the United States* is to better inform Alaskan visitors and others of current Federal research efforts to understand and manage Alaska's wildlife and wildlife habitat.

The National Science Foundation publishes *Arctic Research of the United States* on behalf of the Interagency Arctic Research Policy Committee.

Charles E. Myers
Editor

John R. Haugh
Associate Editor

An Introduction to Stories about Alaska

This introduction was prepared by John Dennis, National Park Service.

This issue of *Arctic Research of the United States* provides a sampler of findings from the many and varied kinds of research conducted in Arctic and adjacent areas of Alaska. As you read these reports, imagine the scale of Alaska, the challenges to researchers that the scale imposes, and the usefulness of the results of these scientists' efforts. I also encourage you to think about the scientists themselves—who they are and what feats of education, logistics, and fundraising they must have experienced to be able to bring you the results of their dedicated, enthusiastic, and challenging endeavors in often spectacular wildness.

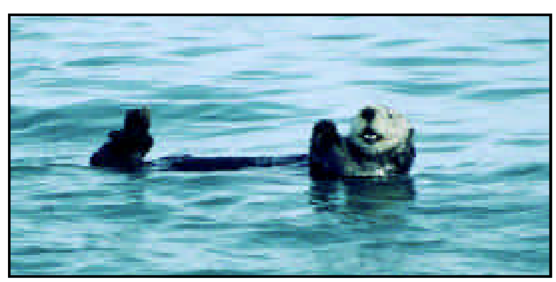
The Great Land

Alaska is large—more than 365,000,000 acres. Local travel distances are measured in hundreds, not tens, of miles. Relief runs from thousands of feet deep in the ocean to more than 20,000 feet above sea level. Salt water is cold, with tidal ranges of almost nothing in the Arctic to more than 20 feet in the Gulf of Alaska. The cold fresh water forms streams and rivers that impede travel in the thaw season but help it when frozen. Frozen water in the form of glaciers carves the land, creates new habitats for plants and animals, and provides major barriers to travel over the many mountain ranges.

The immensity and variety of Alaska's environments challenge the neophyte researcher—from thick, needle-leafed rainforest with 4-foot-diameter fallen logs lying every which way and thorn-rich devil's club plants tearing at bare skin to dense boreal forest and wide, cold rivers to sparse, low-growing, often wet tundra that offers no place to hide when the grizzly bear wanders into view. Temperatures also challenge the neophyte—the three- to four-month growing season brings the long days of summer with warmth into the 70s, 80s, and even a few 90°F days but with the chance that the next day will be in the 40s or 50s with cold rain, wind, and threat of hypothermia. The darkness of winter comes with temperatures far below 0°F and sometimes deep snow, but it also is a crucial time for learning about the many species of animals that remain active throughout the year. The wind can be a curse—when it blows hard and long, chilling the body and toppling sheltering tents, and when it's not there, giving the biting insects of spring, summer, and fall free rein to chase after the researcher who must remain focused on science, not on avoiding bites.

The Research

The reports presented here illustrate some of the types of research that you can find underway somewhere in Alaska every year. Focused primarily on fascinating animals of Alaska, the articles will take you from the whales and sea lions of southern Alaskan waters to the muskoxen of the often-frozen north. The articles will show you some of the smaller, but no less interesting, animals found throughout the state, from the engaging sea otter of the ocean to the migratory birds and resident small mammals of the interior. The articles will also give you an overview of the ecosystems of Alaska for context and a peek at the diversity of humans who have lived and flourished in Alaska for many thousands of years. Finally, you will find that the authors of these articles are your public servants from the Fish and Wildlife Service, National Park Service, and U.S. Geological Survey.



A sea otter floating in the Gulf of Alaska. (See the article on p. 31.)

Challenges to Scientists in Alaska

To learn about Alaska, scientists must conduct their research primarily in the remoteness of the field, with perhaps some additional work in the warm, bright, and dry lab. Fieldwork in Alaska involves boats, aircraft, snowmachines, walking, and often tents. The wind and rain of growing-season storms make boats used for transportation or as research platforms the perpetrators of sea sickness, prevent aircraft from arriving in remote backcountry camps on schedule to bring provisions or take weary researchers back to home, and either make camps into cold, wet prisons or blow or wash them away entirely. The dense vegetation and treefall in the forest, the abundant rivers and wetlands throughout the state, and the cottongrass tussocks covering large swaths of tundra and wetland often make overland travel at any pace faster than a crawl almost impossible during the thaw season and not much easier at other times.

Brown bear and wolf tracks in the mudflats of Tuxedni Bay, Lake Clark National Park and Preserve.

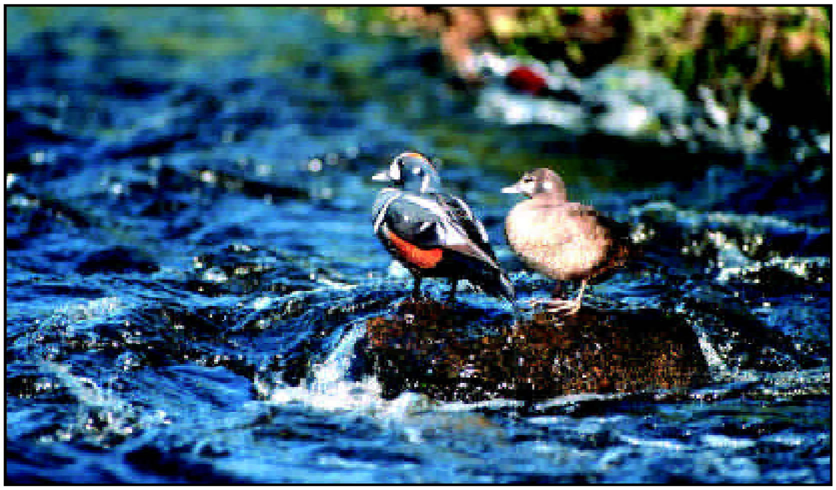
The need to use boats, aircraft, or snowmachines to access research sites severely limits the amount of equipment researchers can bring with them. The first priority for filling the available space and weight in the vehicle goes to the survival gear—sleeping bag, rain gear, extra clothing and food, and perhaps a tent. As a result, researchers usually do not have electricity to power devices for such activities as pulling sediment cores from lakes, collecting soil and rock cores, or hoisting large animals for taking their weights. Of all the accomodations that researchers must make, the largest is to adjust to the shear scale of Alaska—if they were to try to visit all of Alaska in one year, they would need to visit 1,000,000 acres a day.

Students of the Arctic find moments of aesthetic delight while existing in the wild land without the motors and other trappings of home. They can hear the clicking of the caribou feet when thousands of caribou pass through their campsite. They can hear the muffled footsteps of the grizzly bear when it walks down the beach past their tent just as they are beginning to stir in the morning. They can enjoy dinners cooked from the salmon, trout, and greyling that swim in the rivers and lakes next to their camp and desserts concocted from the blueberries, raspberries, and other fruits the tundra produces in abundance. They can watch the early summer sun march through the northern sky without quite going below the horizon and share the excitement of the migratory birds when the shortening days at the end of summer announce the end of the field season and the time to head south.

The Value of this Research

Native peoples throughout what is now Alaska compiled a body of traditional knowledge over thousands of years that helped them survive and prosper in their forest, seacoast, or tundra homeland. Western scientists have been conducting studies in Alaska for at least the past 200 years. Both traditional knowledge and western science depend on adding new knowledge to what has been discovered in the past as the means of better understanding the present and probable future. The kinds of studies reported here meet the needs of decision-makers, resource managers, other scientists, and all people interested in knowing more about the marvels of Alaska.

Alaska's Federal, state, and private resource managers depend on scientific resesarch for discovering resources of value to people, learning how people can utilize resources sustainably, restoring environmental components that have been disrupted by past human actions, and developing informational materials that help audiences better understand the features, opportunities, and constraints that people can find in Alaska. Learning the life histories of different populations of sea otters helps us understand why otters are abundant in some places and disappearing from others, giving us the potential to restore otters where they are disappearing. Studying migratory bird species in Alaska helps us understand, appreciate, and adjust human actions to the life histories of birds that fly the entire span of the Western Hemisphere two times each year and that experience natural and human-caused hazards along the way. Research on voles and their habitats helps us design the roads and trails that give people access to the marvels of Alaska without jeopardizing the sustainability of not only the voles but also the foxes, hawks, and other predators that depend on



Harlequin ducks nest along clear, fast-moving streams in Denali National Park and Preserve.

voles for food. Studying small marine organisms, whales, and air quality in southeast Alaska helps us improve management of tour ships to permit visitors to experience the majestic fjords, glaciers, and animals of southeast Alaska without destroying them. Studying the evidence of past human activities helps us understand when humans arrived in Alaska and what cultural changes they experienced as the climate and its associated plants and animals that surrounded them changed over time.

The types of studies represented in this issue clearly help Alaska's resource managers address and solve perplexing environmental management problems. These studies also help the scientific community around the world better understand the natural and human histories of the circumpolar world and the role of the Arctic region in broader geologic, environmental, and human history. Current global studies of human-induced Arctic haze, natural tundra fires, changes in the abundances and distributions of tundra plants, the presence of contaminants in marine mammals and in the fish that return from the oceans to the rivers and streams each year to spawn, fluctuations in behaviors and distributions of caribou and reindeer herds, or global climate change all benefit from information being developed by management-oriented studies such as those represented here.

Non-scientists, too, benefit from these studies. The information informs authors of magazine articles, books, and video presentations about the existence, status, and trends of Alaska's fascinating natural and cultural features. The readers and viewers of these compositions in turn gain the satisfaction of experiencing a greater understanding of Alaska and its environments, plants, animals, and peoples.

The Scientists Who Conduct the Research

Our ability to understand the wonders of Alaska depends on the talents of the many men and women who conduct the research. Biologists, geologists, archeologists, and anthropologists comprise an obvious group. But broad understanding also requires the involvement of many others—economists and sociologists, historians and geographers, and engineers and mathematicians. These researchers are undergraduate and graduate students, university professors, government scientists, and scientists in non-profit organizations and large and small businesses. Support for these researchers comes from Federal agencies such as the National Science Foundation, the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and the National Aeronautics and Space Administration. Also contributing are state agencies, such as the Alaska Department of Fish and Game and the University of Alaska. Some non-profit organizations participate using donated funds, and a number of businesses also provide funding or logistic support.

The researchers come not only from all over the United States but from around the world—for example, one of the classic scientific reports about Alaska, the 1008-page *Flora of Alaska and Neighboring Territories*, was authored by a Swedish botanist and published by Stanford University Press in 1968.

Conclusion

I hope you will find the scientific reports in this issue both informative and stimulating. As you read the reports, I encourage you to think of all the steps the scientists had to experience to be able to obtain the data on which their writings are based. They had to have the necessary education to be able to prepare research proposals to acquire the funds to support the work. They had to gain the practical experience of working in truly wild and remote conditions at the end of a thin lifeline of logistical support. They had to have a strong love of the land and the subject matter to overcome the educational, experiential, funding, and logistical hurdles that so often prevent field researchers from achieving their goals. As you read these reports, I encourage you to make this love of land and subject matter your own and, through that ownership, to increase your own enjoyment of Alaska.

Home is Where the Habitat is

An Ecosystem Foundation for Wildlife Distribution and Behavior

This article was prepared by Page Spencer, National Park Service, Anchorage, Alaska; Gregory Nowacki, USDA Forest Service; Michael Fleming, U.S. Geological Survey; Terry Brock, USDA Forest Service (retired); and Torre Jorgenson, ABR, Inc.

The lands and near-shore waters of Alaska stretch from 48° to 68° north latitude and from 130° west to 175° east longitude. The immense size of Alaska is frequently portrayed through its superimposition on the continental U.S., stretching from Georgia to California and from Minnesota to Texas. Within Alaska's broad geographic extent there are widely diverse ecosystems, including Arctic deserts, rainforests, boreal forests, alpine tundra, and impenetrable shrub thickets. This land is shaped by storms and waves driven across 8000 miles of the Pacific Ocean, by huge river systems, by wildfire and permafrost, by volcanoes in the Ring of Fire where the Pacific plate dives beneath the North American plate, by frequent earthquakes lifting mountains and shifting faults, and by glaciers retreating up to a thousand feet per year or surging hundreds of feet in a day.

This incredibly beautiful, but constantly shifting, land is home for many species of plants and animals. Some animals come only for the summer months, to breed, raise young, and retreat to warmer climes before freeze-up, when the cold, dark winter sets in. Other species are year-round residents, hibernating through the hungry winter or hunkering down with insulating fat, fur, or feathers or with high metabolism to survive until spring.

During 1999–2001 a group of scientists used old resource and environmental maps of Alaska and new digital datasets to derive a map illustrating the major ecosystems of Alaska. Extensive discussions among 40–50 scientists from many disciplines, representing hundreds of years of field experience in the north, helped refine the final data set. Thirty-two ecoregions were delineated and described, encompassing the landscapes and ecological processes of Alaska and nearby Canada and Russia. These are large ecosystems primarily defined by climate and topography, with refinements from vegetation patterns, disturbance regimes, bedrock geology, and surficial deposits remaining from recent geomorphic activities such as glaciers, floods, and volcanic eruptions.*

Ecosystems in Alaska are spread out along three major bioclimatic gradients, represented by the factors of climate (temperature and precipitation), vegetation (forested to non-forested), and disturbance regime. When the 32 ecoregions are arrayed along these gradients, eight large groupings, or ecological divisions, emerge. In this paper we describe the eight ecological divisions, with details from their component ecoregions and representative photos.

Ecosystem structures and environmental processes largely dictate the distribution and behavior of wildlife species. For example, the numerous shallow ponds and wetlands of the Arctic coastal plain and the Yukon–Kuskokwim Delta provide nesting and rearing habitat for millions of waterfowl that migrate north every summer. However, cold, windy winters freeze the ponds, and snow blankets the tundra, turning a lush landscape into a frozen barren land. As ice fingers reach across the water, the birds fatten up, then swing into the sky and migrate back to their wintering grounds.

Farther south, coastal brown bears spend the summer and fall months gorging on nutrient-rich sedges, salmon, and berries. As the early snowline moves down the mountains, the bears scavenge the final carcasses and head into snug dens to hibernate for the winter. Metabolism rates drop, allowing a bear to survive four to six months on fat reserves. For pregnant sows, this survival extends to nursing cubs that are born during the winter.

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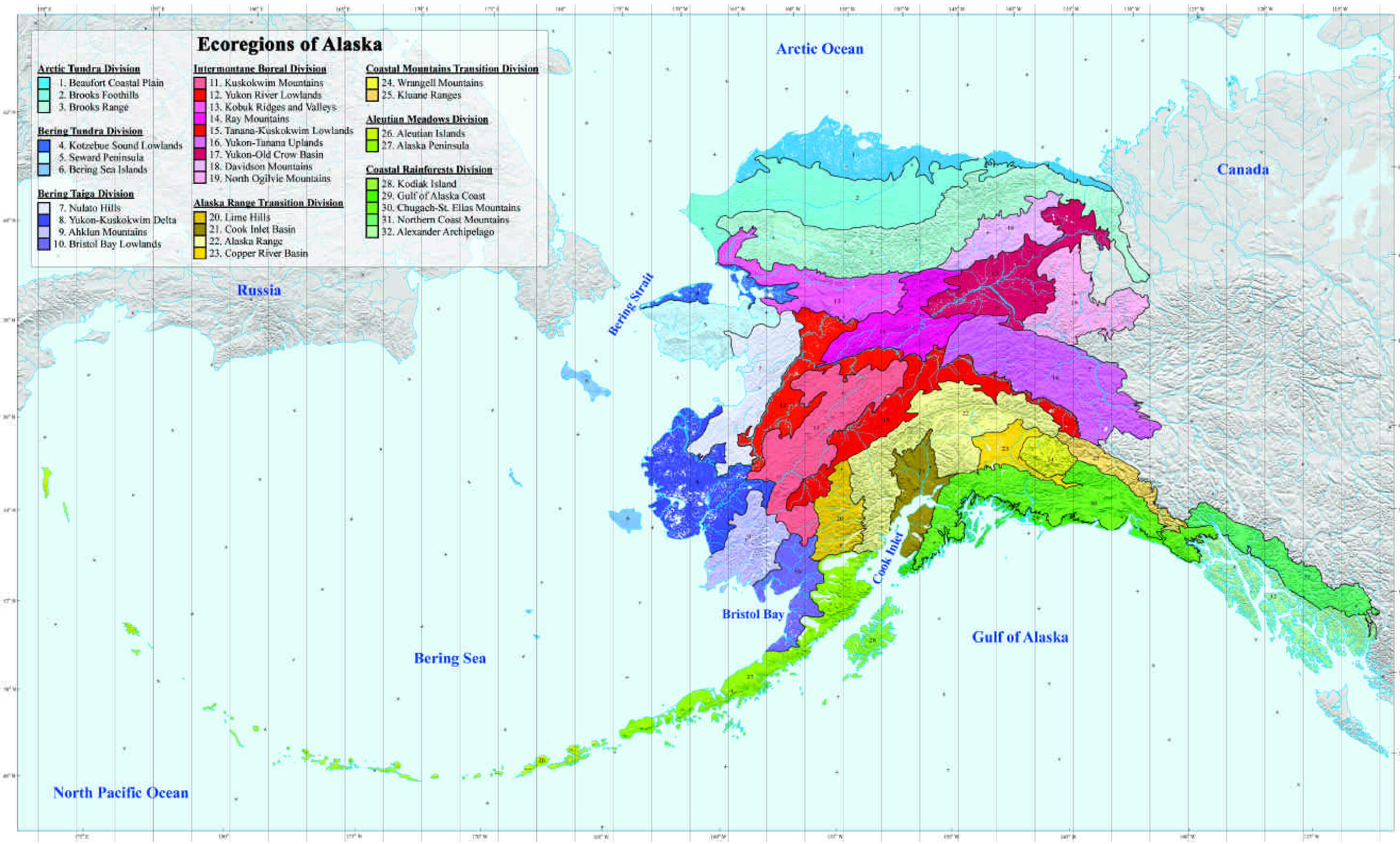
* Full ecoregion descriptions with photos and compilation tables of environmental variables are available in the original publication [Nowacki, G., P. Spencer, M. Fleming, T. Brock, and T. Jorgenson (2002) Unified Ecoregions of Alaska: 2001. USGS Open File Report 02-297. 1 map.] Digital files of the Unified Ecoregions of Alaska are available at http://agdc.usgs.gov/data/projects/fhm.



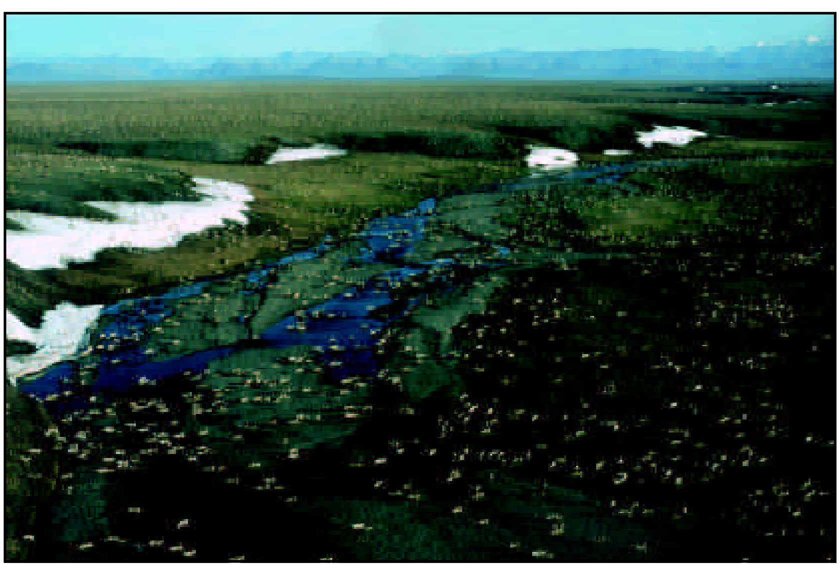
Several map versions were generated over a period of one year incorporating suggestions received from various ecologists, biologists, soil scientists, pilots, and geologists from across the state and adjacent Canadian lands. In areas where data were lacking or pattern changes on the land were indistinct, the advice of local experts was used extensively for line placement. The final data set represents the combined wisdom of 40–50 scientists from many disciplines with hundreds of years of experience in Alaska and nearby country.

The primary map contributors included Lee Anne Ayers, Chris Dau, Jonathon Hall, Janet Jorgenson, Fran Mauer, Ken Rice, Susan Savage, Lisa Sapperstein, and Mike Vivion of the U.S. Fish and Wildlife Service; Blain Anderson, Mary Beth Cook, Bill Eichenlaub, Rich Harris, Penny Knuckles, Lois Dalle-Molle, Bud Rice, Danny Rosenkrans, Patty Rost, Shelli Swanson, and Sara Wesser of the U.S. National Park Service; Dean Davidson, Rob DeVelice, Gary Fisher (GIS work), Rex Friend, Connie Hubbard, Beth Schulz, Michael Shephard, Ken Winterberger, and Kari Youkey (GIS work) of the U.S. Forest Service; Mark Clark and Darrell Kautz of the U.S. Natural Resources Conservation Service; David Brew, Alisa Gallant, and Mark Shasby of the U.S. Geological Survey; Keith Boggs and Carolyn Parker of the University of Alaska; David Banks of The Nature Conservancy; Bob Ritchie of Alaska Biological Resources, Inc.; Tony Button and Dennis Demarchi of the British Columbia Ministry of the Environment, Land and Parks; John Meikle and Jack Schick of the Government of the Yukon; Charles Roots of the Geological Survey of Canada; and Scott Smith of Agriculture and Agri-Food Canada.

Moose spend their summers feeding on lush wetland vegetation and new shrub growth, especially in early successional vegetation communities. During winter, however, snow severely limits food availability, forcing moose to wade through deep snow to browse on shrubs. If the energy gained from browsing willow twigs is greater than the energy expended reaching them, the moose have a good chance of surviving until spring.

The animal species discussed in this issue have each developed adaptations that have enabled them to survive and persist in the various ecosystems in Alaska.

The **Arctic Tundra Division** stretches along the Arctic Ocean and sweeps inland to include the Beaufort Coastal Plain, the Brooks Foothills, and the Brooks Range ecoregions. These open, wind-swept lands are gripped by polar conditions throughout the year. Cold air off the permanent ice pack of the Beaufort Sea has low moisture-holding capacity, and precipitation in this region is less than 20 inches per year. Summer temperatures average less than 50˚F within this division, effectively limiting tree growth to the southern fringe of the Brooks Range. Permafrost is nearly continuous throughout the region, contributing to saturated organic soils in the summer and a variety of freeze–thaw ground features. Repeated freezing and thawing of soils create unique features such as pingos (ice-cored peat mounds), ice-wedge polygons (a repeating pattern of hexagons in the tundra vegetation), oriented thaw lakes (linear lakes shaped by prevailing winds), and solifluction lobes and stone stripes (ground loops and vertical stripes on gentle hills caused by slumping of the thawed active layer or by frost pushing larger rocks to the soil surface).



Migrating caribou swarm across a braided floodplain in the Brooks Foothills, with the peaks of the Brooks Range in the background. Late snowbanks and aufeis deposits provide a refuge from biting insects. On either side of the river, tussock tundra and willows stretch for hundreds of miles across the foothills and into the lower Brooks Range.

The Brooks Range represents the northern extension of the Rocky Mountains and is built up by accreted terranes (fault-bounded rock units with a unique geologic history) originating from the Arctic Ocean. The high central portion of the range possesses steep angular summits of sedimentary and metamorphic rock draped with rubble and scree. Mountain glaciers covered the higher peaks during the Pleistocene, leaving remnant glaciers in the high cirques (steep-walled semicircular hollows created by glacial scouring). These glaciers flowed out of the Brooks Range, carving wide valleys, which serve as corridors for human and wildlife migrations, and leaving terminal moraines looped across the Brooks Foothills. The Brooks Foothills are gently rolling hills and broad exposed ridges flowing out from the northern flank of the Brooks Range. Narrow valleys, glacial moraines, and outwash are interspersed among long linear ridges, buttes, and mesas composed of tightly folded sedimentary rocks. The foothills flatten out into the Beaufort Coastal Plain, a vast undulating surface underlain by unconsolidated deposits of marine, fluvial (carried by streams), glaciofluvial (carried by glacial ice and meltwater), and eolian (carried by wind) origin and covered with a mosaic of lakes, braided rivers, and wetlands.

River systems arising in the Brooks Range flow south into the boreal zone or north to the Arctic Ocean. High-energy stream systems cut narrow ravines in the mountainous Brooks Range, etching a deeply incised dendritic pattern. Streams coalesce into large braided rivers in the foothills. Some of these streams freeze solid to their bottoms, causing large deposits of frozen overflow, or aufeis, that last well into summer and provide refuge for caribou from voracious flies. Break-up and snowmelt in the southern Brooks Range often cause spring flood waters to flow out over still-frozen river channels on the Coastal Plain and flood onto the near-shore ice of the Arctic Ocean.

Tundra and low shrub communities predominate throughout the Arctic Tundra zone. Saturated soils and numerous thaw lakes on the Beaufort Coastal Plain support wet sedge tundra in drained lake basins, swales, and floodplains and tussock tundra and alpine tundra dominated by sedges and *Dryas* (mountain avens) on gentle ridges. Vegetation of the foothills and lower mountain slopes of the Brooks Range is dominated by vast expanses of mixed shrub–sedge tussock tundra,

Wetlands, oriented lakes, and saturated organic soils are characteristic of the Beaufort Coastal Plain near Milne Point. Lakes are still ice-covered in early spring but will soon break up and resound to countless calls of courting and nesting waterfowl.

interspersed with willow thickets along rivers and small drainages and *Dryas* tundra on ridges. Alpine tundra and barrens dominate at higher elevations along the entire crest of the range. On the south side, lower mountain slopes and valleys are covered with sedge tussocks and shrubs. The Arctic treeline skirts across the Brooks Range in Canada and is restricted to the south side of the range in Alaska. Here, sparse spruce and birch forests and tall shrublands occur in larger valleys.

Fish species and populations are sparse in the swift shallow streams of the Brooks Range. As streams become larger and slower, their clear waters teem with arctic char and arctic grayling. Arctic cisco, broad whitefish, least cisco, and Dolly Varden char overwinter in deep holes of the larger rivers of the coastal plain and migrate to near-shore marine waters for the summer. This region has been called the “Arctic Serengeti” because of the huge herds of caribou that migrate across the Brooks Range annually—north to the coastal plain for calving and summer grazing, south for the winter months. Wolves, arctic foxes, and grizzly bears follow and prey on caribou herds, subsisting on voles, lemmings, arctic ground squirrels, or vegetation when caribou are not available. Muskoxen were heavily hunted on the coastal plain during the whaling era and are re-establishing themselves from introduced animals (see p. 74). Dall’s sheep occupy the high country of the Brooks Range (see p. 68). Several species of whales migrate into the Arctic Ocean in summer, and seals and polar bears are year-round residents. The coastal plain is important for breeding birds, including a wide variety of shorebirds, ducks, geese, swans, and songbirds.

The **Bering Tundra Division** includes lands and nearby waters in and near the Bering Sea. The Bering Sea is mostly ice-covered for many months each year and cold and stormy the remaining months. The Bering Sea has limited warming effects on the climate, so the adjacent lands are predominately cold, wind-swept, and treeless. The Bering Tundra Division includes the Kotzebue Sound Lowlands, the Seward Peninsula, and the Bearing Sea Islands ecoregions. The northern Bering Sea covers a large shallow shelf less than 250 feet deep, reaching well north in the Chukchi Sea, through the Bering Strait, and south to the Pribilof Islands. During several glacial maxima, this shelf has been above sea level and vegetated with tundra and steppe communities. This plain served as a migration route between North America and Eurasia for plants, animals, and humans (see p. 55).

Scattered volcanic hills rise above large expanses of marine sediments, outwash plains, and sedimentary bedrock. These hills form the exposed Bering Sea Islands and hills of the Seward Peninsula. Several recent lava flows, cinder cones, and hot springs on the Seward Peninsula indicate ongoing volcanism. The Kotzebue Sound Lowlands are primarily depositional features from materials washed and blown off nearby hills and outwash plains. The Seward Peninsula is gently rolling hills and rounded valleys with a few more rugged mountains in the south. Continuous permafrost of varying thickness underlies the thick wet soils of the Kotzebue Sound rim and the thin rocky soils of the Seward Peninsula and Bering Sea Islands.

The cold soils and bitter climate support moist or wet tundra communities of sedges, grasses, low shrubs, and lichens interspersed with rocky cliffs

The winter sun rises briefly over low mountains and frozen tundra on the Seward Peninsula. Subdued terrain and harsh weather off the Bering Sea are typical of the Bering Tundra Division.

The clear waters of the South River in the Nulato Hills are spawning habitat for hordes of pink (or humpy) salmon that provide fall food for hungry bears. Sparse taiga forests grow on river terraces, grading upward into low shrubs, shrub tundra, and rocky alpine tundra.

and shorelines. Drier ridgetops on the Seward Peninsula and the islands have alpine *Dryas*–lichen tundra and barrens with low shrub tundra on hillsides and willows along streams. Scattered forest patches of balsam poplar and white spruce grow along the rivers in protected valleys of the easternmost Seward Peninsula and the Kotzebue lowlands. Strong ecological affinities to Asia remain to this day, with the presence of Eurasian birds (gray-headed chickadees, yellow and white wagtails, and bluethroats), fishes (Alaska blackfish), and flora. Whales, walruses, and polar bears funnel through the Bering Strait as they migrate between the Bering Sea and the Arctic Ocean. Dense concentrations of lakes and ponds support many species of nesting birds, including the rare arctic loon. Bears, caribou, snowy owls, arctic foxes, and hares are common on the mainland. Millions of seabirds (cormorants, kittiwakes, murres, puffins, and auklets) and marine mammals (northern fur seals, ribbon seals, and sea lions) inhabit the rocky outposts of St. Lawrence, St. Matthew, and the Pribilof Islands during the summer. Wintering flocks of rare spectacled eiders congregate in small polynyas (openings) in the sea ice south of St. Lawrence Island. Muskoxen and domestic reindeer have been introduced to Nunivak Island and the Seward Peninsula.

The ecoregions of the **Bering Taiga Division** spread along the eastern coast of the Bering Sea from Norton Sound south to Bristol Bay. Although the area is dominated by a moist sub-polar climate, the southern Bering Sea is not as covered by ice during the winter as north of St. Lawrence Island. Summers are sufficiently long and warm to allow patches of stunted trees (taiga) to grow, primarily along rivers and streams. However, summer warming is tempered by the cold prevailing winds off the Bering Sea, which in some years result in patchy ice as far south as Bristol Bay. The ecoregions of the Bering Taiga are the Nulato Hills, the Yukon–Kuskokwim Delta (often called the Y–K Delta), the Ahklun Mountains, and the Bristol Bay Lowlands.

The Bering Taiga Division is made up of two units of old weathered mountains: the Nulato Hills and the Ahklun Mountains, with intervening depositional lowlands: the Y–K Delta and the Bristol Bay lowlands. The Nulato Hills are rolling waves of regular northeast–southwest-trending mountains, with beautiful clear rivers in the valleys. The Nulato Hills and Y–K Delta were largely ice-free during the Pleistocene, while the Ahklun Mountains spawned mountain glaciers that left U-shaped valleys throughout the unit and spread terminal moraines across the northwest corner of the Bristol Bay lowlands. These lowlands have been shaped by multiple huge glaciations out of the eastern side the Alaska Range, which left concentric terminal moraines and large outwash plains across the unit and into Bristol Bay. The valleys of the Ahklun Mountains are filled with large "finger lakes" that have filled the glacial basins as the ice retreated. The Y–K Delta and the Bristol Bay lowlands have been formed by the dance of fluctuating sea levels during glacial periods and alluvial deposition from huge river systems draining central Alaska. The resulting layers of glacial, alluvial, and marine sediments form low-lying saturated soils and an incredible mosaic of ponds, sloughs, and wandering streams. Permafrost is nearly continuous on the Y–K Delta, opening to patchy farther south in Bristol Bay. The mountain units have thin rocky soils with sporadic permafrost in the valleys.

The vegetation patterns of the Bering Taiga generally follow the terrain. White spruce and balsam poplar grow in sinuous stands along most river systems in the region. Gently rolling side slopes support black spruce and paper birch forests and tall shrub communities of dwarf birch and alder. The higher elevations are covered with shrub tundra and lichens or barrens on the wind-scoured summits. Lowlands are covered with a rich and productive mix of emergent wetlands and sedge–tussock and sedge–moss bogs, with willows along small streams. Slight rises support low shrublands and scattered spruce.

The river systems of this division are incredibly productive for various fisheries. The Bristol Bay sockeye (red salmon) run is the largest in the world, and huge pink salmon runs ascend the Unalakleet River every summer. Rural residents throughout the region and upstream into Canada depend on king (chinook), red, and chum salmon for winter supplies and dog food. These salmon runs feed coastal brown bears, especially in the Bristol Bay region. The rapidly rotting spawned-out carcasses bring vast quantities of marine nutrients to the terrestrial and aquatic ecosystems, where they nourish the next generation of salmon fingerlings. Likewise, the lake and wetland systems, particularly of the Y–K Delta, support millions of staging and nesting waterfowl and shorebirds. Great numbers of gregarious walruses and sea lions haul out on rocky beaches, while seabirds patrol the skies. Moose and beaver thrive along the rivers, while caribou, wolves, and black and grizzly bears roam the uplands.

The lower Yukon River Delta is typical of depositional wetlands of the Bering Taiga Division. This maze of lakes, creeks, and wetlands will soon host millions of nesting waterfowl and shorebirds during the summer months.

The **Intermontane Boreal Division** in Alaska is a portion of the largest coniferous forest in the world. The boreal forest stretches across the northern circumpolar regions, including Canada, Alaska, Siberia, and Scandinavia. This intermontane terrain, sandwiched between the Brooks and Alaska Ranges, remained largely ice-free during the last ice age, forming part of the "Beringia Corridor" that provided a route for animals and humans moving between Asia and southern parts of North America (see p. 55).

The boreal region is characterized by a continental climate, with extreme weather conditions ranging from long, cold winters to short, warm summers. The continental climate is fairly dry throughout the year, and forest fires rage during summer droughts. The resulting vegetation pattern is a constantly shifting mosaic of successional communities in response to wildfire and river changes. Most of the soils are underlain by ice-rich permafrost and are subject to thermokarsting where ice lenses melt out or form under insulating moss mats. The boreal forests of Alaska, also called taiga from the Russian term meaning "land of little sticks," is vegetated with black spruce, tamarack, and paper birch woodlands; shrubby muskeg on permafrost-rich areas; white spruce and balsam poplar on floodplains where permafrost is missing or very deep; and aspen and shrub on upland areas of recent fires and discontinuous permafrost.

Alaska ecoregions in the Boreal Division are a combination of large river valleys and old mountains. The river valleys include the Yukon–Old Crow Basin, the Tanana–Kuskokwim Lowlands and the Yukon River Lowlands. Units of old, largely unglaciated mountains are the Kobuk Ridges and Valleys, the Ray Mountains, the Davidson Mountains, the North Ogilvie Mountains, the Yukon–Tanana Uplands, and the Kuskokwim Mountains.

The boreal lowlands are drained by several large river systems, including the Yukon (the

The broad valley of the Kobuk River shows the mosaic of conifer and deciduous forests shifting in response to multiple changes in the river channel.

fourth longest in North America), Porcupine, Tanana, Koyukuk, and Kuskokwim. The climate becomes progressively more continental the farther east one travels, as the temperature ranges become greater and precipitation decreases. These river valleys were largely unglaciated during the Pleistocene. However, most of these areas are blanketed in thick loess (fine-grained silt), blown off the glaciated areas of the Alaska Range, and alluvial deposits from side streams in the hills and mountains. The Yukon Flats and Old Crow Basins are gently sloping basins composed of depositional fans, terraces, and mountain toeslopes with deep colluvial (deposited by gravity), alluvial, and eolian deposits underlain by continuous masses of permafrost. The lowlands of the Yukon, Tanana, and Kuskokwim Rivers have deep alluvial sediments overlain by eolian loess. Ice-rich permafrost permeates organic soils with varying patterns of thickness and continuity. The resultant floodplains and wetlands support intricate wetlands, old river sloughs, and subtle hills.

The highly productive vegetation along the major rivers supports vigorous stands of white spruce and balsam poplar. Robust wet sedge meadows and aquatic vegetation are invading sloughs and oxbow ponds. The adjacent permafrost-dominated lowlands support black spruce woodlands, dwarf birch and low-growing ericaceous shrubs of the heath family, and sedge–tussock bogs. The rich aquatic habitats support tremendous concentrations of nesting waterfowl (in the millions!) and other migratory birds and an abundance of moose, bears, furbearers, northern pike, and salmon. Large rivers support important runs of chinook, chum, and coho salmon, while clear tributary streams support dolly varden and grayling. Flat areas are pockmarked with lakes and ponds. These areas support large populations of moose and black bear; the oxbow sloughs and thaw ponds support abundant waterfowl during breeding season; and the lowland forests are important to furbearers, including beavers, muskrats, and martins. Cliffs along the rivers are excellent nesting habitat for ravens and raptors such as peregrine falcons. Yellow-cheeked voles are found in early successional riparian and recently burned areas throughout the Alaskan and Canadian boreal forests (see p. 48).

Boreal uplands are characterized by low- to mid-height hills and mountains, with subtle topography from long-term weathering without the impacts of glaciers. Again, many of the upland units, especially the Kuskokwim Mountains and the Yukon–Tanana Uplands on the southern side of the intermontane valley, are cloaked with loess blown north from the Alaska Range glaciers during the Pleistocene. The Kobuk Ridges and Valley and the Davidson Mountains on the northern side of the boreal division were subject to partial glaciations during the Pleistocene, with morainal remnants strewn along classic U-shaped valley walls. The North Ogilvie Mountains are

Lightening-caused wildfires are constantly burning patches of the boreal forest, creating a mosaic of successional vegetation communities that provide habitat for many wildlife and bird species.

Fall colors drape the lowlands of the Kenai Peninsula in the Cook Inlet Basin. Lakes were created from remnant blocks of ice abandoned by retreating glaciers, and the mixed forests and wetlands are habitat for moose, bears, waterfowl, and beavers.

the oldest portion of Alaska, representing the western extent of the North America stable platform, where terranes rafting from the Pacific and Arctic Oceans finally came to rest and docked. Several of these boreal mountain units are host to hot springs. Vegetation is dominated by white spruce, birch, and aspen on south-facing slopes, black spruce on north-facing slopes, and black spruce woodlands and tussock and scrub bogs in valley bottoms. Floodplains of headwater streams support white spruce, balsam poplar, alder, and willows. Above treeline, dwarf birch and ericaceous shrubs and *Dryas*–lichen tundra dominate. Lightning from frequent summer thunderstorms starts many wildfires each year. These fires contribute to the spectacular mosaic of forest successional stages that provide a wide range of habitats. Caribou, moose, snowshoe hares, martens, lynx, and black and grizzly bears are plentiful (see p. 63). The clear headwater streams are important spawning areas for chinook, chum, and coho salmon.

The **Alaska Range Transition Division** literally rises between the continental boreal interior of Alaska and the marine rainforest coastlands along the Gulf of Alaska. The climate of this division has shorter winters than the continental interior and warmer, drier summers than the marine-influenced coastal rainforests. However, the Alaska Range, including Mt. McKinley (Denali) at over 20,000 feet, generates its own weather, as moisture-laden air rises over the massif and releases heavy snowfalls on the upper elevations. Pleistocene glaciers heavily influenced the entire area, and remnants of glaciers and many glacial features still define the landscape. Boreal forests are distributed in the valleys and lowlands of the division, but wildfire and permafrost have much less influence on vegetation succession and distribution. The ecoregions of the Alaska Range Transition are the Lime Hills, the Alaska Range, the Cook Inlet Basin, and the Copper River Basin.

The Alaska Range is a long arcing wall of accreted terranes that have fused into a complex mix of folded, fractured, and deformed sedimentary and metamorphic rocks with intrusions of granite. The Denali Fault runs parallel to and within the Alaska Range for the easternmost 350 miles,

The Alaska Range rises abruptly from nearby river basins, creating its own climate, which is a transition between the continental conditions of interior Alaska and the marine systems along the north Gulf of Alaska coast. Sparse taiga forests and wetlands are common in the Susitna and Copper River Basins of the Alaska Range Transition Division.

A grizzly sow and her cub forage for blueberries and mossberries in the brilliant fall colors of subalpine ericaceous shrub tundra. This pair was photographed in early September on the north slopes of the Alaska Range.

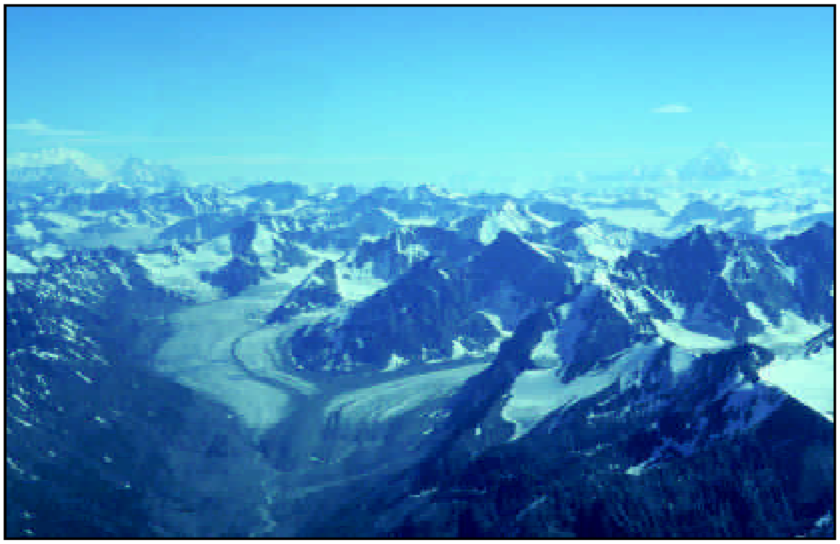
before the range takes a turn to the south and the Denali Fault continues southwesterly into the Kuskokwim Basin. The Alaska Range was the origin for much of the Pleistocene ice that flowed out of the mountains in all directions and substantially formed the landscape. Large valley glaciers and ice caps still flow off the peaks of the Alaska Range. The Lime Hills area immediately west of the Alaska Range is a series of east–west-trending ridges and intervening valleys. This area was repeatedly scoured by huge valley glaciers flowing out of the Alaska Range and, like the Cook Inlet and Copper River Basins, is covered with glacial moraines, lacustrine sediments deposited in lakes, and outwash plains. The Copper River Basin was the location of Great Lake Ahtna, a large proglacial lake dammed by glaciers blocking the Chugach Range to the south. The Cook Inlet and Susitna valleys are a large trough between the Alaska and Kenai Mountains that has been subject to repeated glacial advances. Some of these glaciations also formed large lakes over the current Kenai Peninsula. The region is covered with a subdued pattern of low ridges and lakes or wetlands.

This division forms the headwaters for rivers flowing into all the oceans surrounding Alaska except the Arctic Ocean. Glacial rivers are silty and braided, with broad, gravelly floodplains. Clear streams are generally smaller with narrower floodplains and lose their clear identity as soon as they flow into a glacial stream. Arctic grayling are common in clear mountain streams, and all five species of Pacific salmon migrate into rivers of the Alaska Range Transition.

Soils in the mountainous units of the Alaska Range and Lime Hills are generally thin, rocky, and cold, with scattered pockets of permafrost. The Copper River Basin floor is formed of interleaved lacustrine deposits, glacial material, and volcanic debris that forms fine-grained saturated soils with ice-rich permafrost. Soils of the Cook Inlet Basin are a complex mixture of alluvial, glacial, volcanic, and lacustrine materials with occasional patches of permafrost. Both basins support boreal vegetation patterns, with white spruce and birch on higher ground and black spruce, low shrubs, sedges, and mosses growing in the wetlands. White spruce and balsam poplar form successional stands along the rivers. The lower slopes of the Alaska Range and Talkeetna Mountains are covered with dense thickets of alder that transition to low shrubs in the subalpine and blueberry-rich alpine tundra. Vegetation of all types succumbs to the harsh conditions at about 4000 feet, leaving the higher arena to bare rock, talus (broken loose bedrock), and ice.

The wide variety of habitats, ranging from sea level to several thousand feet, in a transitional climate support many species of mammals and resident and migratory birds. Moose, grizzly and black bears, wolves, foxes, beavers, and various small mammals are fairly common in the Cook Inlet Basin and lower reaches of the Alaska Range (see p. 18). Caribou herds roam the Alaska Range, Lime Hills, and Copper River Basin (see p. 63). Waterfowl nest in the wetlands of the basins, although not in the concentrations found in the Y–K Delta or Yukon Flats. Golden eagles nest in the mountains and disperse farther south for the winter months (see p. 22). Ptarmigan spend the winters in willow thickets with a white coat of double feathers all the way down their feet, and ravens haunt urban dumpsters looking for high-calorie treats and roadkill.

The **Coast Mountains Transition Division** is similar to the Alaska Range Transition in that a range of very high mountains is thrust up between a dry continental climate of the upper Yukon River drainage and the maritime-driven climate of the



Valley glaciers flow between nameless peaks in the towering Wrangell Mountains. Moisture-laden clouds sweeping inland from the Gulf of Alaska are cooled as they rise over the mountains, and the resulting prodigious snowfalls create the largest icefield outside the Arctic and Antarctic latitudes.

Chugach and St. Elias Ranges. Because of their sheer height, these mountains capture ocean-derived moisture as it passes inland. Yet, their proximity to Interior Alaska gives these mountains a fair degree of seasonal temperature change similar to a continental climate. Climatic influences change with elevation, with maritime conditions on mountaintops (feeding ice caps and glaciers) grading to continental conditions at their base (boreal forests). The Wrangell Mountains and the Kluane Ranges ecoregions comprise the Coast Mountains Transition.

The Wrangell Mountains are a compact layer cake of volcanic and deformed sedimentary materials, stacked up for thousands of feet, topped by recent volcanic lava and ash, and etched by massive glaciers. The abundant maritime snows feed extensive icefields and glaciers interspersed by dull gray ridges draped with rock shard slopes and patches of alpine meadows. The Kluane Ranges reach east into Canada in the rain shadow of the St. Elias Mountains along the steep slopes of the fault line scarp in the Shakwak Valley. Occasional glaciers flow onto the Kluane Ranges from the St. Elias icefields, but the unit is generally ice-free.

Continental climates around the toeslopes of the Wrangell Mountains support permafrost soils and boreal forests of black spruce and birch, grading up into drier shrublands, and typical alpine communities of low ericaceous shrubs, lichens, and barrens. The Kluane Ranges have thin rocky soils with discontinuous permafrost. The unstable materials are constantly moving downslope as talus, stream erosion, or solifluction. The dry climate supports white spruce woodlands with balsam poplar and aspen stands, grading upward into willow shrubland and typical low and dwarf shrub communities in the alpine areas. Snowshoe hares and lynx exhibit cyclic fluctuations in abundance, with lynx numbers dropping shortly after the peak in hare population. Dall's sheep roam throughout the area, along with mountain goats, brown bears, caribou, wolverines, and gray wolves.

The **Coastal Rainforest Division** includes the great arc of mountains and the forested fringe that swing around the north and east shores of the Gulf of Alaska. Terranes that originated beneath the Pacific Ocean have been rafted into place and accreted in ridges. Frequent earthquakes along the dip of the Pacific Plate under the North American Plate result from continuing uplifting and faulting of the sedimentary and volcanic materials.

Dominant storm tracks from late summer through early spring curl east from the Aleutians into the Gulf. Upon hitting shore, the moisture-laden air rises over the mountains, dropping copious rain at lower elevations and snow at the higher altitudes. The Gulf of Alaska current flows east to west along the coast, bringing relatively warm temperatures throughout the year. The warm, wet climate supports lush conifer rainforests along the coast and large icefields and glaciers at higher elevations. All of the division has been heavily glaciated several times during the Pleistocene.

The coastlands reflect their glacial heritage, with steep bedrock fjords, tidewater glaciers, and numerous rocky islands. The Coastal Rainforest Division includes the mountainous units of the Chugach–St. Elias Mountains and the Boundary Ranges and the island and fjord lands of the Alexander Archipelago, the Gulf of Alaska Coast, and Kodiak Island.

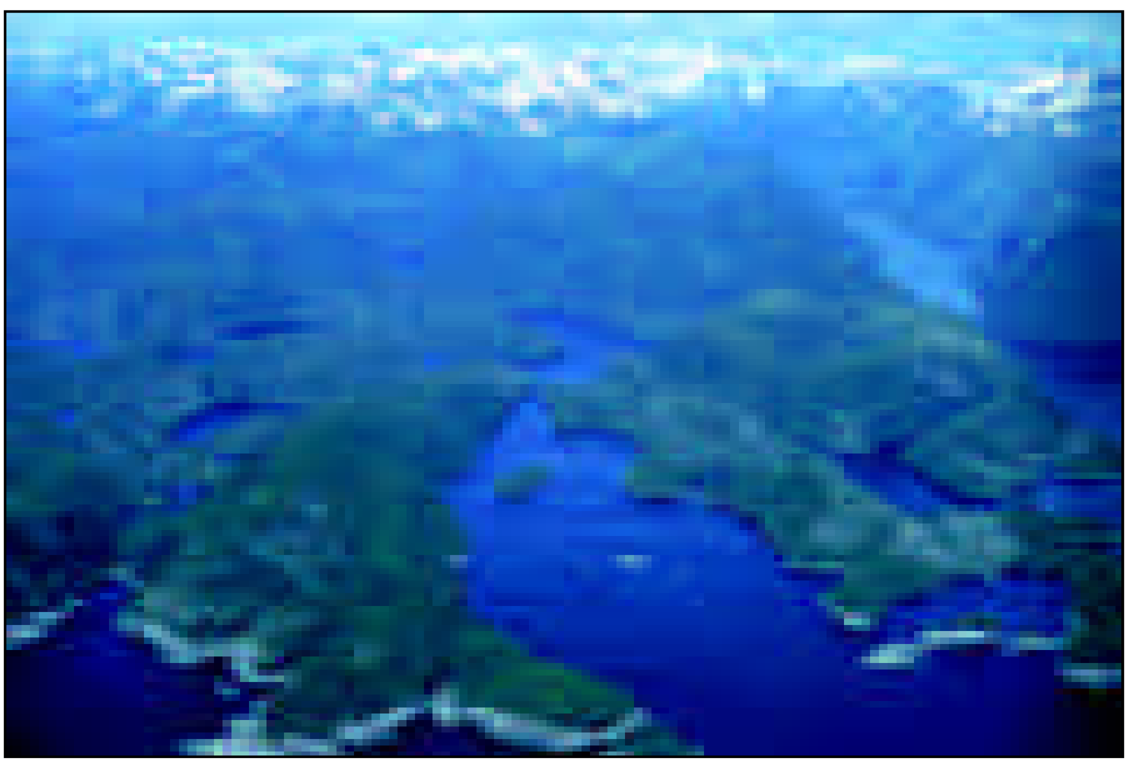
Mountains tower behind the Gulf Coast to altitudes over 19,000 feet. The largest icecap outside of the polar regions drapes the folded sedimentary rocks of the Chugach and St. Elias Mountains. Huge valley glaciers flow out of this icecap, many to tidewater. The Bering Glacier, at more than 2000 square miles, spreads out over the lowlands of the Gulf Coast. The Hubbard Glacier surged during the summers of 1986 and 2002, blocking off Russell Fjord for several weeks each time. The Boundary Ranges, located farther south and lower in elevation, hold only mountain glaciers. The Alexander Archipelago, the Gulf of Alaska Coast, and the Kodiak Archipelago all face the Gulf of Alaska, with intricate glacier-carved coastlines. Long, deep fjords formed where glacier-carved terrain filled with seawater after deglaciation. Thousands of islands, islets, and rocks indicate the summits of submerged mountain ranges and present both a challenge and a delight to mariners.

A few areas along this coast remained ice-free during one or more glacial advances, providing refugia for plant and animal species to survive the Pleistocene advances. Humans may have also migrated along the coast from one ice-free toehold to another. Movements of the earth's crust continue to raise and lower portions of the coast, creating and deleting coastal lagoons, beaches, and tideflats. Soils are exceptionally thin except in riparian zones. Relatively warm winters preclude permafrost.

Short rivers flow out of glaciers in braided floodplains or tumble off rocky mountainsides in barely contained waterfalls. Five species of Pacific salmon migrate into these fast-flowing streams to spawn. Dolly Varden char and steelhead (ocean-going rainbow) trout live in larger clear-water streams along the coast and on Kodiak Island. The land and sea are intimately connected, as spawning salmon return to their native streams and, in the process, cycle tremendous amounts of nutrients back to the freshwater and terrestrial systems that bore them life. Streams become increasingly littered with spawned-out carcasses as brown and black bears, bald eagles, and gulls feast on returning salmon from late spring to early fall.

The warm maritime environment encourages lush moss-draped conifer forests along the coast. Old-growth forests of Sitka spruce, hemlock, and cedar blanket the lower slopes of the Alexander Archipelago. Toward the west, cedar drops out in Prince William Sound, and hemlock reaches to the end of the Kenai Peninsula. On Kodiak, Sitka spruce is expanding south across the island into new habitats. Pockets of wetlands have formed on shallow, poorly drained soils on bedrock throughout the division. The stunted trees, tiny ponds, and bedrock outcrops give the appearance of a giant bonsai garden. Hidden coves and rocky islands are fringed with intertidal communities of kelps, eelgrass, and barnacles. Upper forests give way to a narrow subalpine zone of alder and herbaceous meadows and then alpine tundra and bedrock or ice.

Common forest animals include black and brown bears and Sitka black-tailed deer. Offshore waters are rich with deepwater fish, such as halibut and cod. Grey whales migrate along the coast, following the warm Gulf current as far as the Arctic Ocean for summer, returning to the Gulf of Mexico for the winter months. Humpback whales migrate annually between winter calving grounds near the Hawaiian Islands and summer feeding grounds near Glacier Bay (see p. 42). Bald eagles, common



The fjord-studded Alexander Archipelago was carved by massive glaciers rising in the background Boundary Ranges of southeast Alaska. The retreating glaciers left an intricate coastline with dense conifer forests on the lower mountain slopes, rising to alpine tundra and barrens.

Bear Glacier, one of the largest concentrations of tidewater glaciers in the northern hemisphere, meets the sea along the Gulf of Alaska coastline. The glacially formed lagoons and fjords are habitat for seals, whales, sea otters, and terrestrial mammals.

murres, Bonaparte's gulls, Steller sea lions, harbor seals, and sea otters teem along its endless shorelines (see p. 31 and 36).

The **Aleutian Meadow Division** stretches nearly 2000 miles, reaching from Iliamna Lake west to the Komandorskiye Islands near the Kamchatka Peninsula in Russia. The fog-shrouded Aleutian Islands and storm-pounded coasts of the Alaska Peninsula make up this exposed division, set between the cold Bering Sea and the stormy North Pacific Ocean. This division is defined by cool, moist, and harsh weather, which limits tree growth to a few Sitka spruce perched on rocky promontories on the Shelikof Strait coast. The division is formed by the Pacific Plate Subduction Zone, where the Pacific Plate dives beneath the North American Plate, forming one of the most seismically and volcanically active areas in the world. The area hosts 80% of the active volcanoes in the United States, and many of the gently steaming cones may erupt at any time.

Glaciers have also played a role in shaping this land of fire and ice. Thick ice sheets from the Alaska Range and lower Cook Inlet overrode the mountains near Iliamna and Katmai, rounding off lower mountains and leaving large basins filled with freshwater lakes along the western slopes of the Alaska Peninsula ecoregion. Glaciers also formed on the wetter, southern side of Aniakchak, Veniaminof, and Pavlof volcanoes, expanding south onto the narrow shelf at the edge of the North Pacific. The Aleutian Islands are predominately volcanic features rising above the turbulent seas.

Permafrost is absent from this division, reflecting the relatively warm climate dominated by oceanic influences. Soils are a mixture of volcanic materials, often reworked by glacial and alluvial agents. Areas of recent glaciations and volcanic activity such as Katmai and Aniakchak are largely barren cinder plains. Other parts of the region, well watered by Pacific storms and fertilized by nesting seabirds, support lush meadow and heath vegetation communities, with willows along streams. The flora is a blend of species from two continents, grading from Asian to North American affinities from west to east.

This division is the domain of seabirds, waterfowl, and marine mammals. Sea otter populations have rebounded since near extirpation by Russian and American fur traders and are now distributed through most of their former range along the Aleutian and Gulf of Alaska coasts (see p. 31). Stellar sea lions use low rocky shelves as haulouts and pupping areas, although their numbers have dropped dramatically within the past several decades (see p. 36). Several species of whales reside here or migrate through en route to the Arctic Ocean. Onshore, coastal brown bears feed on lush sedge meadows and salmon runs, moose are expanding gradually down the peninsula, and caribou are native on the peninsula and Unimak Island and have been introduced to several Aleutian Islands. Foxes, introduced to many islands for fox farming, and rats, introduced accidentally from ships, have nearly decimated ground-nesting waterfowl, including the Aleutian Canada goose. Fox eradication and careful reintroduction of the Aleutian goose on several islands have recently resulted in its removal from the endangered species listing.

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Mt. Peulik, a dormant volcano, rises on the shores of Becharof Lake. The low shrubs and sedge tundra are characteristic of the Aleutian Meadow Division.

Grizzly Bear Population Ecology and Monitoring in Denali National Park and Preserve

This article was prepared by Patricia Owen, Wildlife Biologist, Denali National Park and Preserve.

Grizzly bears are an important component of Denali National Park and Preserve. The legislation that created the park (formerly Mt. McKinley National Park) established a game refuge for the animals, so grizzly bears have not been hunted there since 1917. The park now supports a naturally regulated grizzly bear population as an active component of a large-mammal predator–prey system that includes wolves, caribou, moose, and Dall's sheep.

Grizzly bears are also a primary reason that many people visit Denali. A recent survey estimated that 90% of visitors travelling the park road observed at least one grizzly bear on their trip. Numerous studies have described the adverse effects of humans and associated development on grizzly bears. Harvest of grizzly bears outside the park and concerns regarding the impacts of human access within the park resulted in the need for objective information on the status and trends of the grizzly bear population in Denali.

This study was initiated in 1991 to examine the role of grizzly bears as predators of caribou calves. The emphasis of the project was redirected early on to describe the characteristics of a sample population of grizzly bears in Denali National Park and to develop and test noninvasive techniques for determining the density of bears in the park. The focus has since shifted to long-term monitoring of cub production and survival.

A National Park Service biologist collecting data from an immobilized bear.

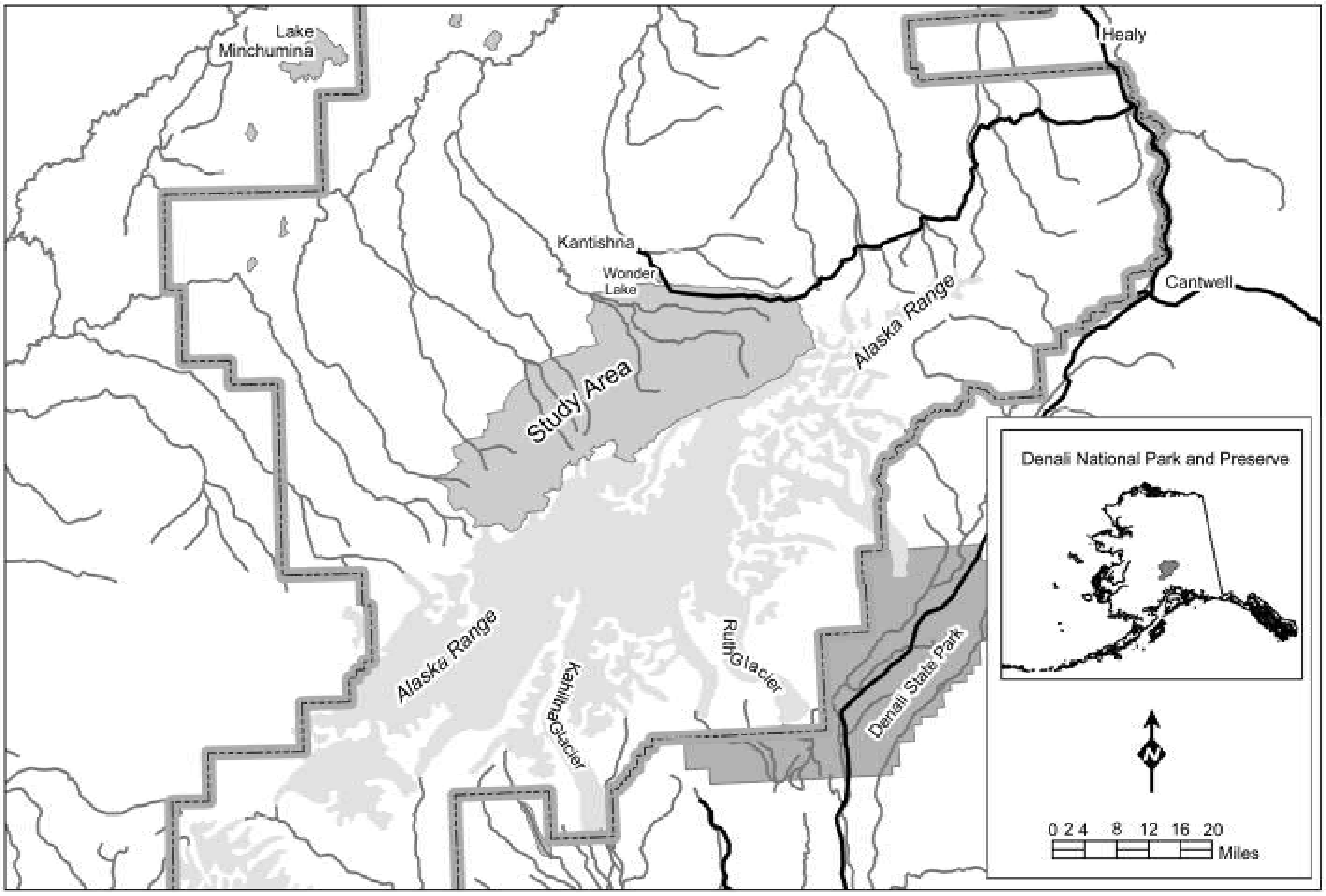
Study Area

Our study area lies along the north slope of the central Alaska Range in Denali National Park and Preserve, from the east side of the Muldrow Glacier west to the Herron River. The 1750-square-kilometer (675-square-mile) study area includes elevations ranging from 600 to 2000 meters (2000 to 6500 feet). The area includes important foraging habitats, such as large, concentrated berry patches on glacial moraines and hillsides, as well as winter denning habitat. It also includes the principal calving area for the Denali caribou herd. The climate is generally cool and wet during the summer, with temperatures around 10–15°C (50–60°F). Freezing temperatures and snow may occur during any month. Snow accumulation usually begins in October and dissipates from lowlands and unshaded portions of foothills by mid- to late May.

Methods

The study relies heavily on radiotelemetry to acquire information about individual bears and therefore requires catching animals to attach radio collars. Bears in the study area are located for capture using a small fixed-wing aircraft. Once located, bears are darted from a helicopter using an immobilizing drug delivered in a projectile syringe fired from a syringe rifle. Darted bears are monitored from the aircraft until they are immobilized, at which time the helicopter crew lands to process the bear.

Standard morphological measurements, such as head and neck circumference and body length as

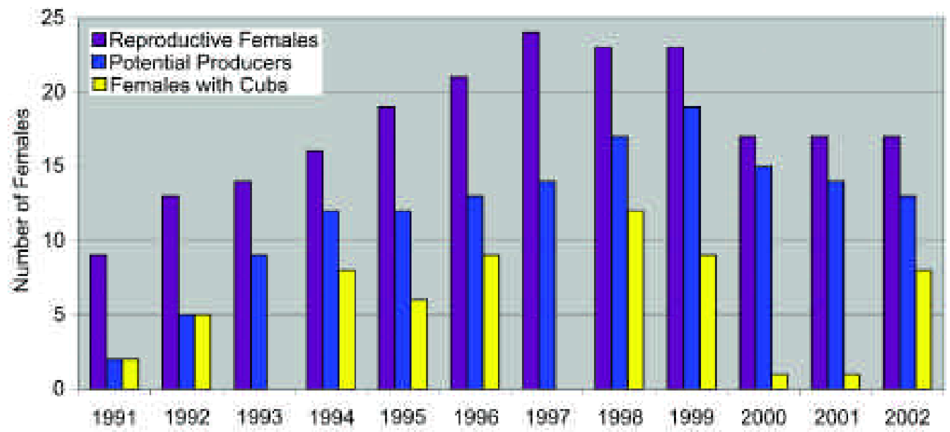


well as weight, are taken to monitor growth and physical condition. Bioelectrical impedance analysis (BIA) is used to determine percent body fat. BIA is the same method used to determine body fat in humans. It is a measure of the body's resistance to the flow of a very weak electrical current. The resistance measurement is entered into a formula specific to grizzly bears to calculate percent body fat. A small vestigial tooth is extracted from independent bears during their initial capture to determine age. Teeth are sent to a laboratory, where they are sliced into thin sections and stained. The rings of cementum on the tooth can then be counted under a microscope, much like the rings on a tree, to determine age. Blood samples are collected to assess disease exposure.

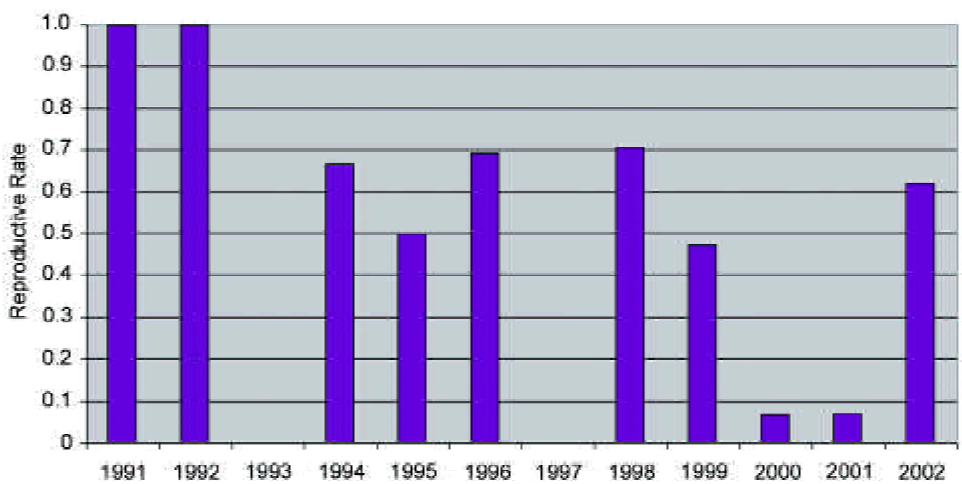
Since much of the study area is not easily accessible from the Denali Park road, bears are subsequently located using a fixed-wing aircraft. The first radiotelemetry flights of the season begin in mid-April each year, continue through the summer, and end in late October once all the bears are determined to be denning. Early-season flights allow us to determine when bears emerge from their dens in the spring so that we can get accurate counts of the number of cubs that each female bear has produced. Flights throughout the summer months enable us to gather information on habitat use and cub mortality as well as mortality of independent bears and family breakup. In the fall we determine den locations and den entrance dates and confirm the remaining numbers of cubs.

Results

Since the study is now focused on cub production and survival, collars have been maintained only on female bears. Each year we examine the previous year's data to determine the number of reproductive females (those six years old or older) and the number of "potential producers" (those reproductive females that were available to breed the previous year). Females are considered available to breed the previous year if they did not produce cubs that year or had cubs but lost them



Female history, 1991–2002.



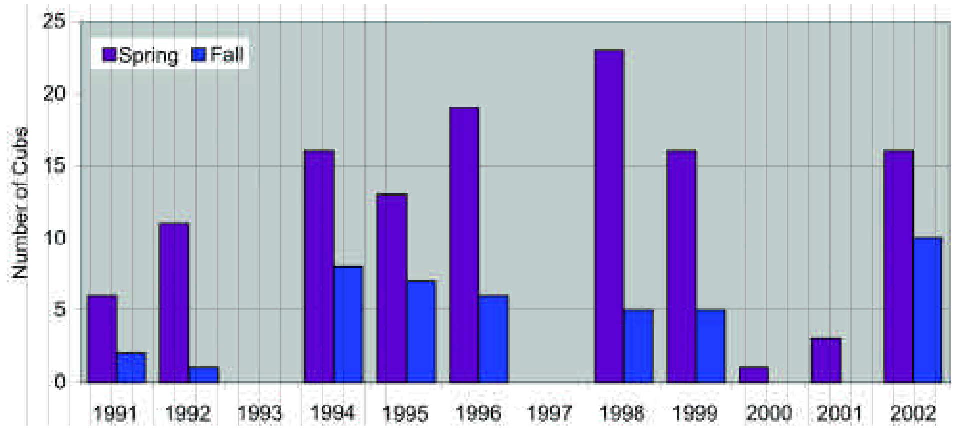
Reproductive rates, 1991–2002.

early enough to breed again. Starting at den emergence, we locate the "potential producers" to determine the number with cubs and the number of cubs produced. The number of females with cubs has varied widely over the years.

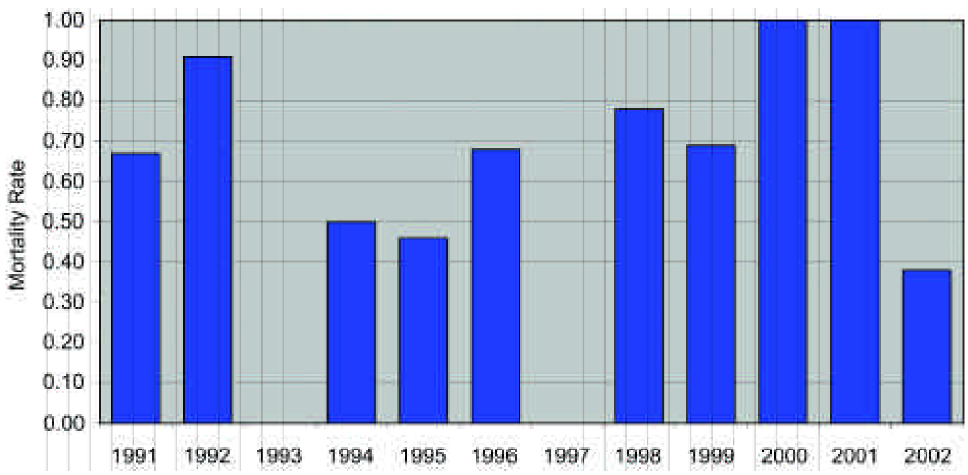
Though the number of collared female bears in the study has varied, we are able to compare years by calculating reproductive rates. Reproductive rates compare the number of females with cubs to the number of potential producers. Reproductive rates of zero in 1993 and 1997 and rates of less than 0.10 in 2000 and 2001 are yet to be fully explained. The lack of productivity in 1993 may be explained by unusual weather patterns that occurred the previous year, when the area received heavy snowfalls in both mid-May and mid-September, resulting in an abbreviated summer season. Female bears may not have had the opportunity to accumulate sufficient fat reserves to maintain themselves and cubs while denning during the winter of 1992-93. Unfortunately, no obvious weather patterns could be identified to explain zero to low productivity in 1997, 2000, or 2001.

Accurate counts of the number of cubs produced each year and the number of cubs still alive at the time of den entrance have allowed us to track cub mortality. Cub mortality was unusually high early in the study. Mortality rates calculated for each year of the study vary from 46 to 100%, with an average mortality rate over the course of the study of about 71%.

We attempted to determine the cause of death in cubs by attaching small radio collars to six cubs in 1994. The collar was designed to enlarge as the cub grew and to fall off before denning. At the time the collars fell off, all six cubs were still alive. Because a small unmarked bear carcass is difficult to locate, we have only been able to determine the cause of death in one cub in the 12 years of the



Numbers of cubs, spring and fall, 1991–2002.



Mortality of cubs of the year, 1991–2002.

study. A necropsy of the carcass revealed that it was killed in a rock slide.

Discussion

Though this study has been in progress for some time, many questions remain about grizzly bears in Denali. From early survey work we have determined that the density of grizzly bears in the study area is about 27 independent bears per 1000 square kilometers (386 square miles). It is difficult, however, to extrapolate this number into an estimate of grizzly bear density for the entire Denali National Park since much of the remainder of the park contains habitat that may or may not support grizzly bears.

We have learned that grizzly bear cub mortality is high and that productivity varies widely, but the underlying reasons for these facts are still largely unknown. Investigations into the role of female physical condition in relation to cub production and survival will continue. The availability of abundant berry crops in the late summer and fall is likely key to the accumulation of adequate fat reserves in bears. Surveys to quantify berry crops in the study area and measure fall body fat are needed to test the relationship between female body condition and cub production and survival. Disease is probably not a significant factor affecting grizzly bear cub survival. Blood samples showed low prevalence when tested for wildlife diseases including infectious canine hepatitis, canine distemper, and leptospirosis.

Even with high cub mortality and variable productivity, the high density, high independent bear survival rates, and lack of human interference suggest that the Denali grizzly bear population is likely stable. Cub production and survival has likely not been monitored long enough to include a pulse in recruitment.

Birds, Bird Studies, and Bird Conservation in Denali National Park and Preserve

This article was prepared by Carol L. McIntyre, Wildlife Biologist, Denali National Park and Preserve.

Mt. McKinley National Park was created in 1917, mainly because of its rich wildlife resources. With the passage of the Alaska National Interest Lands Conservation Act (commonly referred to as ANILCA) in 1980, nearly 4 million acres were added to the original park, and the new complex of park and preserve lands was designated as Denali National Park and Preserve. Denali is well known for its diversity of wildlife and scenery. Thirty-nine species of mammals, 165 species of birds, 10 species of fish, and one amphibian have been recorded in Denali. Of the bird species, 149 occur regularly and 119 are recorded as breeders (nesting in the park and preserve).

Naturalist Charles Sheldon and scientists Joseph Dixon, George Wright, Olaus Murie, and Adolph Murie, who worked in Denali from 1906 through the early 1930s, were the first scientists to study and understand the ecological significance of birds in Denali. These early studies were followed by more in-depth and long-term studies by Adolph Murie extending from the late 1930s until about 1970. The valuable contributions of these scientists are published in several books. The travels and field observations of Charles Sheldon were published in 1930 in *The Wilderness of Denali*. In 1938, Joseph Dixon published the findings of his field studies in the notable book *Birds and Mammals of Mount McKinley National Park, Alaska*. Adolph Murie made significant contributions to understanding many northern species with his landmark books *The Wolves of Mount McKinley* published in 1944, *The Mammals of Mount McKinley* published in 1962, *The Birds of Mount McKinley, Alaska* published in 1963, and *The Grizzlies of Mount McKinley* published in 1985. In *The Birds of Mount McKinley, Alaska*, Murie states…

> "In McKinley Park the visitor has the rare opportunity to enjoy northern landscapes, a variety of lichens and flowers, and grizzlies, caribou, Dall sheep, perhaps a wolf or a wolverine, and a number of birds in their northern breeding grounds. Of special interest among the birds are three species of ptarmigan, each with a specialized voice and an inclination to use it. There are shorebirds, two of which, the surfbird and the wandering tattler, are of special interest because most of the nesting data on them have been gathered in the park. The arctic warbler and the wheatear, visitors from Asia, are relatively common. The golden eagle, unmolested and free, may frequently be seen soaring in the blue sky over its mountain home. May this magnificent bird and other migrants, survive the many new hazards in the south and continue returning each spring in the future, to contribute beauty and spirit to this northern wilderness."

The foresight of Adolph Murie is evident in this passage from his book. Murie and others realized that Denali is not isolated from the environmental hazards created by humans and that its migratory birds face an increasing number of threats on their migratory journeys and wintering grounds. Murie, along with other naturalists and scientists including Charles Sheldon, Joseph Dixon, and George Wright, all realized the importance of preserving the ecosystems and wildlife of Denali in the rapidly changing world.

Denali's bird life is made up of migratory birds from all over the globe and a hardy group of birds that remain in the area year-round. The abundance of birds in Denali ebbs and flows across the seasons, increasing significantly as migrants return to Denali in spring and decreasing when they depart in autumn. Summer birding in Denali rewards visitors with opportunities to view many species in this spectacular northern environment. Birding in winter is slim by numbers but great in rewards, as observations of pine grosbeaks, mixed flocks of ptarmigan, or perhaps a northern goshawk or gyrfalcon await the hardy winter birder.

Visitors are drawn to Denali to search for many northern species of birds. The beauty and the unique lifestyles of these northern breeders rouse the curiosity of many naturalists, scientists, and visitors. While we revere the beauty of Denali's

Opportunities to see the strikingly handsome northern hawk owl lure many birdwatchers to Denali.

birds, we must also acknowledge the threats to their existence. Denali's migratory birds face a multitude of hazards during their migratory journeys and on their wintering areas. Even in the seemingly pristine environments of Denali, year-round residents face changes in habitat, climate, and the presence of chemical contaminants. Broad-scale threats such as chemical pollutants that remain in our environment (known as persistent organic pollutants) and global climatic changes may have long-lasting and far-reaching effects on Denali's birds. On a local scale, increases in human activities may alter the habitats and habits of different species as more humans visit Denali.

The goal of this article is to introduce you to the birds of Denali, describe some of our historic and recent bird studies, and discuss some of the conservation issues facing Denali's birds. By learning more about Denali's birds and how they connect Denali to the world, we can better understand the role that Denali and its bird life play in global ecosystems. By understanding these ecological connections, perhaps we can more clearly see our role in preserving global ecosystems for birds—and for ourselves.

The Birds

Thirty-five species of water birds (loons, grebes, swans, and ducks) occur in Denali, and 23 species are recorded as nesting in Denali. Three species of loons—red-throated, Pacific, and common—and two species of grebes—horned and red-necked—nest in Denali. Geese are most often seen during migration and are not common breeders, except for white-fronted geese, including Tule's white-fronted geese, which nest in Denali. Over 400 pairs of trumpeter swans nest in the productive wetlands in the northwestern portion of Denali and along Denali's southern borders. Tundra swans do not nest in Denali but are commonly seen during spring and autumn migration. Twenty-three species of ducks, including 15 nesting species, occur in Denali. Nesting species include American wigeon, mallard, northern shoveler, northern pintail, green-winged teal, greater and lesser scaup, harlequin, surf scoter, white-winged scoter, black scoter, long-tailed duck, bufflehead, Barrow's goldeneye, and red-breasted merganser. Ducks seen during migration include gadwall, Eurasian wigeon, blue-winged teal, canvasback, redhead, ring-necked, common goldeneye, and common merganser. All of the water birds that occur in Denali are migratory. Some species, such as the long-tailed duck and surf scoter, spend their winters at sea. Other species, such as the white-fronted goose, may winter as far south as central Mexico.

Predatory birds (or raptors), including harriers, hawks, eagles, falcons, and owls, are well represented in Denali. Species nesting in Denali include osprey (rare), northern harrier, bald eagle, sharp-shinned hawk, northern goshawk, red-tailed hawk, golden eagle, gyrfalcon, peregrine falcon, merlin, American kestrel, great-horned owl, northern hawk owl, great gray owl (rare), short-eared owl, and boreal owl. Migrants and occasional visitors include rough-legged hawk and snowy owl. Most of the diurnal raptors—the harriers, hawks, eagles, and falcons—are migratory. Exceptions to this include gyrfalcons and northern goshawks. Gyrfalcons are the largest falcon in the world, and they nest only in Arctic regions. Adult gyrfalcons usually remain on or near their nesting grounds throughout the year unless they can't find food. Juvenile gyrfalcons are more likely to move away from the nesting grounds during the winter in search of food. Northern goshawks are usually year-round residents but will leave this area when food is scarce. Most of Denali's owls are year-round residents, with the exception of short-eared owls. These beautiful owls are migratory, but we haven't identified their wintering areas. Northern hawk owls and great gray owls are nomadic, and they move long distances in search of food.

The wintering range of Denali's migratory raptors and owl spans a large area from central Alberta to South America. Within a species, individuals in a population may also be spread over a large geographic area in winter. For instance, golden eagles from Denali winter from central Alberta to north-central Mexico and merlins from Denali may winter from the southwestern United States (including southern California) to central South America.

Ruffed and spruce grouse and all three species of North American ptarmigan (willow, rock, and white-tailed) are year-round residents in Denali. Grouse are found in the forested regions of Denali. The smallest and least abundant white-tailed ptarmigan is usually found at higher elevations. The larger and more abundant rock ptarmigan is a bit easier to find and occurs in alpine tundra. The most common and largest of the three species, the willow ptarmigan, occurs in shrubby areas, usually at or below tree line. All three species flock together in winter.

The loud haunting calls of the American golden plover are commonly heard in alpine areas of Denali in the summer.

One of the greatest birdwatching experiences in Denali is the spring and autumn migrations of sandhill cranes. In late August the snowlines and temperatures creep down, the tundra turns crimson and gold, and large flocks of sandhill cranes whirl overhead on their way south. From late August through mid-September, the loud, resonating "garroo-garroo-garroo" of the adults and the higher-pitched shrill calls of the juveniles are common sounds near Wonder Lake. The return of sandhill cranes in May is a sure sign of spring.

Many visitors are surprised to learn that Denali is home to nesting shorebirds. At least 21 species of shorebirds nest in Denali, and six other species occur during migration. All the shorebirds are migratory, and most migrate long distances between their breeding and wintering grounds. Shorebirds nesting at higher elevations include American golden plover, upland sandpiper, surfbird, and Baird's sandpiper. Shorebirds nesting at lower elevations include semipalmated plover, greater and lesser yellowlegs, solitary sandpiper, wandering tattler, spotted sandpiper, whimbrel, least sandpiper, long-billed dowitcher, common snipe, and red-necked phalarope. These globe-trotters are a delight to watch in Denali. Birds with intriguing names and habits, like the wandering tattler, attract birdwatchers by the score. The American golden plover has exquisite plumage, an evocative voice, and a globe-spanning reach (they winter in South America). Surfbirds, who spend most of their lives along coastal areas, nest in the mountainous regions of Denali.

Several species of birds that spend a portion of their lives at sea come inland to nest in Denali. Two elegant species—the long-tailed jaeger and the arctic tern—grace the summer skies of Denali. The beautiful long-tailed jaeger nests on the tundra, and these lithe, aerial hunters patrol the tundra in search of prey. As agile and elegant as jaegers, arctic terns nest near the numerous lakes and ponds in Denali. They hover seemingly effortlessly over ponds in search of prey. The wintering grounds of long-tailed jaegers are not well-described, and the wintering grounds of arctic terns include the oceanic regions of Antarctica.

Of all the animals on earth, arctic terns probably enjoy the highest percentage of daylight through the year. Many visitors remark about the presence of "seagulls" in Denali. The term "seagull" is deceptive; the two species that nest in Denali—the mew gull and Bonaparte's gull—are inland nesters. Most visitors quickly become familiar with mew gulls, as this species is often seen begging for food at areas where people congregate. Bonaparte's gulls, with their black heads, are often confused with arctic terns, with which they share similar habitat.

The habitat bordering the many streams in Denali (known as riparian habitat) supports many species of birds. The belted kingfisher, which is familiar to many Denali visitors, lives along streams in Denali. Like bank swallows, belted kingfishers dig into dirt or clay banks to form a nesting cavity. Streams are also home to colorful harlequin ducks, wandering tattlers, northern waterthrushes, and blackpoll warblers.

Denali's forested regions are home to five species of woodpeckers: the downy, hairy, three-toed,

The agile long-tailed jaeger graces Denali's skies and tundra in the summer.

and black-backed woodpeckers, and the northern flicker. All but the northern flicker are year-round residents. Black-backed woodpeckers are rather rare and usually occur in areas after a wildfire.

Flycatchers make a good showing in Denali, and all are migratory. The Hammond's flycatcher, with its characteristic raspy call, is the first flycatcher to arrive on the breeding grounds, usually in early May. Alder flycatchers only spend about 48 days a year in Alaska. They arrive just after the last freezing temperatures in spring, breed, raise young, and leave just before the first freezing temperatures in late summer. Olive-sided flycatchers, with their unique "quick-three-beers" song, and Say's phoebes, which build their nests in cracks of cliffs and rock outcrops, often near golden eagle nests, also occur in Denali.

The northern shrike is another bird that piques the curiosity of birdwatchers in Denali. The most northern and most widely distributed of all shrikes, it breeds throughout the Arctic. This species belongs to the group of birds known as passerines, or perching birds. Unlike most other passerines, shrikes have a unique predatory lifestyle, and their foods include everything from insects to small birds and small mammals. Often referred to as butcherbirds, northern shrikes impale prey that is too large to swallow on pointed objects. While northern shrikes live a predatory lifestyle, these strikingly beautiful and tenacious passerines lack many of the specialized adaptations of raptors, including large and powerful feet, talons, and a crop.

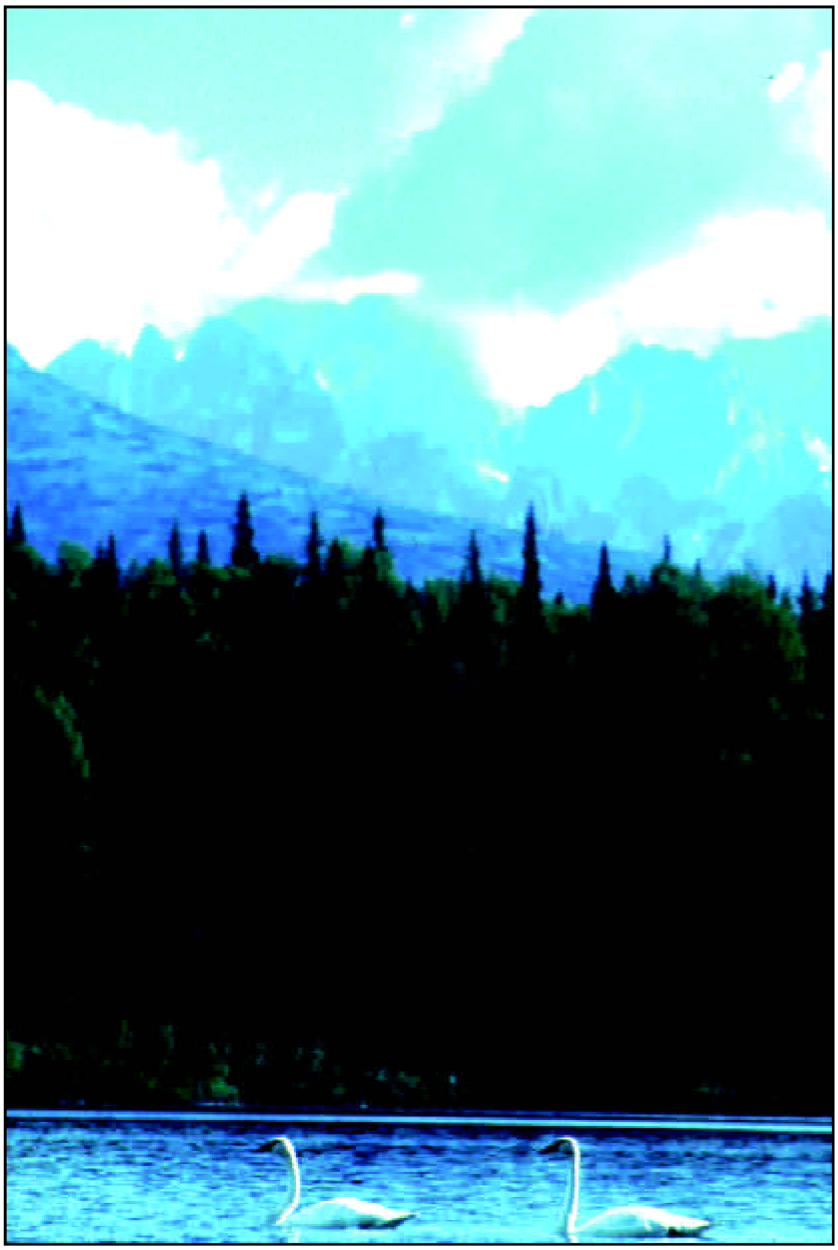
In winter, ravens, gray jays, and black-billed magpies are some of the most common birds in Denali. All three species are year-round residents, and all three are hardy survivors. Ravens and gray jays seem to magically appear no matter where you travel during winter. Gray jays are constant company at winter camps and campgrounds, and their behavior of begging and stealing food scraps from people and dogs has earned them the well-deserved name of "camp-robbers." Ravens are a bit more elusive around people, but they often follow wolves on their hunting trips during winter. Ravens are more predatory than either gray jays or magpies, and they will seek out and kill live prey when the opportunity arises. Ravens also occur at high elevations, and it is not unusual for mountain climbers to see ravens at altitudes exceeding 17,000 feet. Ravens swagger, strut, stroll, hop, and dash in and out of contact with humanity, exhibiting no dependence but a willingness to exploit. They treat people much like wolves or bears, always quick to pick up our scraps.

A variety of other passerines occur in Denali, ranging from swallows to sparrows to longspurs. Horned larks, American pipits, and Lapland longspurs are the characteristic passerines of the tundra. Each of these species has a highly specialized flight display or characteristic vocalizations. Lapland longspurs are one of the most common summer tundra inhabitants in Denali. The handsome males usually find a prominent perch to sing their sparkling jumble of notes throughout June.

Six species of warblers, including orange-crowned, yellow, yellow-rumped, blackpoll, and Wilson's warblers and northern waterthrush, nest in Denali. Most of these species spend the winter in Central and South America. Sparrows, including savannah, fox, Lincoln's, white-crowned, and golden-crowned, are well represented in Denali and occur in a variety of habitats. Denali's sparrows usually winter at lower latitudes in North America. These species combine their voices each June to create glorious sunrise symphonies.

Gray-cheeked, Swainson's, and hermit thrushes nest in Denali, and their unique songs are characteristic sounds of summer. The familiar American robin also occurs regularly in Denali and is a common nester. The varied thrush, one of the earliest spring migrants, nests in the forested regions of Denali and has a unique extraterrestrial voice. An evening or early morning visit to shrubby or forested areas in Denali will leave you with mixed emotions and probably a stiff neck—while you'll enjoy listening to the calls of all these thrushes, you'll strain to get a good look at any of these species.

Over 400 pairs of trumpeters swans nest each year in Denali National Park and Preserve.



Several species of passerines are true globetrotters, attracting much interest from birdwatchers and scientists alike. Northern wheatears are summer visitors that nest in the tundra in Denali and spend their winters in sub-Sahara Africa. Arctic warblers are common nesters in willow thickets, and their harsh calls are difficult to ignore. This Old World warbler winters in southeastern Asia (China, Indonesia, the Philippines, and Borneo). Blackpoll warblers are tiny birds that breed across the boreal regions of North America. This tiny bird is a celebrity in the migration world. Their annual journeys between North America and South America are among the longest of passerine birds.

Perhaps some of the most interesting passerines in Denali are those that stay in the area year-round. In addition to ravens, gray jays, and black-billed magpies, the passerines of winter include American dipper, black-capped and boreal chickadees, pine grosbeak, white-winged crossbill, and common and hoary redpolls. These small birds are hardy. Black-capped chickadees weigh just a half-ounce (12 grams), yet they survive temperatures dropping to –40°F and lower. Chickadees living in northern areas are nearly 25% larger than those living in the temperate regions of North America. They store more fat in winter to provide greater insulation from the cold and store more fuel for keeping warm. They also cache food to ensure that they have an ample supply of food through the winter and can lower their body temperature to survive the long subarctic nights. Northern black-capped chickadees are extremely efficient at modifying an enzyme (lipoprotein lipase) to provide free fatty acids for metabolism by muscles and storage by fat. Redpolls are even smaller than chickadees. They store food in a pouch in their esophagus and can take on large amounts of high-caloric foods before nightfall and digest these seeds after they go to roost. American dippers are North America's only truly submersible songbirds. Even in the depth of winter, they forage in the few open leads along streams, feeding mostly on aquatic insect larvae. To survive in these harsh environments, American dippers have low metabolic rates, extra oxygen-carrying capacity in their blood, and a thick coat of feathers.

The Bird Studies

Bird studies in Denali are as diverse as the species themselves. Most historic studies focused on describing the birds occurring in the area and, in limited cases, describing the natural history of a species. In more recent years, studies were developed to determine population trends, identify nesting area, and describe nesting habitat in response to management needs and to understand how birds respond to changes in their environment. Over the years, many scientists have made significant contributions to our knowledge of northern nesting species by studying birds in Denali.

In 2001 the American Bird Conservancy, an organization dedicated to conserving wild birds and their habitats throughout the Western Hemisphere, recognized Denali for its significance in the ongoing effort to conserve wild birds and their habitats and designated Denali a Globally Important Bird Area. The American Bird Conservancy's Important Bird Areas Program was launched in 1995 and has concentrated on identifying and documenting the bird conservation sites throughout all 50 states—those of significance on a global level.

Historic Studies

The first scientific investigations of birds in Denali were those made by Charles Sheldon, Joseph Dixon, and George Wright. The field studies conducted by these men provided the first scientific information on the birds present in Denali. Adolph Murie probably made the first scientific study of a single species of bird in Denali in the late 1930s. Murie studied the food habits of golden eagles by collecting pellets that the eagles had regurgitated and by noting the remains of food in eagle nests, with special effort to find remains of Dall's sheep lambs.

The period from 1940 through the late 1970s saw few bird studies in Denali. While many birders visited the area, only a few bird studies were conducted. These included cooperative studies, which continue today, with the U.S. Fish and Wildlife Service to determine population trends of waterfowl and trumpeter swans. In the early 1980s several studies on the nesting ecology of northern hawk owls (by Kenneth Kertell) and merlins (by Karen Laign) marked the beginning of more intensive studies on single species in Denali. Kertell also conducted several inventories of birds in the new additions to Denali in the early 1980s. From 1984 to 1994 the U.S. Fish and Wildlife Service and the National Park Service conducted field investigations of the nesting ecology of merlins in Denali. In 2000 and 2001 the National Park Service and Boise State University conducted field investigations of the nesting ecology of northern hawk owls in Denali.

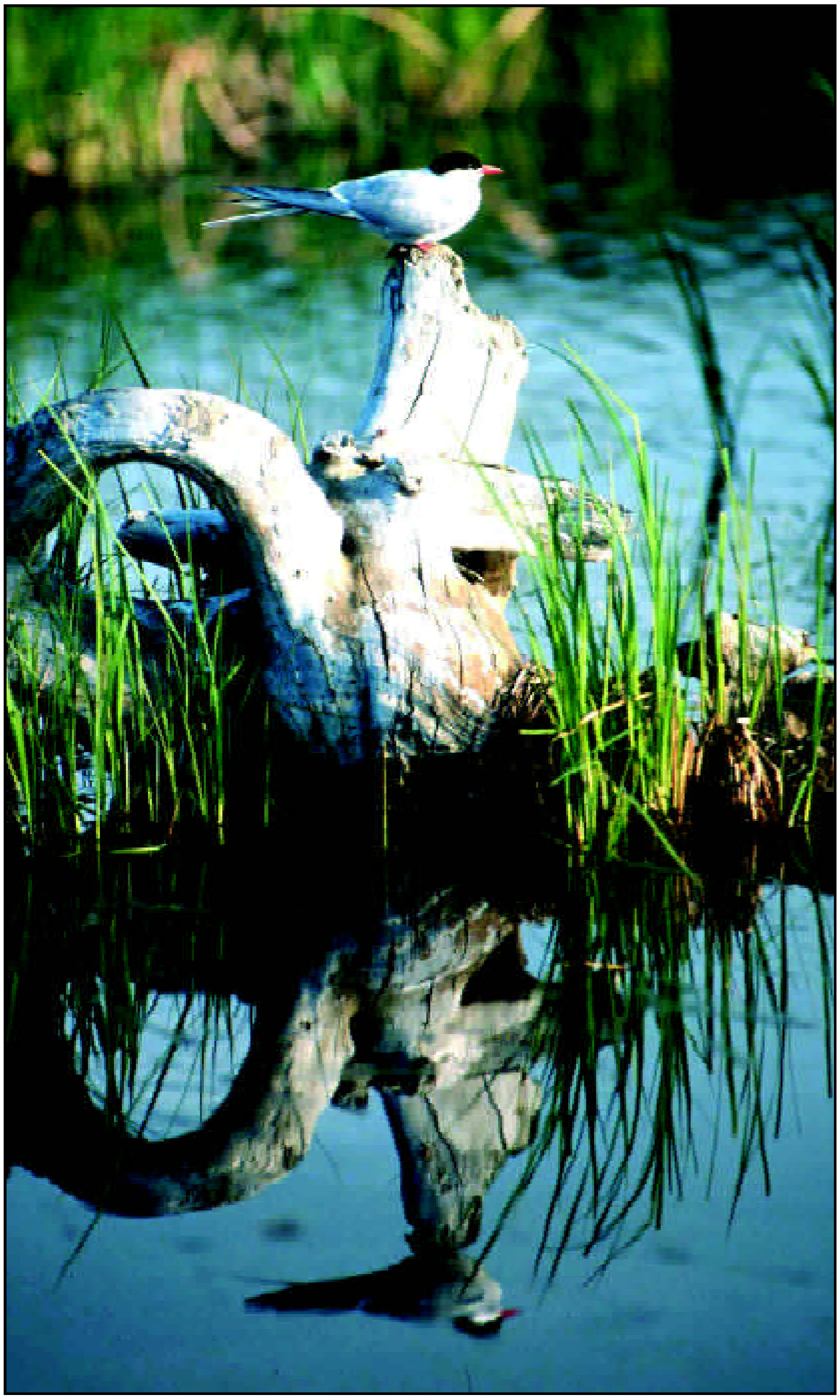
In 1987 the National Park Service began to study the reproductive characteristics of golden eagles and gyrfalcons and conduct raptor surveys in many of the areas added to the original park in 1980. The study of the nesting ecology of golden eagles and monitoring of the reproductive success of gyrfalcons continue today. Our golden eagle study has spawned research into many aspects of golden eagle ecology, including migratory behavior, food habits, and survival of both breeding birds and juveniles. Using satellite telemetry, we recently identified the migration corridors, winter ranges, and summer ranges of juvenile golden eagles.

In 1991 the National Park Service published its Vail Agenda, a comprehensive strategy for serving America's noble trust into the 21st century. To meet our resource stewardship responsibilities, the Vail Agenda action plan calls for park managers and superintendents to have solid natural resource information at their disposal. Providing natural resource information in a comprehensive and timely manner is the Vail Agenda's mandate to the National Park Service's Natural Resource Inventory and Monitoring Program. The goal of this national program, launched in 1991, is to acquire the information and expertise needed by park managers in their efforts to maintain ecosystem integrity in the approximately 250 National Park System units that contain significant natural resources.

With the launch of the Inventory and Monitoring Program, Denali began several monitoring projects focused on birds other than raptors and waterfowl, with an emphasis on passerines. One project, run cooperatively with the Alaska Bird Observatory from 1993 to 2001, developed and implemented field techniques to assess population trends in selected species of songbirds in spruce forests along the Denali park road. The other project, run cooperatively with the Institute for Bird Populations, assesses productivity and survivorship of selected passerines. This program, known as Monitoring Avian Productivity and Survivorship, or MAPS, is a continent-wide monitoring program and continues today. In 1993 a local naturalist, Nan Eagleson, reinstated the Audubon

Christmas Bird Count on the very eastern edge of Denali. The Christmas Bird Count, a volunteer-based, continent-wide monitoring program, provides information on the broad trends of winter birds in the count area. In 1994 the National Park Service reinstated the two Breeding Bird Survey routes in Denali that were run opportunistically in the 1980s by various volunteers. The Breeding Bird Survey is another continent-wide monitoring program that is used to assess trends in bird populations across North America.

Arctic terns nest travel over 25,000 km each year between their breeding grounds in Denali and their winter grounds in Antarctic waters.



More recently, Denali's scientist were tasked with developing studies to better understand the distribution of birds in areas slated for development or increased human activities. In the late 1990s, Denali's scientists designed and implemented studies to identify the nesting habitat of trumpeter swans, other waterfowl, and raptors in areas slated for increased human activities in the southern portion of Denali. Few studies had been conducted in these areas, and the pressure to develop visitor services and the possibility of increased human activities in previously undisturbed areas prompted local citizens, state managers, and park managers to develop a strategy for protecting Denali's resources in this area.

Recent surveys show that many of the wetlands on the south side of the Alaska Range are used by nesting trumpeter swans and other waterfowl, including the Tule white-fronted goose. Nesting bald eagles are commonly observed along many of the waterways in the study area, and nesting golden eagles and gyrfalcons are common in the mountainous regions of this area. Park managers will use information from this study to plan the development of future visitor services without disturbing or destroying nesting habitat of these important park resources.

New Studies

Two new birds studies were designed and implemented in 2001 to monitor the long-term changes of park resources. The first study, conducted cooperatively with the molecular genetics lab of the Alaska Science Center, involves using a noninvasive monitoring technique to estimate the survival of adult golden eagles. One of the most important aspects of the population dynamics of long-lived species is adult survival rate. Determining the survival rates of animals usually requires capturing and marking the animal with a marker that can be identified remotely (such as a radio-transmitter) or when the animal is recaptured (such as a band). These marking techniques are commonly used on many animals in Denali, but capturing adult golden eagles is extremely difficult. Therefore, we are using molecular genetic techniques to identify individual golden eagles at selected nesting areas to determine if eagles use the same nesting areas in consecutive years and to estimate the probability of eagles living from one year to the next. By collecting shed feathers at nesting areas over a series of years and extracting

Gyrfalcons begin incubation in mid-March, often when mean daily temperatures hover around freezing.

DNA material from these feathers, we can determine whether the same eagles occupy the area in consecutive years. Using these data we can calculate the probability of an eagle surviving from one year to the next. After the DNA material has been extracted from the feather, all feathers are deposited in the National Eagle Repository near Denver, Colorado.

The second study focuses on describing and detecting changes in the distribution and abundance of passerines across Denali. Until the implementation of this study, passerine studies in Denali were focused on a narrow corridor along the Denali road, which runs approximately 90 miles through the north-central portion of Denali. While these studies provided data to track the population trends of a few passerines, they were not designed to provide information on a park-wide scale. In 2001, scientists working with the long-term monitoring program in Denali adopted a new strategy and initiated projects to better understand and assess changes in park resources across the entire park. Our new approach uses a sampling design that allows us to make inferences across the entire six million acres of Denali. The new study design also integrates several monitoring components, including passerines, vegetation, soils, and permafrost. This integration allows us to study changes in passerine populations and how they responsd to these other measurable environmental attributes. This study is conducted with assistance from the Alaska Bird Observatory.

The Future of Denali's Birds

At least 80% of the breeding species in Denali are migratory. Each spring the migratory birds, representing six continents, join the hardy year-round residents on this rich subarctic landscape to breed and raise young. The migratory behavior of so many of Denali's birds presents a complex conservation challenge to Denali's managers. The winter ranges of Denali's birds range from southern Alaska to the tip of South America, extends across Asia and into Africa, and includes much of the Pacific Ocean region. With so many birds spread over such a vast area, it is impossible to identify many of the forces that shape the long-term survival of Denali's birds. While most of these species are fully protected under the Migratory Bird Treaty Act of 1918, habitats along migration routes and on wintering areas of many of the species that breed in Denali are changing rapidly. Native habitats are being converted to more human-dominated landscapes through urbanization, agriculture, industry, forestry, and other activities. Other obstacles to survival, including communication towers, energy transmission lines, and mortality caused by domestic cats, are also increasing. One only needs to look around their own neighborhood to note the changes that are occurring around the world.

Most of the historic and ongoing bird studies in Denali occur on the breeding grounds. So far, only the golden eagle work has focused on identifying migratory routes, wintering areas, and areas used by non-breeding birds. We are working with scientists from the Alaska Bird Observatory, the Institute for Bird Populations, the U.S. Geological Survey's Alaska Science Center, the U.S. Geological Survey's Forest and Rangeland Ecosystem Science Center, the Department of Fisheries and Wildlife of the University of Alaska Fairbanks, Oregon State University, Boreal Partners in Flight, and the Alaska Department of Fish and Game on many projects developed to better understand and protect birds in Alaska.

We have only begun to scratch the surface in developing our understanding of the bird resources of Denali. Our task is to describe the ecology, identify the threats, and protect Denali's birds. These tasks are challenging, and our responsibility to protect park resources becomes more difficult as funding opportunities and park priorities change and threats to park resources increase. To meet this challenge, we are developing an Avian Conservation Plan for Denali. Its goal is to provide

Golden eagle productivity in Denali is influenced by spring prey resources. Triplet eaglets are common only in years when prey resources are abundant.

park managers, scientists, and the public with comprehensive information about the nature and condition of the bird resources placed under our stewardship. The plan will outline what we know about Denali's birds, describe our existing studies and conservation efforts, and identify the conservation and research needs of Denali. It will also include strategies for securing funding for projects and developing new partnerships with other scientists.

Education and Outreach

One of the best ways to protect birds and their habitats across the earth is through education. Denali's scientists actively engage in many forms of science education and public outreach to teach people about birds and Denali's science programs. Throughout the year we give many public presentations on the birds of Denali. We also work with local schools to help teachers, students, and local residents better understand the birds in their backyard. Our recently developed educational web site (www.nps.gov/dena/home/resources/wildlife/ birdweb/ index/homebirdpage.htm) provides users with comprehensive information about Denali birds, our bird studies, and our many partnerships and cooperative efforts.

We also worked with staff at the National Park Service's Alaska Support Office to create a web-based science curriculum for the program ParkWise using data from our long-term golden eagle studies in Denali. ParkWise was developed by the Alaska region of the National Park Service to teach school children around the country about the National Park Service and the valuable cultural and natural resources of Alaskan parks. We also work closely with local non-profit groups, including the Denali Foundation with Elderhostel programs, ecology-centered community events, and other scientific presentations, and the Denali Institute with field seminars, workshops, and an autumn passerine migration banding station. Denali staff are active members of Boreal Partners in Flight, a coalition of individuals who are working together to help conserve bird populations throughout the boreal regions of North America. Boreal Partners in Flight is the official Alaska state working group of the international Partners in Flight program.

We also work with the Alaska Natural History Association (ANHA), a non-profit organization dedicated to enhancing the understanding and conservation of the natural, cultural, and historical resources of Alaska's public lands to provide educational materials for the public. ANHA has collaborated with Denali to publish the Denali National Park Bird Checklist and a recently released book, *Birds of Denali*. We also worked cooperatively with the American Birding Association on another new book, *A Birder's Guide to Alaska*. Denali's scientists also publish results of their research in peer-reviewed scientific journals and present results of their studies at meetings of scientific organizations.

The future of Denali's birds depends on all of us to be good stewards of the earth. Denali's avian conservation program hopes to lead the way in conserving these valuable park resources through scientific studies and science education for many generations to come.

Sea Otter Population Structure and Ecology in Alaska

This article was prepared by James Bodkin and Daniel Monson, both of the Alaska Science Center, Anchorage, Alaska.

History of Sea Otters in the North Pacific

Sea otters are the only fully marine otter. They share a common ancestry with the Old World land otters, but their route of dispersal to the New World is uncertain. The historic range of the species is along the northern Pacific Ocean rim, between central Baja California and the islands of northern Japan. Because they forage almost exclusively on bottom-dwelling marine invertebrates such as clams, snails, crabs, and sea urchins, they predominantly occur near shore. Their offshore distribution is limited by their diving ability; although they are capable of diving to more than 100 meters deep, most of their feeding takes place between the shoreline and depths of 40 meters. They are social animals, generally resting in protected bays or kelp forests in groups, commonly referred to as rafts. Because they are gregarious, possess a fine fur, and occur primarily near shore, they have been exploited by humans for as long as they have co-occupied coastal marine communities.

An adult male sea otter at rest. The hind flippers bear the color-coded tags used to identify individuals that are resighted.

During the late Pleistocene, glacial advances and retreats in the northern latitudes likely influenced genetic exchange within the sea otter's northern range. When the glaciers were at their maximum, ice sheets extended over large coastal areas, isolating sea otter populations and causing local extinctions. During periods of glacial retreat, sea otters likely recolonized the newly available habitats, allowing exchange of individuals and gene flow between populations.

Beginning in about 1750, sea otter populations underwent dramatic declines as a direct result of commercial harvest for their furs. Explorations by Vitus Bering led to the discovery of abundant sea otter populations in the Aleutian Islands. The early harvest, conducted by Russians with enslaved Aleut hunters, began in the eastern Aleutians. Eventually the harvest became multinational and contributed significantly to the exploration and settlement of the North Pacific coastline by Europeans. There were two distinct periods of harvest—one reaching its peak about 1800 and averaging about 15,000 per year and a second about 1870, averaging about 4,000 per year. The causes for this harvest pattern are unknown, but it may represent two distinct periods of overexploitation separated by a brief period of population recovery.

By 1890 the species had been eliminated throughout most of its range, persisting in small numbers at 13 isolated locations in California, Alaska, and Russia. The number of sea otters that survived the fur trade is unknown, but available data suggest that some remnant populations may have been as small as a few dozen individuals. In 1911, sea otters were afforded protection under the International Fur Seal Treaty, and populations apparently responded by gradually increasing in abundance. The rates of population recovery varied among locations, averaging 9% annually and ranging from 6 to 13%. The population at Amchitka Island in the central Aleutians had the highest growth rate among those surviving, apparently reaching carrying capacity by about 1950.

Efforts to aid the recovery of the species into the vast unoccupied habitats between California and Prince William Sound began in 1965. Sea otters from Amchitka and Prince William Sound were translocated to Oregon, Washington, British Columbia, and several locations in southeastern Alaska. With the exception of Oregon, these translocations have resulted in the establishment of successful colonies. Population growth rates of translocated sea otters have been significantly greater than among remnant populations, averaging 21% and ranging from 18 to 24%. We don't know why the growth rates of the remnant and translocated populations are so different, but it may be partly because of the abundant food and space available at the translocated sites.

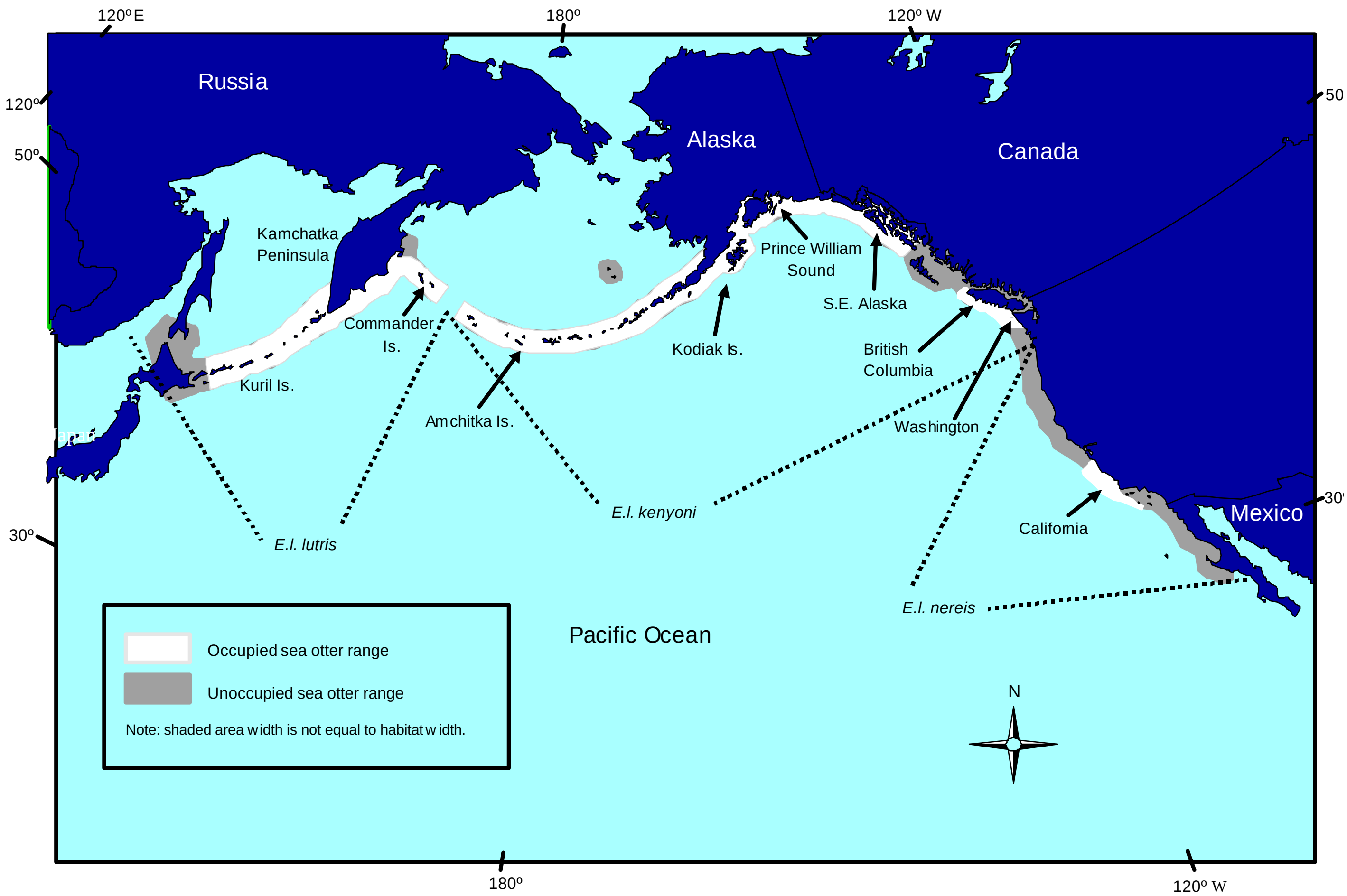
The varying patterns of sea otter population decline and recovery provide a unique and powerful tool for studying the effects of historic reductions on populations, as well as how populations respond to varying environmental conditions. During the past decade, using molecular genetics, researchers have been trying to understand how sea otter populations might differ throughout the North Pacific and what effects population reductions and recovery have had on population genetics. Also, as a result of the varying degree of recovery among isolated populations, we have the opportunity to contrast life history attributes (such as condition, reproduction, and survival) among populations throughout their range. These contrasts may be useful in developing methods to assess the status of populations where traditional methods of surveying abundance are difficult and expensive.

Population Structure in Sea Otters

The molecular-level population structure of modern sea otters likely reflect the combined influences of long-term natural processes and recent human harvests. Several factors historically restricted gene flow within the sea otter population. One is the relatively small home ranges of sea otters. Although sea otters have been known to travel as much as a few hundred kilometers, they tend to stay close to home, with home ranges that average a few tens of kilometers of coastline. This, in conjunction with a essentially linear population that extends over nearly 20,000 km, tends to limit the exchange of genetic material over long distances. In addition, long distances between island groups in the Aleutian archipelago and periodic advances of glacial ice sheets would serve to restrict the movements of sea otters, further limiting gene flow. More recently, overexploitation through commercial harvests has severely reduced sea otter distribution and abundance. By 1900, probably no more that several hundred sea otters persisted in 13 widely separated locations between California and the Kuril Islands of Russia. The long distances between most neighboring populations (for example, California and Prince William Sound) almost certainly prevented gene flow among remnant populations since late in the commercial fur harvest.

The reductions in distribution and abundance, or bottlenecks, consist of two components. One is the magnitude of the reduction, or how few animals persisted. The other is the duration of the bottleneck, or how long the population stayed at or near the minimum population size. Both of these factors can reduce genetic diversity, with implications for individual and population fitness. Since about 1990 we have been studying sea otter population genetics. Our goal has been to improve understanding of how populations might differ relative to location within their remnant range and what the potential effects of the recent human-induced population bottlenecks might be.

Our studies of sea otter genetics using the maternally inherited mitochondrial DNA show that populations separated by large distances share common genes, indicating a recent common ancestry and some degree of gene flow prior to 1750. We identified at least four major groups that generally correspond to the three recognized subspecies of *Enhydra lutris* (*E.l. lutris*, *E.l. kenyoni*, and *E.l. nereis*), based on cranial morphology. The molecular genetics work identified two populations within the *E.l. kenyoni* subspecies, one from Prince William Sound and another from Kodiak and westward through the Aleutian Archipelago. The results also indicated that the Commander Island population was more closely related to the Aleutian population than to the Kuril population (*E.l. lutris*). We found large differences in mitochondrial DNA among contemporary populations, indicating restricted gene flow or drift because of the recent population bottlenecks. In more recent work we have looked at factors other than genetics to identify potential population structuring within Alaska. Based on population distributions and physical characteristics, as well as genetic



Sea otter distribution in the north Pacific Ocean, illustrating the geographic distribution of the three subspecies in Alaska.

data, at least three stocks are evident in Alaska: southeast Alaska, Prince William Sound, and from Kodiak westward through the Aleutian archipelago.

Our ability to overharvest sea otters has been clearly demonstrated. Because sea otters in Alaska continue to be harvested for their furs, it is important to manage those harvests in a sustainable manner. To avoid overexploitation, sea otters must be managed on a geographic scale compatible with their well-known behavioral and reproductive biology. For example, had the average annual harvest of sea otters between 1750 and 1900 (about 3000–6000) occurred evenly throughout their range, it is likely there would have been no detectable decline in their overall abundance by 1900. However, because the harvest systematically progressed across relatively small portions of their range, the species was nearly hunted to extinction.

Translocating individuals is an increasingly common tool for aiding in the recovery of wildlife populations that have been reduced or eliminated from portions of their historic range. Between 1965 and 1972, 544 sea otters were moved from Amchitka Island and Prince William Sound to vacant habitat in Washington (43), British Columbia (89), and southeast Alaska (412). Because of mortality and emigration following translocation, the estimated founding population sizes were 4, 28, and 150, respectively. British Columbia and southeast Alaska received sea otters from both parent populations, while Washington received otters only from Amchitka.

We used founding population data (the number of individuals and the duration at the minimum number) and mitochondrial DNA data from remnant and translocated sea otter populations to examine the effects of population bottlenecks on genetic diversity and subsequent population growth rates. We found that genetic diversity is negatively correlated with the length of time a population remained at a minimum number (the longer the population remained small, the less genetic diversity) and positively correlated with the minimum population size (the larger the minimum population size, the greater the genetic diversity). Although we found higher population growth rates in translocated populations, we also found that growth rates were not correlated with genetic diversity. Translocated populations have exhibited higher average growth rates (21% per year) than remnant sea otter populations (9% per year), and translocations with two sources resulted in increased genetic diversity. Despite the dramatic population bottlenecks, caused by both harvests and translocations, we have been unable to identify negative effects, in terms of population growth rates, caused by loss of genetic diversity in contemporary sea otter populations.

Population Ecology

Reproductive Rates

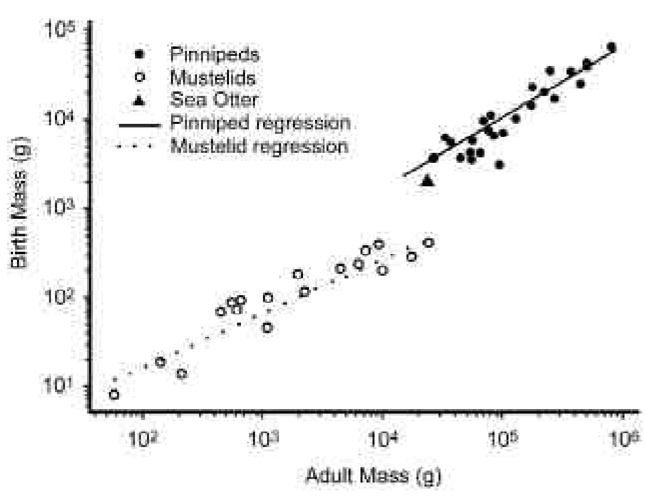
We found that age-specific sea otter birth rates are nearly constant throughout their range, regardless of food and space availability. A small proportion of females have their first pup at two years of age, about 50% first reproduce at the age of three, and most females have produced a pup by the age of four. After their first pup, successful adult females generally have one pup per year, with the annual reproductive rates for mature females holding at 85–90%. If a pup dies before it is weaned, the female usually breeds again within days of losing her pup. There is some indication that females over 12–15 years of age may have fewer pups.

The overall reproductive potential of sea otters is primarily limited by the litter size of one. The birth of one "large" pup that can survive in the harsh environment into which it is born appears to be a necessary adaptation to life in the sea. The trait of a single offspring is one the sea otter shares with all other completely marine mammals (cetaceans, pinnipeds, and sirenians), as opposed to all other mustelids, which give birth to multiple young. In fact, European land otters living along the coast tend to have smaller litters than their inland counterparts, possibly because of the harshness of the environment and the limited availability of protected den sites along the coast. This suggests a pathway for the evolution of this trait. That is, as litter size decreased, pup size likely increased. Fewer and larger pups allowed ancestral sea otters to exploit more-exposed dens and less-hospitable stretches of coast than their larger-litter cousins that needed den sites that were more protected. As this trend continued, ancestral sea otters would have occupied increasingly hostile environments until they were able to actually give birth at sea, away from the protection of the den. At this point a single young was the most a mother could possibly protect and raise, leading to larger and larger single pups, with the rate of multiple births becoming less and less common over time. But it also allowed sea otters to occupy the entire coastline at high densities, regardless of the availability of land-based den sites.

Survival Rates

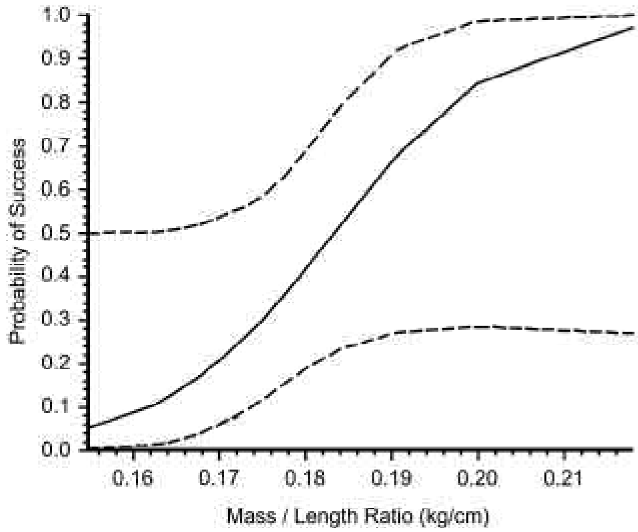
In contrast to reproductive rates, post-weaning survival rates appear to be dramatically affected by food availability. Sea otter populations living with an abundance of food have relatively high survival rates in all age classes, with especially high survival for juveniles. However, long-established populations with limited food resources have a different survival rate pattern. Survival rates from weaning through the first year of life are generally low but variable. Survival for the middle age classes is uniformly high, and survival rates in the older age classes decline rapidly with age. Juvenile survival appears to be the primary mechanism of population regulation in undisturbed sea otter populations.

Pre-weaning pup survival appears to depend on the age and condition of the mother at the time of birthing—pups of healthier, more experienced mothers are more likely to survive. Female sea otters must spend extensive amounts of time grooming and nursing their newborn pups, keeping them warm and dry on their chest or hauled out on rocks. This necessarily restricts the amount of time they can spend foraging for food themselves.



The relationship between mean adult female mass and mean birth mass (mean litter size × mean pup mass) for 26 species of marine mammals (pinnipeds) and 19 species in the otter family (mustelids). Sea otters are much closer to the pinniped group than to the mustelid group. The pinniped data are from Lee et al. (1991), and the mustelid data are from Parker (1990) and Nowak (1991).

The relationship between weaning success and female mass/length ratio at capture for sea otters at Amchitka Island, Alaska from 1992 to 1994. The solid line represents the average, and the dashed lines represent the confidence intervals.



A female in poor condition will not be able to restrict her feeding time to the extent a female in good condition can, and her pup will be exposed to longer periods in the water and less grooming and nursing. The result is poorer pup survival during the first few weeks of life, the period during which most pre-weaning pup mortality occurs.

This effect may be exaggerated during winter, when conditions are particularly harsh. In sea otter populations with limited food resources, pups born in winter are more likely to die soon after birth. Because the female generally breeds soon after losing her pup, her next pup will likely be born during spring or early summer, when the pup will have a better chance to survive. After a 5- to 7-month period of dependency, she will wean the pup, breed again, and have another pup about a year after the birth of the previous pup.

Thus, even though some females may produce and successfully wean pups at any time of year, the environmental effects on pre-weaning pup survival, along with a reproductive cycle of approximately one year, tend to produce and maintain peak pupping periods in the spring and early summer. The breadth and peak of the pupping period depend on the severity of winter weather conditions and the general availability of food. If food is abundant (as in newly occupied habitat) or seasonal conditions are fairly uniform (as in the more southerly latitudes), pupping peaks may be absent, variable, or very broad, depending on chance environmental events. In the northern latitudes of the sea otter's range in Alaksa, because of strong seasonal differences in environmental conditions, there tends to be a sharp peak in pupping in spring, although pups can be born during any month.

Conclusion

The twentieth century was a period of recovery from near-extirpation for sea otters throughout the North Pacific Ocean. The presence of populations in varying stages of recovery has provided unique opportunities to study the response of sea otters to population bottlenecks and the changing ecological conditions they encounter following recovery. As we enter the twenty-first century, we find sea otter populations in southeast Alaska still expanding into previously unoccupied habitat and demonstrating rapid growth. Other populations, such as in Prince William Sound, appear to be relatively stable. However, throughout the Aleutian Archipelago and much of the Alaska Peninsula, we have seen dramatic declines in sea otter abundance over the past decade. This situation will continue to provide opportunities to study how sea otters respond to, and recover from, population declines.

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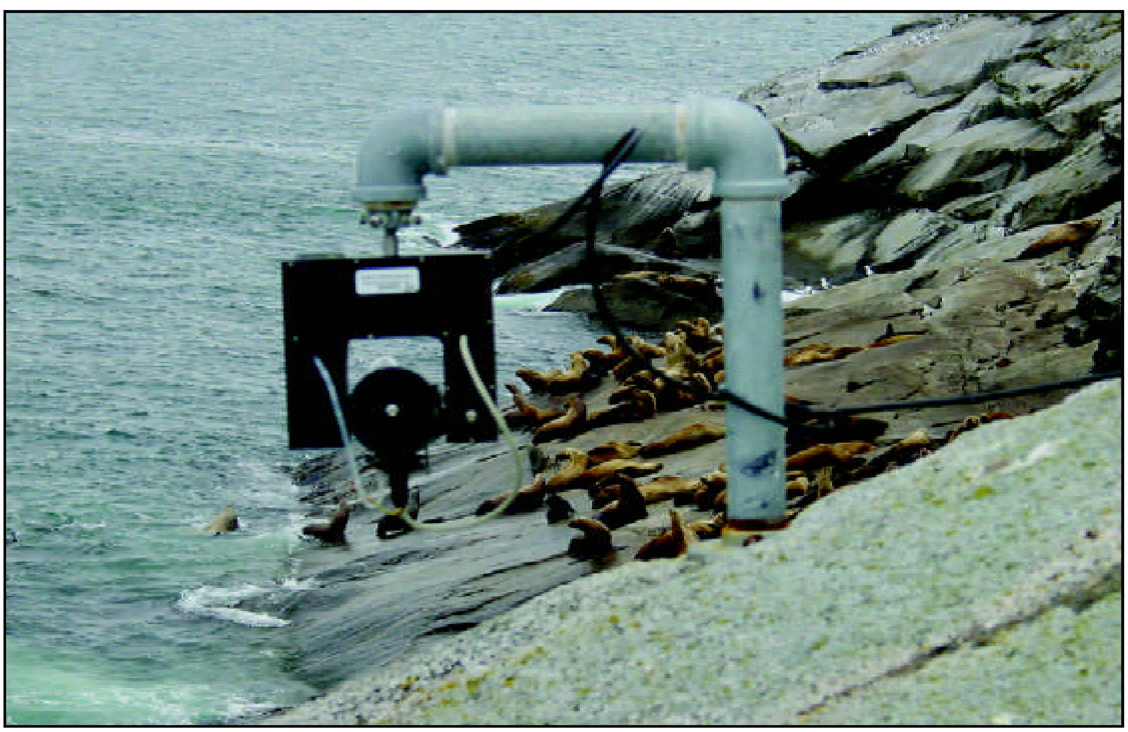
Early Maternal Care and Pup Survival in Steller Sea Lions

A Remote Video Monitoring Project in the Northern Gulf of Alaska

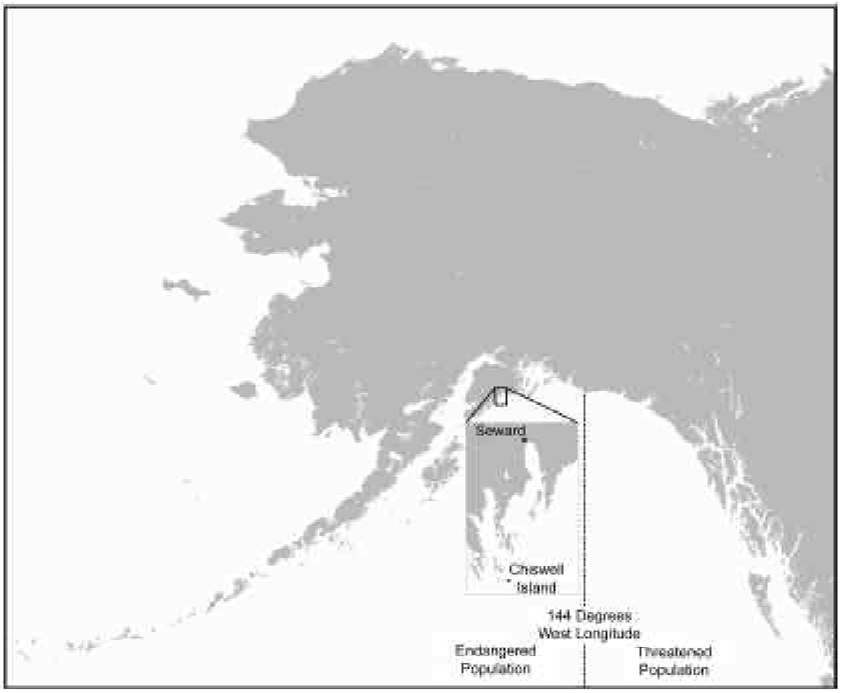
This article was prepared by John Maniscalco and Shannon Atkinson, Alaska SeaLife Center and University of Alaska Fairbanks, and by Peter Armato, Kenai Fjords National Park and University of Alaska Fairbanks.

The endangered western population of Steller sea lions that occurs within and adjacent to several of Alaska's National Parks (Anaikchak National Monument and Preserve, Katmai National Park and Preserve, Kenai Fjords National Park, and Lake Clark National Park and Preserve) has undergone a major population decline over the last several decades. In an effort to understand the mechanics of the decline, the Alaska SeaLife Center, in cooperation with National Fish and Wildlife Foundation, the National Marine Fisheries Service, and the Ocean Alaska Science and Learning Center, is studying, through the application of remote cameras and field research, the behavioral ecology of this species throughout its range. One component of the study is investigating the importance of early maternal care to young Steller sea lions.

Early maternal care in mammalian species is a key factor affecting the health and survival of young well into their future. Increased time and energy spent caring for offspring generally translates into stronger, healthier, and socially well-adapted individuals. However, many species, including Steller sea lions, must forsake the care of their offspring for varying intervals of time in order to obtain food. Steller sea lions, like other eared seals, give birth to one pup on land and remain with the newborn for a period of time ranging from a few days to a few weeks before returning to forage at sea. This interval, termed the perinatal period, can indicate how well the mother was able to feed prior to giving birth. For one year or more after the perinatal period, female sea lions alternate foraging trips at sea with time spent on shore resting and nursing their pup. The periodicity of this alternating cycle between foraging and caring for the young predominantly depends



A remotely controlled camera spies on Steller sea lion behavior at Chiswell Island in the Gulf of Alaska.



Location of the Chiswell Island Steller sea lion rookery and the delineation between the eastern (threatened) and western (endangered) populations.

on the mother's ability to obtain sufficient food near the home site. For instance, if the abundance or quality of prey near a sea lion rookery is depleted, longer foraging trips to sea would be expected, with less time available to care for pups. This example is one of the hypotheses put forth to explain the decline of the western stock of Steller sea lions in Alaskan waters.

Dramatic declines in Steller sea lion abundance began in the early 1970s and prompted the listing of the species as threatened under the U. S. Endangered Species Act in 1990. Continued declines in central and western Alaska, west of 144°W longitude, resulted in a 1997 decision to up-list this western stock of Steller sea lions to endangered status. There are at least three broad hypotheses for explaining the observed declines:

- Commercial fishing effects from entanglements, incidental catches, or competition for sea lion prey;
- Ecosystem changes resulting in alterations in the abundance, distribution, or quality of prey species available, or alterations of some form of critical habitat; and
- Predation, primarily by killer whales, which may have shifted to preying more upon sea lions after other large prey items such as baleen whales were removed from the ecosystem by hunting.

Other hypotheses that are thought to be less likely reasons for the decline include disease, pollution, subsistence use, and redistribution. However, some of these are under renewed investigation.

Food quality, quantity, or availability can be affected by the first two hypotheses and should be reflected in how much time and energy female sea lions expend in pup care. Several maternal investment studies conducted in recent years have provided evidence along these lines.

The purpose of our study was to assess various aspects of maternal care in Steller sea lions using a remotely controlled camera system to continuously observe sea lion behavior. We were also able to observe probable and actual causes of pup mortality due to predation and storms.

Study Methods

Our study focused on a small Steller sea lion rookery at Chiswell Island in the northcentral Gulf of Alaska. Remotely operated cameras were first installed on this island in October 1998 by See-More Wildlife Systems, Inc. of Homer, Alaska. The cameras were used initially to monitor the utilization of this rookery by different age and sex classes and for observations of marked or otherwise identifiable animals. Additional cameras were later placed on nearby island haulouts to broaden the study of sea lion population dynamics in this area.

Currently ten cameras on Chiswell Island and nearby haulouts are operated from the Alaska SeaLife Center (ASLC) in Seward, Alaska. Each camera is equipped with 12- to 18-power optical and 180- to 300-power digital zoom lenses mounted in fully weatherproof housings and with remotely controlled pan, tilt, zoom, and windshield wiper/washer functions. Audio and video signals are sent via cable to a central control tower on Chiswell Island, which transmits the images and sound approximately 35 miles to ASLC via microwave transmission. The cameras and control tower are powered by a 12-volt battery system charged by solar and wind power. At ASLC, audio and video signals are viewed and recorded in real time with typical television monitors and VCRs, while commands for controlling the cameras are sent from custom-made software running on a desktop computer. This technology allows us to observe the sea lions in their natural habitat without disturbance and without impairment by the extreme weather conditions that often occur in the Gulf of Alaska.

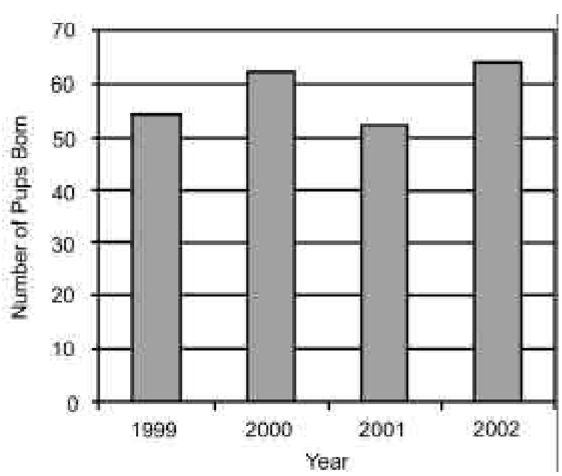
The first few years that this system was in place, daily population counts were conducted and pupping success and survivability were estimated. In the spring of 2001, we expanded our research to include a detailed maternal investment study. During this portion of the study we monitored approximately thirty individually recognizable females during 2001 and 2002, from their arrival in late May, when they gave birth, through early August in order to estimate maternal investment by recording the amount of time spent nursing and the duration of foraging cycles. We were also able to determine some causes of early pup mortality by watching these animals from dawn until dusk during the long summer daylight hours.

Maternal Care

The number of Steller sea lion births on Chiswell Island during the past four years has shown a biannual cycle, with more births occurring during even-numbered years. In 1999 there was one stillborn and one pup that died very shortly after birth, and in 2001 there were two stillbirths. Only one stillbirth occurred during 2000 and one during 2002. The observations of stillbirths are not significant on their own but lend credence to an overall pattern in maternal dynamics at this rookery.

Birthdates of Steller sea lion pups on Chiswell Island ranged from May 23 to July 4 during the years 1999–2002, except for one stillbirth on May 20, 2001. The consistency we have observed in timing of births, which is common in most animals living at high latitudes, is likely the result of evolutionary selection for coinciding births with food abundance and optimal weather conditions. However, the timing of births varies between years and throughout the range of Steller sea lions. Births were generally earlier in 2001 than in 2002. Paired comparisons of 16 known females that had pups during both years showed a significant three-day difference, averaging June 8 in 2001 and June 11 in 2002. The variability for those 16 females was 0 to 11 days, showing some plasticity in the timing of giving birth. This may result from variation in their ability to locate sufficient prey from year to year, or it may be caused by some other, not so obvious, cue. Pupping was also more synchronous in 2002, with the range of birth dates seven days shorter than in 2001. Factors controlling the consistent timing of births in marine mammals have rarely been studied; it has been assumed that this is simply a function of normal biological variation. Our data suggest that there may be physiological and behavioral controls over the timing of pupping, which warrant further study.

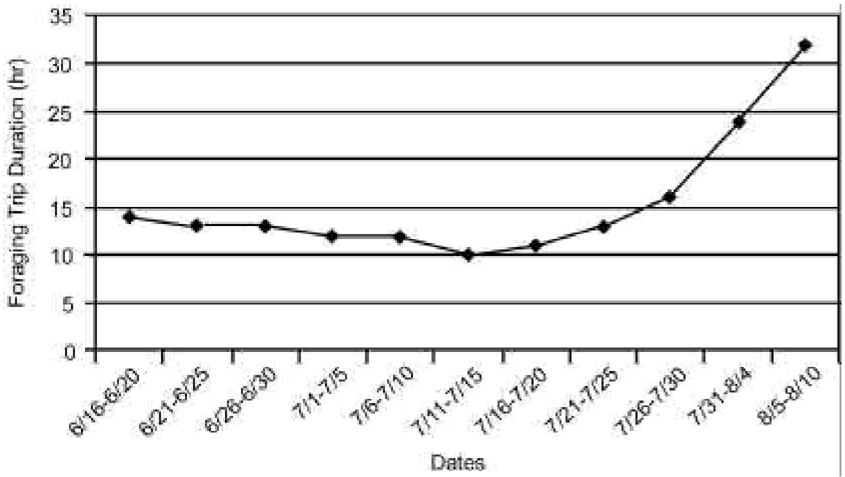
Numbers of Steller sea lions born at Chiswell Island, 1999–2002.



During years of poor food availability, female sea lions tend to have a relatively short time between giving birth and the subsequent foraging trip to sea (the perinatal period). It is likely that they have insufficient energy reserves to meet early lactation needs and therefore must replenish them sooner in poor food years than in years of good food availability. This has been shown to be the case elsewhere; sea lions along the California coast had perinatal periods averaging only 3–4 days during El Niño years, compared to 6–7 days in other years. The average perinatal period for sea lions at Chiswell Island was more than two days longer in 2002 (11.9 days) than in 2001 (9.8 days), suggesting that 2002 may have been a better year for obtaining sufficient prey prior to giving birth. However, the perinatal periods in both years were relatively high compared to those known for Steller sea lions throughout their range. Other studies in Alaska have estimated average perinatal durations between 8.0 and 10.1 days. This indicates that the Chiswell Island animals were probably well fed prior to giving birth, though interannual variations do occur.

There was a significant correlation between the duration of the perinatal period and the timing of births—females that gave birth later in the season generally left to forage sooner than females that gave birth earlier. Among seal and sea lion species, older females tend to give birth earlier in the season than younger ones. Also, older females are presumably more experienced at capturing prey, and rapid, skillful acquisition of large quantities of food prior to pupping would allow them to remain on the rookery for longer periods after giving birth.

After the perinatal period, lactating females begin a routine of feeding at sea followed by resting and nursing pups on shore. Feeding trips from Chiswell Island during the first few months after



Foraging trip duration from combined 2001 and 2002 data showing changes throughout the summer.

pupping averaged 15.6 hours in 2001 and 11.4 hours in 2002, which also indicates that food was more abundant during 2002. Time spent on shore was correspondingly longer in 2001, averaging 22.5 hours compared to 19.9 hours in 2002. Yet, on a percentage basis, females still spent relatively more of their time foraging at sea in 2001 (41%) than in 2002 (36%).

At Chiswell Island, foraging trip durations decreased slightly in the first month after birth from approximately 14 hours to 10 hours. The longer trips shortly after giving birth may indicate that females required more time feeding in order to replenish lost energy from the perinatal fast. However, after approximately a month, foraging trips increased steadily for at least another 25 days, reaching an average of greater than 30 hours. Some foraging trips lasted up to four days at two months after giving birth. By this time, most of the pups are increasingly active and swimming frequently, so their growth and energy demands are increasing. The mothers must spend more time foraging to meet these increasing demands, as lactation is costly in terms of energy expenditure. Foraging trip duration increased sharply at the end of July in both 2001 and 2002. This may also suggest that prey resources nearby the rookery had been consumed or had moved elsewhere.

Our research suggests that Steller sea lions on Chiswell Island may experience alternating "good" years and "not-so-good" years for pup production and postnatal care. If this cycle is actually related to prey abundance, we would expect to see a similar pattern there. The best-known fish species in Alaska that has a biannual cycle is the pink salmon. Pink salmon runs are currently stronger during even years than in odd years in the Resurrection Bay area and the northern Gulf of Alaska, which corresponds with years of healthy production at the Chiswell Island rookery. Salmon species are common in the diet of Steller sea lions in Alaskan waters, though they are not thought to be a predominant prey item for the western stock. Therefore, the biannual cycles in pink salmon may not, by themselves, explain the similar cycles in Steller sea lion productivity. Current investigations by ASLC and the University of Alaska Fairbanks of Steller sea lion diet and food availability in the Chiswell Island area may help us understand these cycles more completely.

We recorded and analyzed 336 half-hour behavior samples on randomly selected females between June 1 and August 10, 2001. Lactating females spent 9.6% of their time nursing during the afternoon, compared to 7.1% in the morning and 4.2% in the evening. The amount of time per day spent nursing varied widely. The amount of time spent nursing was the same during the perinatal period as after the perinatal period (6.1%). In other sea lion species, suckling time increases during the first few months of the pups' life and has been correlated with milk intake. Suckling times for Steller sea lion pups do not necessarily increase during this period, but rather their suckling efficiency improves, allowing them to ingest more milk as they grow. The overall percentage of time spent suckling is similar to that at other rookeries in Alaska.

Causes of Pup Mortality and Survival

The stillbirths observed at Chiswell Island were not collected nor were their mothers examined, so the true reasons for these failures to produce live pups are not known. Furthermore, an unknown number of females may abort their pups before arriving at the rookery. Alaska Department of Fish and Game research published in 1998 reported reproductive failures to be as high as 45% during the 1980s. Those females that did successfully reproduce were healthier, as determined by weight and blubber thickness, than those that did not reproduce. Other potential causes for reproductive failure may include high body burdens of contaminants, genetic incompatibility, disease, and naturally produced toxic algal blooms.

One female pup died eleven days after being born in 2002. A necropsy on this animal revealed massive amounts of bruising around the hips and right shoulder and a puncture wound near the right hip. Death was attributed to an infected abscess near the vaginal cavity. Female Steller sea lions are often intolerant of offspring that are not their own, and it is not uncommon to observe them picking up and tossing other pups that get too close. These instances rarely result in a fatality for the pup, but we believe that this was likely the cause of death in this case. Breeding bulls on the rookery can weigh up to one ton and are often indifferent toward the pups. An inattentive bull may also inadvertently crush a pup during a territorial conflict with another bull, although we have not observed this on Chiswell Island.

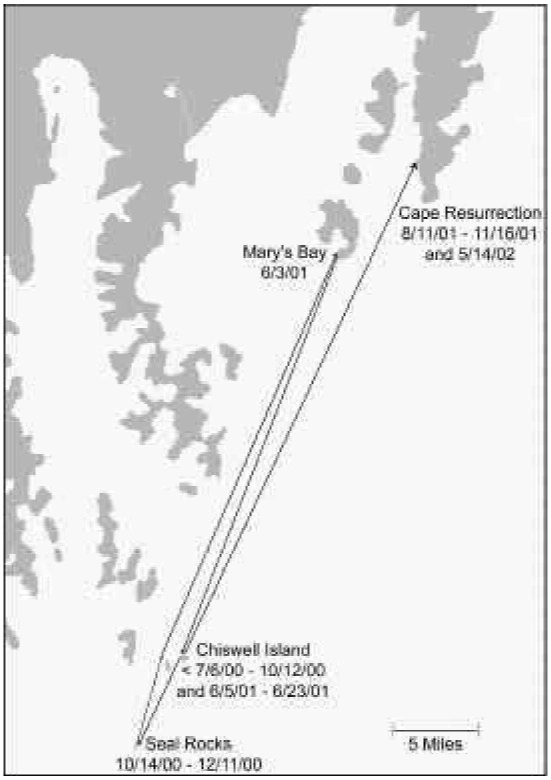
During 2002, two major storms with seas of 20 feet or more buffeted Chiswell Island during the month of June, washing pups from the rookery. Storms of this proportion are common in the Gulf of Alaska during winter but not in summer. Most of the pups were less than one week old and unable to swim effectively on their own when the first storm hit on June 8, 2002. At least eight pups were lost during that storm, and another three were lost during the second storm in late June, representing 17% of the pups born on Chiswell that year. Maternal care also includes removing pups from harm's way, and pups that did survive these storms were pulled by the nape of the neck high onto the rookery and, in some cases, out of the surf. Pups that were washed away were presumed dead from starvation or drowning. Storms of this proportion had not been observed during June in the preceding three years.

The extent of predation by killer whales on Steller sea lions is another issue that is currently being investigated by ASLC and the North Gulf Oceanic Society (NGOS). Other predators such as sharks are not currently thought to take sea lions to any significant extent in Alaskan waters. One or more transient killer whales have been seen near shore at Chiswell Island on 35 days in 2001, compared to 14 days in 2000 and only 4 days in 1999. Increased sightings during 2001 may be due, in part, to greater observer effort and greater awareness of these predators. A single killer whale, identified by NGOS in 2000 as AT109, a female more than 30 years old, was seen most often at Chiswell Island. This killer whale exhibits unusual behavior for a transient, such as tail-slapping and breaching immediately in front of the rookery. (Transient killer whales are normally stealthy predators of marine mammals, unlike residents, which primarily eat fish and do not need to remain quiet.)

There has only been one confirmed report of a kill by AT109 at Chiswell Island on July 31, 2001, from a local tour boat captain. This animal, with a sea lion in her mouth, swam directly under the vessel about 150 m from the island. The age or sex of the sea lion could not be determined, but it was assumed to be approximately six weeks of age. Once in 2000 and twice in 2001, we observed AT109 making charges into sea lion groups in the water. However, she disappeared below the surface after these attacks, so her success in capturing her prey was unknown. We assume that she is preying upon pups and other young individuals because we saw no flocking birds or prey pieces from the tearing apart of large sea lions that would indicate such activity; pups and other small individuals could probably be swallowed whole. As further evidence, AT109 visited for nine days in 2001; pup numbers dropped significantly from an average of 50.2 for four days prior to the visit to 38.2 for four days after the visit. During the same four-day periods in 2000 when no killer whales were present, there was not a significant change in pup numbers. At a minimum, AT109 causes a major disturbance to the rookery. Of 31 identifiable females known to have pups prior to the 2001 killer whale visit, only 27 of them still had pups after the visit. These data give us a range of pup losses from 13 to 24% at Chiswell Island due to predation during only one and a half weeks in 2001. As of September, AT109 had not been seen at Chiswell Island during 2002, though she has been sighted elsewhere in north gulf coast waters.

While not all Steller sea lion pups survive through their first year of life, we determined that at least 46% of the Chiswell Island pups born in 2000 survived to at least April 2001. The easiest way to estimate sea lion survival and movements is by marking these animals as pups. The National Marine Fisheries Service, the Alaska Department of Fish and Game, and ASLC have tagged and branded hundreds of pups throughout Alaska during the past few years. Thirty pups were tagged at Chiswell Island in 2000. The following is a case study of one individual that remained in the Chiswell Island/Resurrection Bay area over its first few years.

A female pup was tagged with the number 971 on July 6, 2000, weighing 29 kg at approximately one month of age. She remained on Chiswell Island through October 12, 2000, then moved five miles to the south, where she was seen on October 14, 2000, at Seal Rocks with her mother. The pair was subsequently observed several times at Seal Rocks until December 11, 2000. However, partly due to camera difficulties through much of the winter, they were not observed again until the



The travels of tagged pup number 971 through its first two years of life.

next summer. On June 3, 2001, 971 was identified by a local tour boat captain at the Mary's Bay haulout near the mouth of Resurrection Bay. Two days later, 971 returned to Chiswell Island with her mother and was still nursing. On June 6, 971's mother gave birth again, and 971 was immediately weaned. However, she was subsequently seen with the mother and new pup until late June.

We continued to follow 971's mother through most of the early breeding season, but her natural markings were not strong enough to confidently identify her when she was more active later in the season. Later, we observed 971 by herself at the Cape Resurrection haulout on August 11 and November 16, 2001, and then again on May 14, 2002. She appeared to be very healthy and retained both of her tags. We hope she returns to breed at Chiswell Island some day.

The Chiswell Island group is part of the U.S. Fish and Wildlife Service's Alaska Maritime National Wildlife Refuge. The placement of equipment and research conducted on refuge land was done under a special use permit issued by the U.S. Fish and Wildlife Service and under NMFS permit No. 782-1532-00 issued under the authority of the Marine Mammal Protection Act and the Endangered Species Act.

Summary

Interannual variations do occur in Steller sea lion pup production and maternal care at Chiswell Island. Maternal investment during both "good" and "not-so-good" years is comparable to or better than that seen in the eastern population of sea lions, which appears to have stabilized in recent years. The biannual cycle at Chiswell Island does suggest, however, that these animals may need more food or higher quality food than they are able to obtain in certain years. The animals of the western stock are somewhat distinct from the eastern stock and therefore may need more or different types of prey to successfully produce and raise a pup; this may be caused by differences in their genetic makeup, the environment (such as colder water), or the lipid, protein, or vitamin content of their predominant prey species.

Early pup mortality can be caused by killer whale predation or unusual storms that occur when pups are too young to swim effectively. Stillbirths and intraspecific aggression are not thought to be major factors of early pup mortality; the occurrence of abortions prior to the females arriving at Chiswell Island is not known. The amount of maternal care that Steller sea lion pups receive can affect their ability to survive storms, feeding killer whales, accidents, or other fates as changes occur in the health and attentiveness of their mothers and of themselves.

These and other results from the Alaska SeaLife Center's comprehensive Steller sea lion research program continues to provide the information needed by resource managers to better understand and develop the best possible management strategies for the species and its ecosystem.

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The Occurrence and Significance of Humpback Whale Songs in Glacier Bay, Southeastern Alaska

This article was prepared by Christine Gabriele, National Park Service, Glacier Bay National Park, and Adam Frankel, Marine Acoustics Incorporated, Arlington, Virginia.

Humpback whale songs are among the longest and most complex vocalizations made by any animal. Underwater acoustic monitoring in Glacier Bay National Park since May 2000 has revealed that humpback whales sing much more frequently in the late summer and early fall than previously believed. Prior to this study, humpback whale songs had rarely been recorded in Alaskan waters. By describing the occurrences of Alaskan whale song and comparing them with recordings made in Hawaii, we hope to learn more about the functions of song and the importance of high-latitude feeding areas to the humpback whale mating system. The presence of whale songs also highlights the potential effects of vessel-generated noise on endangered humpback whales in Glacier Bay.

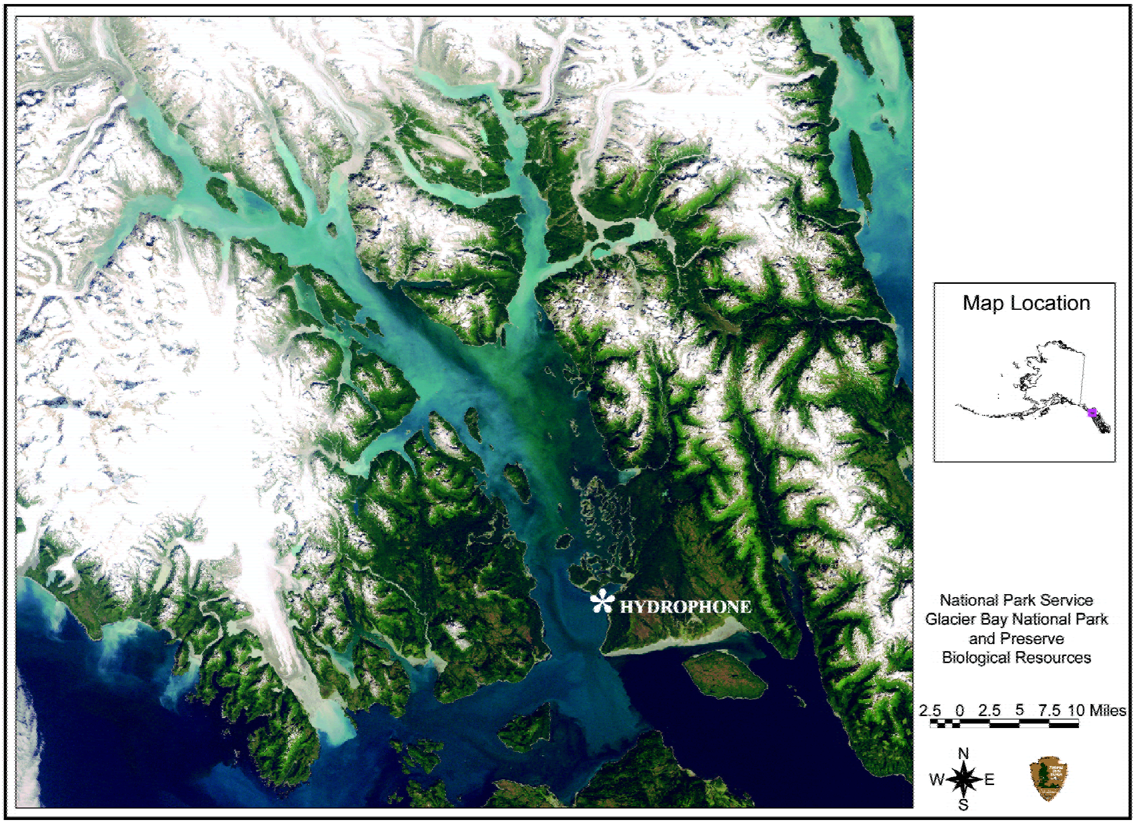
Humpback whales are migratory baleen whales that spend summers in high-latitude feeding grounds and migrate to tropical mating and calving grounds in the winter. The humpback whales in the Glacier Bay area are part of the southeastern Alaska feeding herd, comprising approximately 1000 individuals. For these humpbacks, the winter migration entails a 2500-mile swim to the Hawaiian Islands, the largest of three main wintering areas in the North Pacific. The other humpback whale wintering areas in the North Pacific are in Mexican waters off the Baja Peninsula and in the western Pacific near Japan and the Philippines. The greatest numbers of humpbacks occur in Hawaiian waters in January through April each year, although some whales can be found there from November through June. Biologists employed by commercial whalers in the mid-twentieth century examined many thousands of carcasses and discovered that humpbacks don't feed on their winter grounds and that male and female reproductive organs are inactive in the summer.

A "song" is essentially a series of sounds made in a predictable order. In the case of humpback whales, the song is typically about 15 minutes long, punctuated when the whale surfaces to breathe. It is thought to be a mating-related display because it primarily occurs during the winter and is performed only by males. All males on a breeding ground sing essentially the same song, but singers adopt changes during the winter that result in progressive change in the song.

Despite much research in the years since song was first scientifically described in 1971, the functions of the song remain unclear. The leading theories on why male humpbacks sing include sexual advertisement to females, male–male coordination, and maintenance of space between competing males. Male–male competition is a key feature of the humpback whale mating system because most females give birth every other year, increasing the ratio of males to available females to at least 2:1. Many researchers believe that song may be a form of acoustic competition, analogous to the vigorous and sometimes injurious physical competition among males for access to females. Although scientists don't fully understand song function, its importance to humpback whale social life is clear, given that an individual male will sing for hours on end, and a chorus of whale song can be heard all day and all night during the winter in Hawaii.

Recording and Processing Alaskan Whale Songs

The humpback whale songs reported here were recorded during passive acoustic monitoring to characterize ambient and vessel-generated noise in Glacier Bay National Park, a steep-walled glacial fjord system in southeastern Alaska. The seafloor in the area is the remnant of a glacial moraine that is flat and sporadically rocky at a fairly stable depth of 40–60 meters. The park's humpback whale population monitoring shows that Glacier Bay and the surrounding area is inhabited by 50–100 humpback whales between June and August, with fewer whales from September to May. Approx-

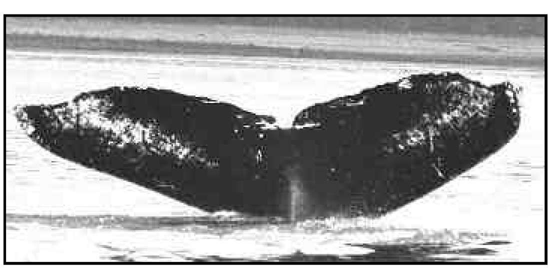


Map of Glacier Bay, showing the location of the anchored hydrophone.

imately 355 humpbacks have been individually identified in the Glacier Bay area since 1985, including at least 36 mature males. Although the long-term population monitoring program focuses on individually identified whales, we monitored songs remotely, so there were no opportunities to determine the identity of individual singers or whether non-continuous episodes of song were made by the same whale.

Alaska Recordings

We listened to and made digital recordings of underwater sound using an anchored hydrophone and computerized monitoring system near the mouth of Glacier Bay, southeastern Alaska. A submerged five-mile cable connects the hydrophone to a custom-built control unit at park headquarters that provides power to the hydrophone and is the electrical interface between the hydrophone, the computer, and the recorder. We recorded humpback whale vocalizations with a digital audio tape recorder or directly onto a computer hard disk. All recordings were archived onto compact disc for later analysis.



Tail flukes of a mature male humpback whale first identified in the Glacier Bay area in 1978.

We listened from May 20, 2000, to March 8, 2001, and from July 13, 2001, to June 20, 2002. Although the acoustic monitoring system is automated to make 30-second ambient noise recordings on a set schedule, longer recordings of whale vocalizations could only be made if a person was there to detect the song and make a recording. Acoustic monitoring effort varied during the summer months because staff were in the field several days per week but was more consistent at 30–40 hours per week from September through March. No acoustic monitoring was possible between March and late June 2001 because of equipment problems, so we did not have the chance to detect spring singing as whales arrived in the area. However, acoustic monitoring in March through mid-June 2002 detected no whale song.

Comparison to Hawaii Recordings

We compared the highest-quality Alaska recordings with a small sample of songs recorded off the

A hydrophone, mounted on a customized aluminum anchor, being installed in Glacier Bay.

whales' winter range in the Hawaiian Islands in the winter of 2000 and 2001, and we measured their degree of similarity on a variety of acoustic parameters. We extracted individual song units (notes) from the digitized recordings using customized detectors written in Matlab computer software. We used the computer program Acoustat, developed at Woods Hole Oceanographic Instititution, to make 97 measurements of each unit's frequency, temporal, and contour characteristics. We used a SAS (Statistical Analysis System) principal components analysis to reduce the dimensionality of the measurements, determining how many principal components accounted for 80% of song unit variance. A SAS discriminant analysis classified the resulting 18 principal components by year and region.

Glacier Bay Song Characteristics

We discovered that humpback whales frequently sing while they are in the Glacier Bay area in August–November. We heard no song earlier than August, despite the presence of whales. We heard no song later than November, probably because the whales had left the area. Humpbacks probably continue to sing after November, resulting in the songs heard during migration by other investigators monitoring vocalizations in the open ocean in the North Atlantic and North Pacific. Acoustic monitoring continued approximately 40 hours per week through mid-January 2001 and 2002, but no additional whale songs were heard. The absence of song in the spring of 2002 as whales moved back into the Glacier Bay area suggests that song is not as prevalent in spring as it is in the late summer and fall.

The songs we heard were solos, not the multi-whale chorus that is typical in the wintering grounds. We rarely heard any other whale vocalizations in the background, although feeding whales can be quite vocal. On eight occasions, song sessions were preceded by or ended with episodes of unstructured vocalizations. Song sessions were much shorter than reported in the Hawaii wintering grounds, where whales commonly sing continuously for hours. The longest song session observed during this study was on November 8, 2000, when a single whale sang almost continuously for 4.5 hours; most sessions were much shorter. Song sessions were quite variable in length and were significantly longer in 2000 than in 2001. Singers recorded in 2001 also tended to be farther away from the hydrophone than singers in 2000, based on the apparent loudness and quality of the recordings. Both the apparent decrease in singing in 2001 and their increased distance from the hydrophone were probably due to a lack of whales in the area, based on population monitoring in lower Glacier Bay during the summer and fall.

Hawaii and Alaska songs from the same year were similar. Statistical analysis quantified this similarity by using the song unit measurements to blindly assign a given unit or "note" to a particular region and year. Hawaii 2001 and Alaska 2000 and 2001 were similar to one another, as measured by the number of times that song units from one area and year were misclassified as being from a different area or year. Alaska 2000 and 2001 song units were quite similar, because they were the most frequently mistaken for one another. Hawaii 2000 song units were so distinct from the other areas and years that they were rarely misclassified. However, we had only one recording of Hawaii song for each year, so we couldn't draw definitive conclusions about which areas and years were most similar to each other. We collected song recordings in Hawaii in 2002 and plan to continue these analyses with additional data in the future.

The song unit measurements also showed that Hawaii and Alaska songs were statistically distinct

Statistics on song occurrences in Glacier Bay, 2000 and 2001.

	2000	2001
No. of Days Song Observed	18	11
No. of Hours of Song Observed	21.9	2.8
Date of First Song	Aug. 29	Aug. 23
Date of Last Song	Nov. 16	Nov. 9
Mean session length in minutes	73.1	15.7
Maximum session length in minutes	270	48

Song unit similarity by region and year shown by principal components classification of song units. Cells contain the number of observations (% classified). Misclassifications of song units from one region-year into a different region-year indicate similarity. Song units for a given region-year were correctly classified 46–86% of the time. Hawaii 2000 song units were rarely misclassified.

	Alaska-2000	Alaska-2001	Hawaii-2000	Hawaii-2001	TOTAL
Alaska-2000	605 (60.87)	238 (23.94)	0 (0)	151 (15.19)	994 (100)
Alaska-2001	7 (33.33)	14 (66.67)	0 (0)	0 (0)	21 (100)
Hawaii-2000	9 (9.00)	3 (3.00)	86 (86.00)	2 (2.00)	100 (100)
Hawaii-2001	4 (30.77)	2 (15.38)	1 (7.69)	6 (46.15)	13 (100)

Song unit distinctiveness by region and year shown by discriminant analysis Mahalanobis Distances (and their probabilities). All region-year combinations were statistically significant except Alaska 2001 vs. Hawaii 2001, probably because of the small Hawaii sample size.

	Alaska-2000	Alaska-2001	Hawaii-2000	Hawaii-2001
Alaska-2000	0	1.6 (0.021)	20.6 (0.0001)	2.3 (0.047)
Alaska-2001	1.6 (0.021)	0	21.8 (<0.0001)	3.5 (0.0748)
Hawaii-2000	20.6 (0.0001)	21.8 (<0.0001)	0	22.4 (<0.0001)
Hawaii-2001	2.3 (0.047)	3.5 (0.0748)	22.4 (<0.0001)	0

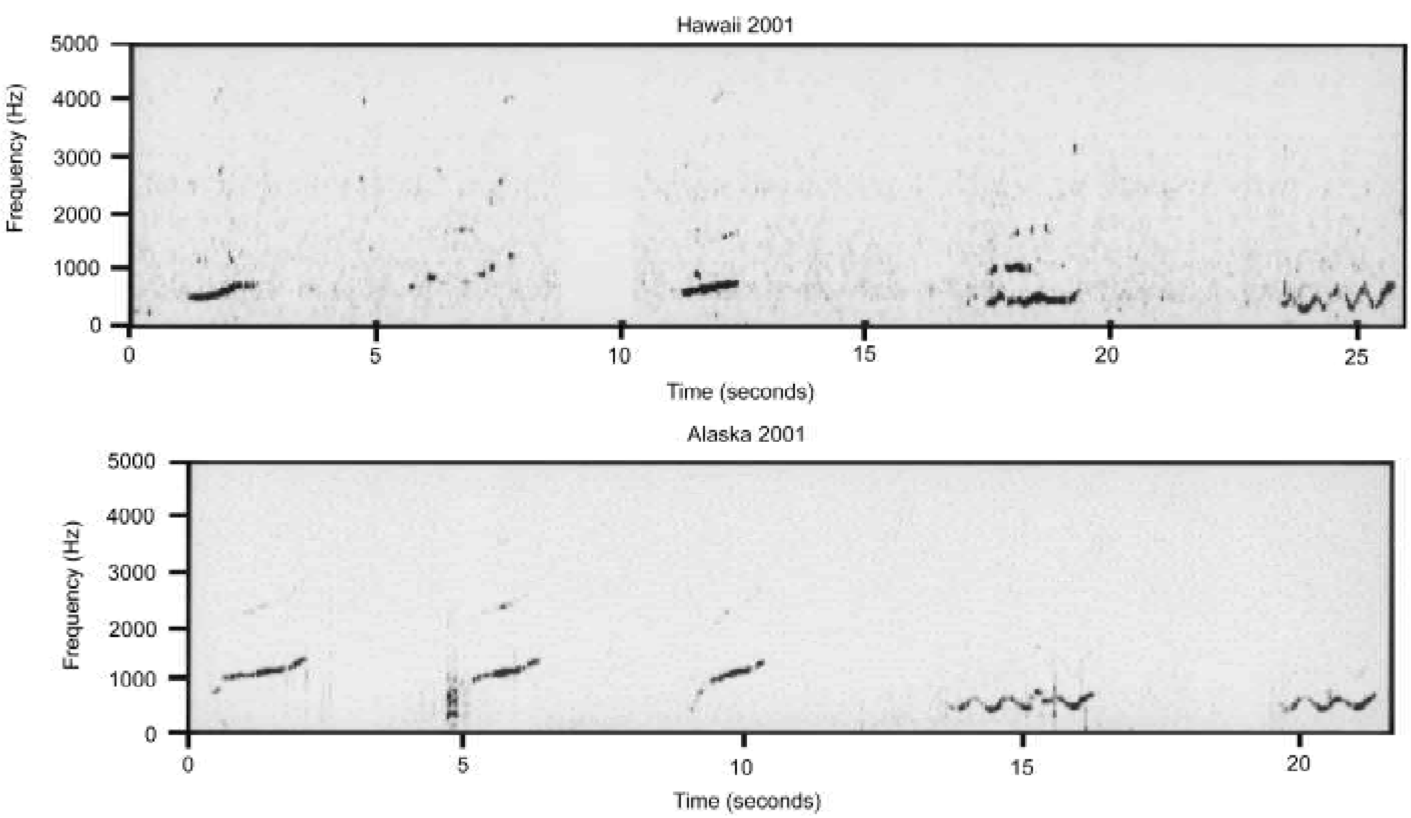
Sample phrases from Alaska and Hawaii humpback whale songs show the similarity between areas and years. Sound spectrograms show changes in pitch (frequency) over time, with louder sounds appearing darker.

from one another by year and area, as shown by a statistical technique called discriminant analysis Mahalanobis Distances. Some of the distinctiveness comes from the individual variability of singers. Within the Alaska samples, there was enough song unit variability to suggest that several singers were recorded. However, the similarity between the highest-sample-size areas of Alaska 2000 and 2001 indicates that individual differences probably do not account for all the variance shown.

Comparisons With Previous Studies

Prior to this study, humpback whale songs had rarely been recorded in Alaskan waters. In one study in southeastern Alaska, researchers reported hearing singing from one or more whales in a group in late December 1979 and early January 1980. In a different study, researchers detected only two occurrences of humpback whale song in five summers of effort and concluded that whale song in southeastern Alaska was rare. Two factors probably account for the difference from our results. First, we suspect that these investigators did not monitor in September and October, although the dates of their monitoring were not specified. Second, our study used passive acoustic monitoring of a remote hydrophone, allowing us much greater acoustic monitoring effort and giving us much greater flexibility with regard to weather, sea conditions, and daylight.

The humpback whale songs we recorded in Glacier Bay occurred earlier and were much more prevalent than songs previously documented in



Visit the Glacier Bay National Park web site to listen to recordings of whale vocalizations made during this study and learn more about acoustic monitoring and the humpback whale population study: http://www.nps.gov/glba/learn/preserve/projects/index.htm

For additional information on whale sounds and the effects of man-made sounds, look at the web site for the Bioacoustics Research Program at the Cornell University Laboratory of Ornithology: http://www.ornith.cornell.edu/brp/ResWhale.html

any feeding area. Humpback whales appear to sing quite commonly in late summer and fall in Glacier Bay, corroborating research findings from Stellwagen Bank (off Cape Cod) of whale songs in November and May. However, it is not clear why southeastern Alaska song began in late August, while the Stellwagen Bank song was not observed until November, since humpbacks are present in both areas throughout that time period. Details of acoustic monitoring effort in the Stellwagen Bank study may reveal the source of this difference.

Autumn Humpback Whale Song in High Latitudes

Based on our results, it appears that (presumably male) humpbacks sing sporadically between feeding bouts in the autumn. Since we have no visual observations of the singers we recorded, we can say very little about their behavior or the presence, proximity, or identity of other whales in the vicinity. Humpback whale song in mid-summer appears to be rare or nonexistent, although other vocalizations are heard. Our acoustic monitoring effort was lower in the summer, but we do not believe this accounts for the lack of songs in May through late August. We predict that with sufficient acoustic monitoring effort, song recordings could be made in any area where humpback whales congregate in the autumn.

We speculate that the increase in song in late summer and fall corresponds with the beginning of seasonal hormonal activity in male humpbacks prior to the migration to the winter grounds. During twentieth-century whaling, studies of the reproductive tracts of male humpbacks revealed that testis weights in the wintering areas are much greater than in the feeding areas. Behavioral indications of increased male hormonal activity in the autumn are probably often subtle, but overt observations have included singing and agonistic behavior between whales in Sitka Sound in December and January (observed by University of Alaska Southeast researcher Jan Straley) and a known mature male apparently pursuing a known mature female in Glacier Bay in September.

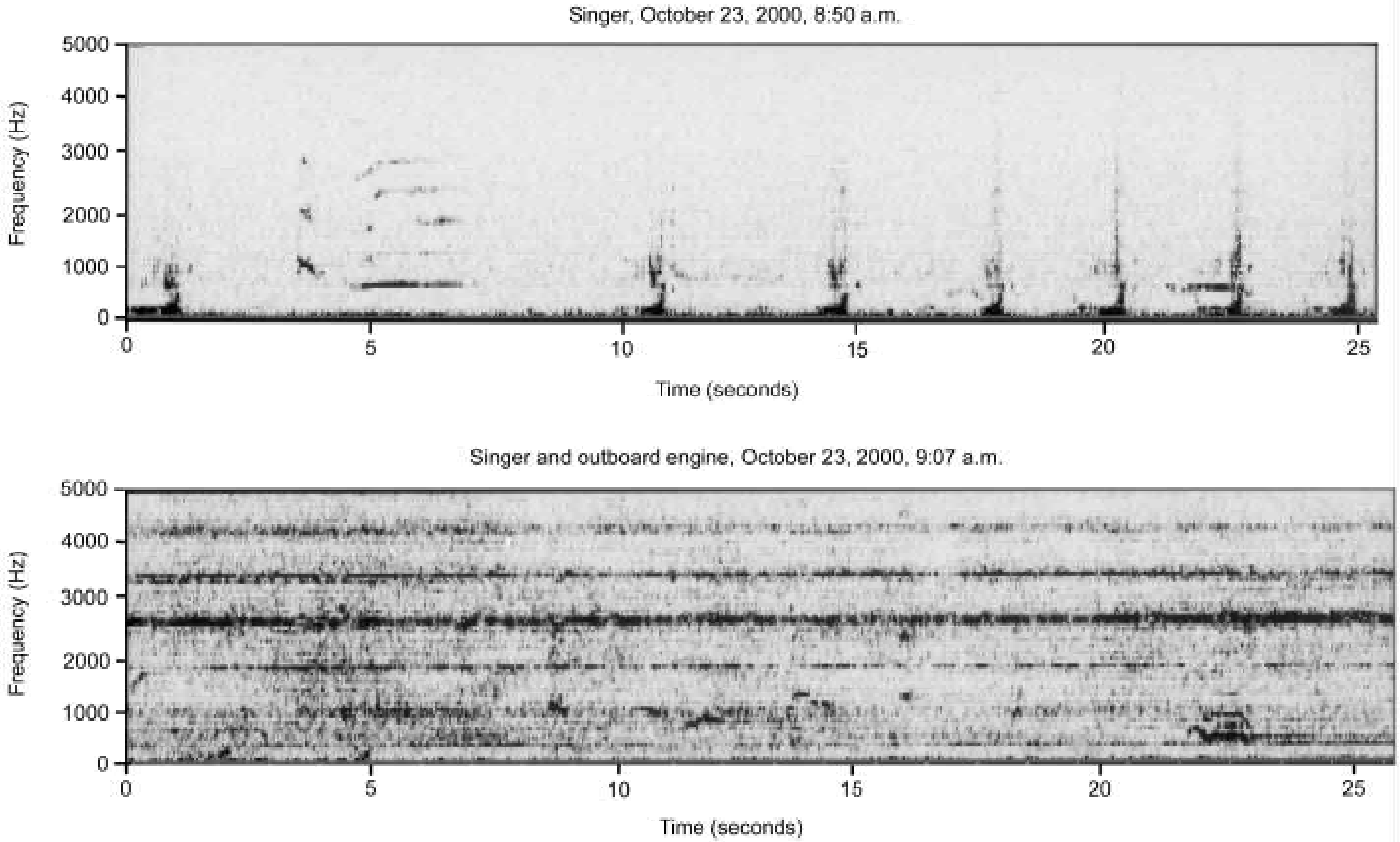
We do not know whether autumn humpback whale songs or other behaviors directly result in reproductive success. It is also unknown whether the prevalence of humpback whale song in Alaska indicates that the full range of mating behavior occurs in the autumn and winter in high-latitude waters. Recent findings by Straley indicate that some male and female humpbacks of various ages overwinter in southeastern Alaska. The occurrence in southeastern Alaska of humpback whale singing and other behavior typical of the mating season may indicate that even when mature males and females forgo migration they may not be sacrificing the opportunity to mate. We hope that continued investigations will shed light on the importance of high-latitude song to humpback whale mating strategies.

Disturbed humpback whales are more likely to perform aerial behavior, like this head-slap. (This photograph was taken during research authorized under National Marine Fisheries Scientific Research Permit #945-1499-00.)

Implications for Human Impacts on Whale Habitat

Reports by the National Research Council indicate growing concern about the effects of man-made noise on marine mammals. The underwater acoustic monitoring program that made our study possible originated from concerns that vessel-generated noise could harm endangered humpback whales in Glacier Bay. Baleen whales such as the humpback could be considered auditory specialists, because their acute hearing appears to be essential to their ability to navigate, socialize, detect predators, and find food and mates. These whales seem to rely more on acoustic cues, which can travel for miles, than visual cues, which are limited by underwater visibility, especially in plankton-rich feeding habitats such as Alaska.

Adding man-made noise to typical ocean noise originating from wind and rain makes it harder for whales to hear vocalizations, interferes with passive listening for predators and prey, and can change vocal behavior. For example, studies have shown increases in humpback whale song tempo



Spectrograms of humpback whale songs in Glacier Bay before (top) and during (bottom) pass-by of a vessel with an outboard engine in close proximity. In the bottom spectrogram the whale song is dimly visible in the background of the strong horizontal lines near 300 Hz, the dominant frequencies of the outboard engine noise. To hear these and other examples of whale sounds, visit the Glacier Bay National Park web site.

and length in the presence of vessel noise and other man-made sound sources. Typical non-vocal reactions of whales to disturbance include changes in swim speed and respiration as well as increases in the occurrence of aerial behavior. Now that we know that humpbacks sing in Glacier Bay, we wonder about the potential effects of vessel noise on singers and listeners. An outboard engine passing by at close range can almost completely overshadow a whale song. Underwater noise pollution is an important form of habitat degradation for marine species, becoming ever more pervasive as human use of coastal and offshore waters increases. Continued research into the functions of whale vocalizations, and the effects of man-made noise on the production and reception of sounds, will help focus concerns about the recovery and long-term conservation of many species of endangered whales.

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Wildlife in Miniature

A Biologist on the Trail of the Yellow-Cheeked Vole

This article was prepared by Karin Lehmkuhl, a biologist with the U.S. Fish and Wildlife Service at the Koyukuk/Nowitna National Wildlife Refuge Complex in Alaska.

Alaska. The name invokes images of snow-capped mountains, massive glaciers, throngs of caribou, grizzly bears, wolves, and moose. But nestled within all of this grandeur lies a secret land of wonder that people seldom notice—and it belongs to Alaska's small mammals. To experience this enchanting place, you must learn to see on a different scale. Blueberry bushes become tall trees, small lakes are immense oceans, and predators are monsters of mythic proportions. Here you will encounter Alaska's mice, voles, lemmings, and shrews. And if you are lucky in your exploring, you will meet one of North America's largest microtine rodents, the yellow-cheeked vole. (Microtine rodents are voles and lemmings, which belong to the subfamily *Microtinae*. This name comes from the Latin *micro* meaning "small" and *otos* meaning "ear.")

Named for its chestnut-gold cheek patches, the yellow-cheeked vole is a social rodent, establishing colonies in moist, grassy areas of the boreal forest region. Enter a yellow-cheeked vole colony and you will discover their well-worn trails, holes, and burrows, perhaps find a stash of horsetails, and hear the voles' high-pitched whistles that alert others in the colony of your presence. Spend long enough in the colony and you may learn the meaning of various vole chirps and whistles or recognize individual voles by their markings and mannerisms.

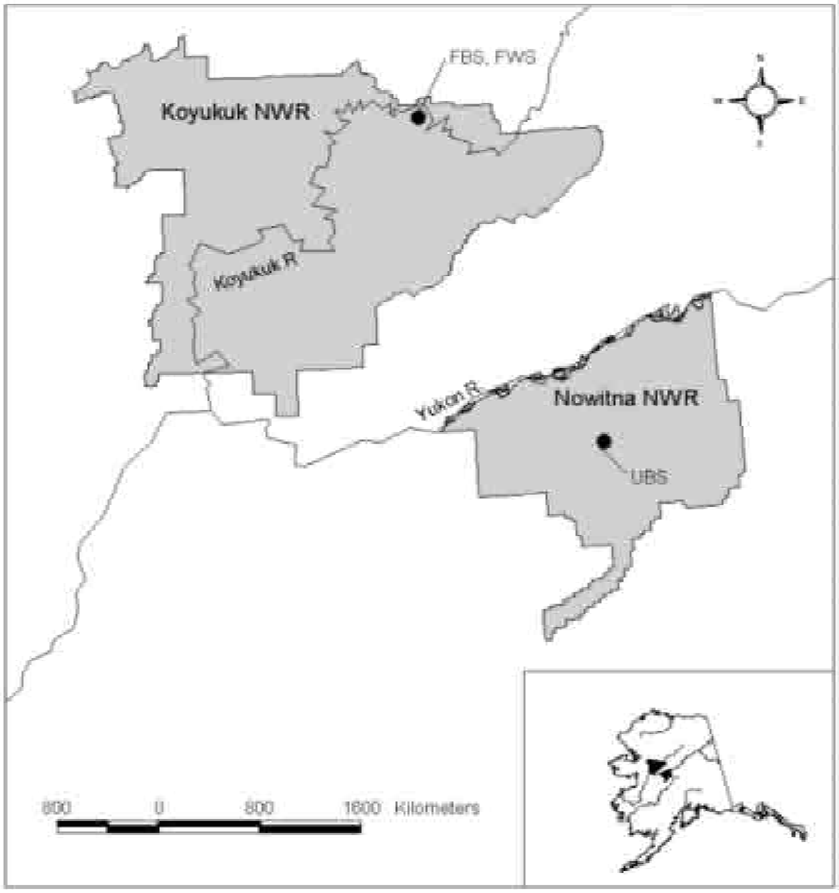
An adult yellow-cheeked vole, weighing about 140 g. Note the chestnut-colored nose patches and oily flank gland secretion above the back leg.

These are things I came to know during three summers spent researching yellow-cheeked voles in interior Alaska for the U.S. Fish and Wildlife Service and the University of Alaska Fairbanks. I conducted a mark–recapture study on the Koyukuk and Nowitna National Wildlife Refuges (NWR) to investigate population dynamics and habitat associations of yellow-cheeked voles in regenerating burned areas.

The Mystery

When I began this project, I gathered all the available literature pertaining to yellow-cheeked voles, reaching back to the mid-1800s. Although this boreal forest species ranges from interior Alaska to the shores of Hudson's Bay, the articles pertaining to its life history filled only a single folder. In 1948 one researcher wrote, "what we know of this northern woodland vole can be put in a few words." Only a handful of researchers have studied the species since. How exciting, in this age, to be studying a mammal about which we know so little!

As I read, another mystery emerged. At times, it seems, large colonies of yellow-cheeked voles simply vanish. Where once were hundreds of voles, building trails and churning up soil in their search for roots, there will be none. Where do they go? What do the voles need to survive, and why might they leave? Would my research shed any light on this question? My fascination with yellow-cheeked voles increased as I learned more about the species' life history and social behavior.



Location of yellow-cheeked vole live-trapping grids on the Koyukuk and Nowitna National Wildlife Refuges, Alaska.

The Voles

Except for their nose patches, yellow-cheeked voles are gray-brown, with smaller ears and "boxier" heads than their mouse cousins. Their bicolored tails, dark above and light below, are about one-third their body length, not nearly as short as a lemming's. Mature yellow-cheeked voles are hamster size and can weigh 140–170 g (5–6 oz.), with total lengths of 186–226 mm (7–9 in.). Juveniles do not reach sexual maturity until they are nearly a year old, and they remain smaller than adults throughout their first season.

Yellow-cheeked voles begin breeding in early May as the snow melts and herbs and grasses begin to emerge. Females produce one to two litters of 6–13 young (averaging 8–9) between May and July. During this time, males are territorial, aggressively defending their home ranges from other males. Females have overlapping home ranges and primarily defend the areas around their underground nests. Non-reproducing adults and juvenile voles show little aggression toward one another.

In each colony, yellow-cheeked voles build and maintain a network of trails and communicate in part using scent at latrine sites in trail junctions. Oily glands located on the flanks of adult voles secrete a scent that is rubbed onto scent posts or scratched onto the hind foot. Glandular odor may indicate reproductive condition and individual identity, and it may be used in territorial defense.

In mid-August and September, territorial behavior lessens, juveniles begin to mingle and disperse, and food is gathered and stored for the coming winter months. Large underground food caches and middens are excavated. Cache chambers are 20–30 cm high and 0.5 to 1 square meter in size. One cache of horsetail and fireweed rhizomes was found to weigh 3.6 kg (dry weight), about one bushel! These caches supply 90% of the winter food for the voles. Mature yellow-cheeked voles gather winter food with their offspring, but most adults live only until late fall (18 months total). What role adults play in overwinter survival of their offspring is still unclear.

Yellow-cheeked voles spend winters underground in communal nests with five to ten others. This strategy helps them maintain their body temperature during the cold, dark winter months. Interior Alaska winter temperatures average –20°C (–5°F) and can reach –60°C (–76°F). Snow insulates the ground, and surface and soil temperatures are generally higher than the air temperature. The huddling behavior of voles offers even greater warmth. In one study, mean daily air temperatures ranged between –5° and –23°C, while temperatures inside a yellow-cheeked vole midden ranged from +4° to +7°C. Voles left the midden a few at a time to obtain food from the cache, while the others remained in the nest to maintain heat.

Midden groups are apparently made up of individuals from separate families, although female littermates may be found together, and an adult female may visit middens in which her young are staying. The non-relatedness of individuals in middens may prevent interbreeding and reduce the risk of losing a family line to predation. The strategy of communal living and food storage for winter allows yellow-cheeked voles to survive year-round in places that are too harsh for many other small mammals.

Yellow-cheeked voles have been reported from a puzzling variety of habitats within the boreal forest zone. Their range extends from central Alaska to the west coast of Hudson's Bay and from the northern coast of the Yukon and Northwest Territories to central Alberta. The voles seem to prefer moist, early successional stage habitats—areas with good burrowing conditions and lush herbs and grasses for food. Yet the species has been observed in marshes, sphagnum bogs, banks of streams and rivers, deciduous and mixed woods, lake edges, black spruce forests, burned spruce sites, and grasslands. What do these places have in common? What do yellow-cheeked voles need to survive? What makes *good* yellow-cheeked vole habitat? These are some of the questions that filled my mind as I began my research.

In science there are always more questions than one researcher can try to answer. I knew I could only attempt to understand a small portion of the species' life history, so I chose to study yellow-cheeked voles in forests that were regenerating following wildfire. It had been suggested in the literature that burned areas provide good yellow-cheeked vole habitat, yet no studies had been conducted specifically to investigate vole populations in burned areas and to identify habitat characteristics influencing their numbers. Yellow-cheeked vole populations in relationship to wildfire had become of particular interest in interior Alaska because trappers were concerned about fire effects on pine martens. Martens are primarily associated with mature spruce forest, but on the Nowitna NWR, biologists found them using recently burned areas, where they fed on yellow-cheeked voles. It stands to reason that a better understanding of the prey population would lead to further insight into marten ecology and contribute to our understanding of fire in interior Alaska.

Fire and the Boreal Forest

Wildland fires play an integral role in the boreal forests of interior Alaska. Tens of thousands of acres burn each year, initiating the long process of forest succession. Plants arrive and establish at different times in response to the changes created by fire, resulting in a gradual shift in plant communities over time that ultimately results in mature forest. Spruce forests of interior Alaska are composed of two major community types: black spruce and white spruce. White spruce communities tend to be found in sandy or well-drained soils along riverbanks and on slopes with southern exposure. Boggy areas and slopes with less sun exposure tend to be occupied by black spruce. Fire effects and successional patterns in these two communities are similar but vary in interesting ways. These differences may affect the potential of each habitat type to sustain yellow-cheeked vole populations.

It can take over a hundred years for mature spruce to re-establish in a burned area. Fire in the boreal forest can remove the thick insulating moss layer that has maintained cold soil conditions, creating a bare soil seedbed and blackened surface that heats up in the summer sun. Herbs, mosses, and grasses flourish in these growing conditions. Some plants are adapted to resprout from surviving underground roots and rhizomes, while others arrive as seeds blow in from adjacent areas. This early stage of succession is called the *moss–herb* stage. After about five years deciduous shrubs and saplings have arrived and grow taller than the grasses and herbs, creating the *tall shrub–sapling* stage. In about 30 years the saplings have grown into the *dense tree stage*. Black spruce saplings are usually present now, and by about 60 years after fire a *mixed hardwood–spruce* community has developed. As the hardwoods mature and die out, the *black spruce* community has returned, occupying the site by about 90 years after the burn. White spruce is slower to return to a burned site, and *hardwood* communities dominate for 50–150 years after the fire. Eventually the *white spruce* community is re-established and remains until a disturbance such as fire begins the process again.

Black Spruce Sites	
0–1 years	newly burned
1–5 years	moss–herb
5–30 years	tall shrub–sapling
30–55 years	dense tree
56–90 years	mixed hardwood–spruce
91–200+ years	spruce

White Spruce Sites	
0–1 years	newly burned
1–5 years	moss–herb
5–30 years	tall shrub–sapling
26–45 years	dense tree
46–150 years	hardwood
150–300+ years	spruce

The Study Area

In 1988 a wildfire burned a 16,700-acre (68-square-kilometer) region in the northeast portion of the Koyukuk NWR. Here the topography is relatively flat (the elevation is 5–100 m), with many sloughs and small lakes scattered across the landscape. The fire burned along the west bank of the Koyukuk River, just upstream of the confluence of the Hogatza River. The Koyukuk River provided access to yellow-cheeked vole colonies in both regenerating white spruce and black spruce com-

Voles were captured in Sherman live-traps.

munities in the floodplain. I established two sets of paired live-trapping grids in this region: one in the black spruce community and the other in the white spruce.

A third pair of grids was established on the Nowitna NWR near the edge of a 35,000-acre (140-square-kilometer) region that burned in 1985. This gently rolling upland region is primarily vegetated sand dunes, with black spruce communities, lakes, and bogs in the flat valleys between the dunes, and white spruce and deciduous communities on dune ridges. The live-trapping grids were situated in regenerating upland black spruce habitat.

Trapping

Two eager helpers and I established the grids based upon accessibility and evidence of yellow-cheeked vole colonies. The 2,500-square-meter (27,000-square-foot) grids were situated to encompass areas of apparent high vole activity. Each grid contained 100 trap locations spaced at 5-m intervals in a 10 × 10 configuration. The voles were captured in small, folding live-traps that were supplied with bait (sunflower seeds) and cotton bedding material. We trapped at each grid for four days a month during June, July, and August 1997 and 1998 and in June 1999. Rain or shine, a faithful assistant and I ventured out by canoe or on foot to check the traps at 6:00 a.m., 2:00 p.m., and 8:00 p.m. daily. We had to be on time to let the voles out, as they could become too hot, cold, hungry, or dehydrated if left in the traps too long.

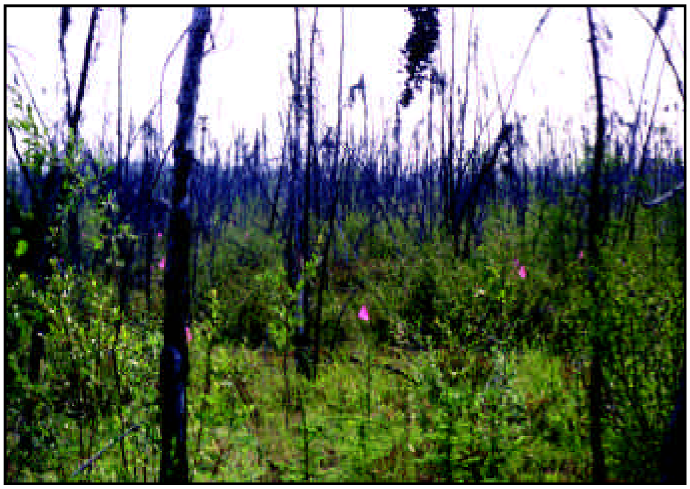
An electronic scanner reads the unique code from the microchip tag that has been inserted under the vole's skin.

When a vole was captured, it was marked with a passive integrated transponder tag inserted under the skin. Each tag contains a microchip containing a unique identification code that is transmitted to a handheld electronic reader when scanned, similar to scanning groceries at a supermarket. We kept track of all the new captures and recaptures so that later I could estimate vole abundance and survival and recruitment rates at each site. We also recorded the weight, age class, sex, and reproductive condition of each individual prior to release. We soon learned to distinguish between juvenile (less than 40 g), subadult (young of the year), and adult voles. The few voles that died in the traps were collected for stomach content analysis (in 1997) and museum specimens, and are now archived at the University of Alaska Museum. Occasionally we caught other animals, including red-backed voles, shrews, sparrows, and wood frogs, but these were not tagged.

How Many Voles?

My time spent in the field was rigorous, with many long days, mornings that came far too early, and long hikes and windy canoe trips, but also beautiful evenings, wildflowers, sunny days, and, of course, many voles. All the hard work paid off; in 1997 I captured 482 yellow-cheeked voles 1534 times, and in 1998 I captured 536 voles 2055 times! I kept track of each individual, when and how many times it was captured (called its "capture history"). Some voles were "trap-shy," meaning that after their first capture they avoided the traps. Others were "trap-happy," and we caught them frequently, sometimes twice during the same trap check! We learned to recognize many voles by their appearance and behavior.

We were able to watch juveniles mature into subadults during their first summer, and we saw them again as adults the following year. I tagged one female as a juvenile in 1997 and caught her as an adult in 1998 and again as a "grandmother" in 1999, which means she lived at least six months longer than most yellow-cheeks.



A regenerating black spruce site, showing the small snags and the dwarf birch and young black spruce in the understory.

A regenerating white spruce site, lush with grasses and herbs such as fireweed. The snags are larger and less dense than in black spruce sites, and there are fewer shrubs.

Now that I had collected all these data, I needed to estimate population characteristics (such as abundance and survival) at each trap site so that I could determine the relative quality of each habitat. Alaska winters are long but not long enough for one biologist to sort through all of these data by hand! Luckily I was able to use several cutting-edge computer modeling programs that use the capture histories of each vole and generate population parameter estimates. I specifically looked at vole abundance and density at each site in each month of trapping, as well as survival, reproduction, and immigration rates between months.

At nearly every site, vole captures and abundance estimates increased over the summer. Most new voles entered the populations through reproduction between June and July and through immigration through July and August. The immigrants were mostly subadults from adjacent areas that were beginning to move away from their birth sites.

Yellow-cheeked vole abundance was generally higher in the floodplain white spruce grids than in the black spruce sites. The estimated density peaked in August 1998 at 163 voles per hectare on one of the floodplain black spruce sites. Compare this to a low of 13 voles per hectare observed at one of the upland black spruce sites in June 1998!

The vole populations in the white spruce had higher rates of reproduction, immigration, survival, and site fidelity than those in the black spruce sites. In fact, of the 40 voles that were tagged in 1997 and recaptured the following summer, 30 were residents of white spruce grids, indicating that overwinter survival was high. On the other extreme, I encountered a case of "disappearing voles" in the upland black spruce. I captured 34 voles at one upland site in June 1997 and never saw any of them again! Other voles moved into the area, so the colony remained populated, but what happened to the voles that vanished? I even set out live traps in adjacent areas to see if some had wandered away, but I never found any of the missing voles.

What Makes "Good" Vole Habitat?

The evidence we saw while trapping, and the population characteristics I estimated, indicated that yellow-cheeked voles were utilizing all of the study areas and were particularly flourishing in the burned white spruce habitat. I investigated some of the unburned areas near the trapping grids but rarely saw signs of yellow-cheeked vole activities there. Why did the voles prefer the burn? What made the regenerating white spruce communities such a good place to live?

For a given habitat to sustain viable populations of a species, it must supply sufficient food, water, predator escape cover, and shelter. Yellow-cheeked voles need vegetation for food, cover, and shelter, and they rely on proper soil conditions for burrow construction. To get a vole's eye view of each grid, I measured characteristics of the vegetation and soil and compared conditions between burned and unburned areas.

Soil Conditions

Soils in the burned areas were warmer than in adjacent unburned areas, and the seasonally thawed layer (the active layer) above the permafrost was thicker. Such temperature differences are important to an animal living underground during the harsh northern winter. A deep active layer allows the voles to excavate large middens and food caches. Soil warming is a typical result of fire in the boreal forest, because the fire removes the insulating layer of moss and creates a blackened surface that absorbs the sun's rays.

The soils at the floodplain sites tended to be warmer and drier than in the upland sites. Remember the voles that vanished from the upland black spruce site? That area had particularly wet soil, and the water table rose during the month that the voles left, flooding some of the burrows. Perhaps the increased moisture, which was accompanied by low soil temperatures, contributed to the voles' disappearance.

Snags and Logs

Logs provide important cover for yellow-cheeked voles, and runways were often constructed underneath them. Burrows, especially those in which young were born, were frequently located in the root wads at the base of snags and logs. Since white spruce tends to be much larger than black spruce, the cover provided by the snags and logs at these sites was significant. The taller, larger white spruce trees were probably more susceptible to windfall, so there tended to be more logs in the white spruce sites and more standing snags in the black spruce habitats.

Vegetation

Plants may be the most important factor influencing the distribution and population dynamics of microtine rodents. Vegetative cover affects the microclimate at the soil surface, combines with loose snow cover to enhance winter insulation, and provides escape cover from predators. Vegetative cover in the black spruce grids was patchy, with dense shrubby areas interspersed with open areas of little vertical cover. The white spruce sites were more uniformly covered with a dense growth of grasses and herbs.

A juvenile yellow-cheeked vole, weighing under 40 g.

Of course, plants also provide food for yellow-cheeked voles. Both the literature and the results of our stomach content analysis indicated that yellow-cheeked voles have a preference for horsetails, grasses, fireweed, and blueberries. These species can be common in early post-fire successional communities and tend to be less common in mature spruce forests. The plants were present to some extent at all of the trapping grids, but horsetails, grasses, and fireweed were particularly abundant on the white spruce grids. Bluejoint reedgrass is a particularly aggressive invader of burned white spruce stands and has been reported to persist in association with fireweed for 100 years or more! Both plants can sprout from rhizome sections, and their growth may be fostered by the digging, collecting, and caching behavior of yellow-cheeked voles. While trapping we saw areas of vole-churned soil in which grasses were sprouting, as though a garden had been tilled and planted!

What's on the Menu for a Yellow-Cheeked Vole?

In 1997 the stomach contents of 29 yellow-cheeked voles that had died in traps were analyzed to determine what the voles had been eating. The voles were collected in all study sites, and the diets were similar despite differences in the vegetative communities. Species of horsetail contributed approximately 50% to the vole diet, and berries (mostly blueberries) made up another 15–30%. A fair amount of fungal spores were present in the diet, especially at the floodplain black spruce sites. Other berries, forbs, grasses, and lichens contributed to their diet in small amounts, while shrubs and mosses occurred only rarely.

It is interesting that yellow-cheeked voles are so fond of horsetails. The plant has been nicknamed "scouring rush" because of its rough texture. Horsetails contain silica and can be used by campers to scrub pots. The stem of the plant is segmented and can be easily "popped apart." Several times I watched yellow-cheeks pluck up a horsetail and pull apart each section to eat. Often I would find piles of horsetails at burrow entrances where the voles would sit and eat. The voles were clearly fond of berries as well and would reach up

Whenever you see grasses, horsetails, and fireweed—three of the yellow-cheeked voles' favorite foods—keep an eye out for yellow-cheeked voles.

to pluck blueberries off the bushes as you might pick an apple.

Other researchers have also documented the species' affinity for horsetails and berries. In addition, grasses and fireweed have been observed to be important food items for yellow-cheeked voles. These plants may be of greater use during seasons not represented in my sample (June–August). Fireweed possesses thick starchy rhizomes that are stored for winter consumption. I recently encountered an autumn food cache that was composed almost entirely of grasses and sedges.

My experience in interior Alaska has been this: wherever there are grasses, fireweed, and horsetail growing abundantly, there are likely to be yellow-cheeked voles!

Why Live in a Burn?

All of the yellow-cheeked vole colonies we studied were located in sites where the fire had caused soil warming, created snags and logs for cover and burrows, and provided favorable conditions for preferred forage species. The white spruce sites were particularly suitable for colonization because of the warmer, well-drained soils, large logs and root wads, and abundance of grasses and forbs. Differences in successional patterns in black and white spruce communities may allow yellow-cheeked vole populations to persist at higher densities and for longer periods in regenerating white spruce sites than in black spruce habitats. Only time will tell how long the voles remain and prosper at my study sites. And further study will reveal whether the patterns I observe hold true in other areas.

Still Learning

As I finish writing this article, I am sitting in a tent in the middle of a colony of yellow-cheeked voles. Outside I can hear them whistling to each other, speaking a language I have yet to master. My time spent trapping voles was enlightening and fulfilling, but I know I learned only one small piece of the puzzle. The wonderful small world of yellow-cheeked voles will always fascinate me. On your next walk outdoors, look down, pay attention to little things, and perhaps you will find yourself lost in the land of small mammals too!

Suggestions for Further Reading

Conroy, C. J., and J. A. Cook (1999) *Microtus xanthognathus*. Mammalian Species, vol. 627, p. 1–5.

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Wolff, J.O., and W.Z. Lidicker, Jr. (1980) Population ecology of the taiga vole, *Microtus xanthognathus*, in interior Alaska. *Canadian Journal of Zoology*, vol. 58, p. 1800–1812.

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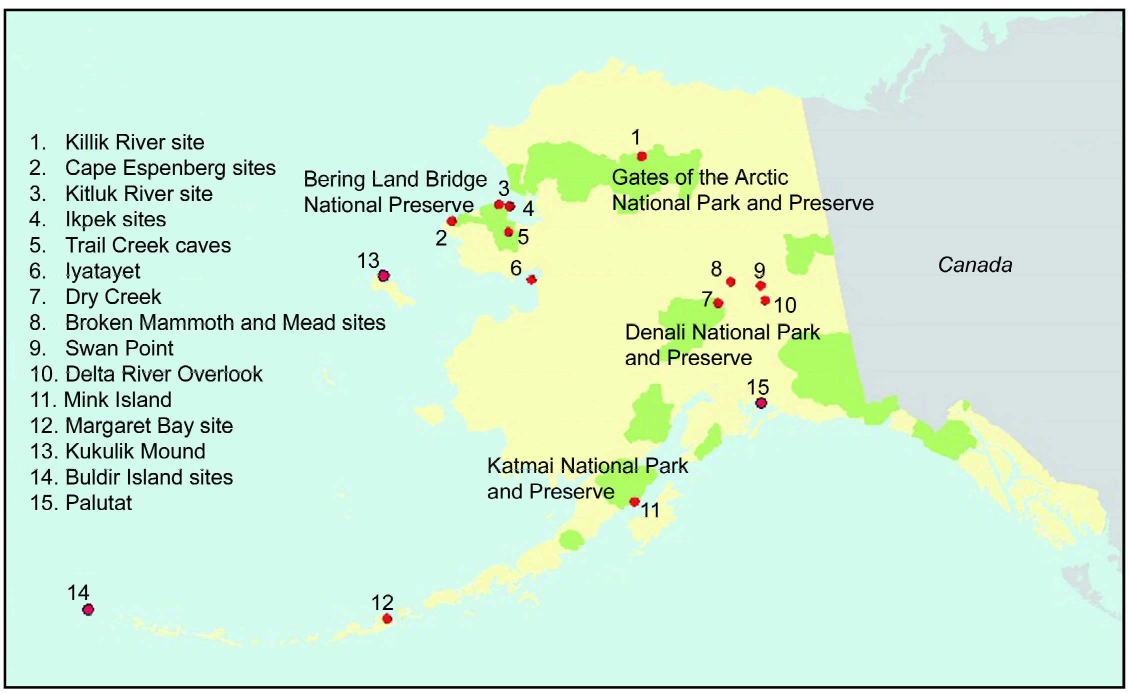
Out of Place Bones

Beyond the Study of Prehistoric Subsistence

This article was prepared by Becky M. Saleeby, an archeologist for the National Park Service.

Zooarcheologists specialize in old bones. Unlike paleontologists, who study fossil bones, and physical anthropologists, who study human skeletal material, zooarcheologists study the osteological refuse of long-past meals. Our expertise is in identifying and analyzing discarded, usually fragmentary, and often burnt skeletal remains of mammals, birds, fish, and shellfish excavated from archeological sites. During excavation, these fragments are carefully retrieved, bagged, and labeled with their exact site provenience, or place of origin within the site, before being brought back to the lab. With some collections numbering upwards of 10,000 specimens, analysis can take several months or even years. Frequently the goal of zooarcheological or faunal analysis is to provide a detailed picture of past human subsistence practices.

Even before the first bag of catalogued bones is opened, the zooarcheologist puts together a list, inventorying all faunal species that are available in the general site area, on either a year-round or a seasonal basis. However, sometimes after the analysis has begun, there can be surprises. Sometimes the fragments are "out of place," or *not* what is expected using modern faunal distribution maps. These fragments may represent species that once lived in an area but are now extinct or no longer present within the region or species that were brought into the site as the result of long-distance hunting forays or trade. In this review, the focus will be on bones identified from archeological sites throughout Alaska that are "out of place" geographically. It highlights some of the Pleistocene megafauna—the big game animals—hunted by the earliest Alaskans, as well as some species of sea mammals—walrus, ringed seal, and polar bear—hunted far outside their current ranges at times when past climatic and ice conditions were much different than today.



Analysis of large zooarcheological collections is time-consuming, beginning with the sorting of bones and bone fragments that are potentially identifiable. Later, we tentatively identify skeletal elements and species based on drawings and photographs in reference books and on simple pattern recognition. For example, the distal (lower) ends of the upper arm or forelimb of most mammals look similar, regardless of species. Subtle differences in morphology, such as the angle on a bony ridge or the shape of a particular ligament attachment, may be all that separate fragments of two closely related species, so we turn to comparative collections of skeletal material for positive species identifications.

In Alaska, one collection of comparative faunal material is housed at the Anthropology Laboratory at the University of Alaska Anchorage. Over the last several years, members of the Alaska Consortium of Zooarcheologists (ACZ), which is a special interest group of the Alaska Anthropological Association, have added many specimens of mammals, birds, and fish to broaden the existing comparative collection. By virtue of state and federal permits, we have been allowed to collect animal carcasses for processing. Properly prepared as clean, white skeletons, they are accessioned into the growing inventory of modern specimens used for comparative purposes by archeologists throughout the state. National Park Service (NPS) archeologists have made frequent use of these collections for identifying faunal remains from sites within Aniakchak, Bering Land Bridge, Cape Krusenstern, and other NPS units in Alaska.

Humans, Bison, and Elk

For zooarcheologists working on collections from early Alaskan sites dating between 10,000 and 12,000 years ago, it is exciting to realize that some bone fragments do not match any modern species from the comparative collection. These sites represent the hunting and foraging camps of people who ranged over the narrowing isthmus of the Bering Land Bridge (Beringia) at a time when the late Pleistocene environment was rapidly changing. In general, faunal preservation at these sites is so poor that bones are either absent or so deteriorated that they cannot be identified. Fortunately there are some exceptions, notably the Dry Creek site in the Nenana River valley, adjacent to Denali National Park and Preserve.

Dry Creek is a multi-component site excavated during the 1970s by researchers from the University of Alaska Fairbanks (UAF). It was heralded in archeological circles not only for its 11,000-year-old dates,* but also for its preservation, albeit poor, of faunal remains in association with ancient stone tools. R. Dale Guthrie, a Quaternary biologist and paleontologist now retired from UAF, worked with the team of archeologists at the site and identified fragments of Dall's sheep, wapiti or elk, and bison in the small but significant faunal assemblage, composed mostly of teeth. Neither wapiti nor bison are native to Alaska today, though some small herds have been reintroduced into the state.

Guthrie's paleoecological reconstruction of the site allows us to imagine Beringian hunters living in an interior Alaska landscape changing from dry grassland or steppe, which was once the dominant Pleistocene habitat in Alaska. Today the environment in the region is primarily boreal forest. Pale-

Zooarcheologist Bob Kopperl checks the differences in seal skulls during a workshop sponsored by the Alaska Consortium of Zooarchaeologists at UAA in 1999.

*All the dates that appear in this article are uncalibrated. These are the dates listed in the originally published site reports. Calibrated dates may be several hundred (or more) years older than uncalibrated dates.

Lorraine Alfsen uncovers a mammoth bone point from the lowest component of the Broken Mammoth site during excavation in 2000.

ontological specimens of mammoth, dating to about 12,300 years ago, were found in surveys around Dry Creek, but the bones of these behemoths were not found at the site. Guthrie argues that although mammoths, horses, camels, saiga antelopes, lions, and other species may have already become extinct in Alaska at the time when the lower two levels of Dry Creek were occupied, the regional extinction of wapiti and bison had not yet occurred. It is also interesting that the sheep, bison, and wapiti specimens from the site were as large as their Pleistocene forms, so Holocene dwarfing had apparently not yet begun.

A trio of early sites located on Shaw Creek Flats in the Tanana River valley—the Broken Mammoth site, the Mead site, and the Swan Point site—are also among the handful of early sites with faunal preservation despite the fact that their lowest occupations date to almost 12,000 years ago. This preservation is due to the sites' deposits of wind-blown glacial silt from the nearby floodplain of the Tanana River. Similar in setting to the Dry Creek site, they probably served not only as hunting overlooks for spotting and intercepting game animals, but also as "spike camps" or processing stations for the meat and hide brought back from kill sites. Best known of the three is the Broken Mammoth site, discovered in 1989 and revisited almost annually for summer test excavations and field schools sponsored by the University of Alaska Anchorage (UAA) and the Alaska State Office of History and Archaeology (OHA). Charles Holmes, an archeologist with OHA, and David Yesner, associate anthropology professor and zooarcheologist at UAA, are the principal researchers at the site.

David Yesner identified a wide range of waterfowl, small to medium-sized mammals, and fish, representing species still living in Alaska, from the earliest cultural layers at the multi-component Broken Mammoth site. He also identified small numbers of Dall's sheep, caribou, and moose bones, along with much higher frequencies of long-horned steppe bison and elk or wapiti remains. Measurements of a bison horn core from Component 3 (second from lowest) are compatible with this extinct species, and the site is outside the range for the wood bison, a northern species still found in free-ranging herds in Canada. Large-horned bison and elk were clearly the chief prey of the Broken Mammoth hunters, who also left behind an assortment of stone tools, mammoth ivory projectile points, toggles for clothing, and eyed bone needles.

The provocative name "Broken Mammoth" and the earliest dates that are at least 600 years younger than those from the Dry Creek site beg the question, "where's the mammoth?" Did humans and mammoths coexist in Alaska? Archeological evidence does prove their coexistence at several sites in the "lower 48," but the evidence in Alaska is still circumstantial. The name "Broken Mammoth" actually comes from the numerous mammoth tusk fragments uncovered during initial site testing. Similar fragments were also recovered from the nearby Mead and Swan Point sites. No other mammoth skeletal elements have been recovered from these sites. Yesner originally postulated that the mammoth ivory, and possibly hide and meat, at the Shaw Creek sites may have been obtained at kill sites located away from the bluff-top campsites and brought back for raw material. After many field seasons of excavation, the evidence now suggests to him that the ivory represents scavenged material from the skeletons of recently extinct animals that was brought back to camp specifically for tool production. Ongoing analysis and dating of the specimens may yet bring to light indisputable evidence in support of the possible coexistence of humans and mammoths in Alaska.

Hotly debated since the topic was proposed decades ago is whether the large-scale die-off of North American megafauna at the end of the Pleistocene (approximately 10,000 years ago) was the direct result of over-predation by human hunters. The issue of whether the extinction was caused by humans, environmental change, or a combination of factors has not been resolved. An accumulating body of zooarcheological evidence indicates that for some species it may have not have been abrupt as previously thought, particularly for the bison. The persistence of bison in Alaska and Canada virtually throughout the Holocene is documented in a recent study by Fairbanks researcher Robert Stephenson and his colleagues, in which they provide a long list of radiocarbon-dated paleontological and zooarcheological specimens. They also present oral narratives of Athapaskan elders living on the upper Yukon and Tanana Rivers that suggest that bison may have been sufficiently abundant to be a resource of some importance as recently as 200–300 years ago. Their zooarcheological evidence in Alaska consists of a bison tibia fragment from the Delta River Overlook site, dated at about 2,200 years ago, and a bison foot bone in probable association with the Killik River site, dated at about 2,300 years ago. The latter is located in Gates of the Arctic National Park and Preserve. Bison bones are also present in the upper component (about 2,000 years ago) of the Broken Mammoth site. The Gerstle River quarry site and the Silver Fox site, both in the Tanana Valley, provide evidence for the persistence of elk until about this same time period, suggesting that east-central Alaska may have served as a refugium for these species. Refugia are areas of relatively unaltered environment inhabited by relic forms of plants and animals during periods of climatic change, such as occurred at the end of the Pleistocene.

Scarcity of Moose in the Zooarcheological Record

Eventually, bison and elk did become extinct in Alaska, while other large mammals, such as caribou, moose, and Dall's sheep, survived. From ethnographic and historic records we know that moose and caribou were the primary big game species hunted by the interior Alaska Athapaskans, but was this also the case prehistorically? The flip side to the *presence* of geographically out of place bones in zooarcheological assemblages is the absence or scarcity of a key species, such as moose, which we would expect to find in abundance, given present-day distributions. Today moose populations exist almost throughout Alaska, with the exception of islands in the southeast and in the Aleutians.

My experience in identifying moose and caribou comes from the analysis of zooarcheological collections from a very large sample of sites located on the Susitna River in south-central Alaska. Seventy-eight of these sites produced bone and resulted in a huge collection of almost 143,000 specimens, ranging from minute fire-whitened fragments to complete unburned large mammal bones. Moose bones were only found at nine of the sites, including one paleontological site where five mandibles of late Pleistocene moose were recovered. The other eight sites were younger than 600 A.D. Even within the subsample of late prehistoric sites, fully 93% of the large mammal remains were identified as caribou; the remainder were moose and Dall's sheep.

David Yesner undertook a much more extensive survey of the occurrence of moose in the prehistoric archeological record of the Alaskan sub-Arctic some years ago. Questioning whether the apparently heavy reliance on moose by Athapaskans in ethnographic accounts was an accurate portrayal of their subsistence prehistorically, he turned to published accounts from 19 sites or site clusters from a vast area of interior Alaska and western Canada. Yesner's overall impression from looking at these data was that moose appear only rarely in any of these assemblages until quite recently, perhaps within the last 400 years or so. He suggests that climatic and vegetational changes, fire, and natural population cycles have all been factors in this apparent scarcity of moose in the region during most of the prehistoric period. As with the findings for the Susitna River sites discussed above, his study indicated that the species of primary importance for prehistoric populations in northern interior Alaska was caribou.

Cave Sites and Bear Bones

Not all the faunal collections that zooarcheologists identify come from unequivocally cultural contexts. This is particularly true of cave sites, where the refuse from early human occupation can be difficult to differentiate from the refuse left behind by other species of predators. Work done at Trail Creek caves, on the Seward Peninula within Bering Land Bridge National Park, provides an excellent example of the type of meticulous analysis needed to unravel the complexities of bone deposition within cave sites. Quaternary geologist David Hopkins and Danish archeologist Helge Larsen were the first to test and excavate several of the twelve caves on Trail Creek in the late 1940s. From two of the caves, Larsen and his crew recovered artifacts of ancient caribou hunters, as well as those of the historic Inupiat. The oldest tools date back 8,000 years or older.

He also reported thousands of bone fragments of extinct and extant species, including bison, horse, and mammoth dating back about 15,800 years ago. For decades after the original excavations, questions remained about the possible association of human artifacts with the bones of Pleistocene megafauna.

Within the faunal assemblages were broken canine teeth from several levels of two Trail Creek caves. Larsen identified them as dog teeth. Their size and the fact that they were broken led him to believe that they had been purposely knocked out by humans to prevent the dogs from chewing on skins or on tethering lines. Archeologists E. James Dixon and George Smith, both formerly of the University of Alaska Museum in Fairbanks, recognized that if this identification were accurate, these would be among the oldest specimens of domesticated dog in the world. Animal domestication is known archeologically from Old World sites, so these teeth were clearly out of place in an Alaskan assemblage. Dixon and Smith compared the canines with the permanent teeth of a variety of mammals that could be expected in a cave deposit, but they found no morphological and size matches until they compared the specimens with the deciduous dentition of brown bears. These teeth exfoliate during the second winter of hibernation. Their presence in the faunal assemblage from Trail Creek and other caves sites of similar age was thus attributed to a very long history of bear denning, rather than dog domestication.

Subsequent zooarcheological work at Trail Creek caves has shown that brown bears were responsible for more than simply hibernating and dropping their deciduous teeth. According to Dale Vinson, who methodically analyzed the bones from two of the Trail Creek caves tested in 1985 by the NPS, disturbance within the layers of the cave deposits was probably due to bear denning activities. Although not completely ruling out the possibility that early Alaskans brought in and modified the bones of Pleistocene mammals found in the caves, Vinson made a strong case for non-human scavengers and carnivores being responsible for the bone breakage and cut marks he documented.

Polar Bear, Walrus, and Ringed Seal

Exactly when the ancient caribou hunters of northern Alaska began to dwell along the coast and hunt for sea mammals is not known for certain. Some of the earliest evidence for sea mammal hunting on the northwest coast of Alaska is represented by only a few charred fragments of seal bones in a hearth at the earliest cultural level at the Iyatayet site on Norton Sound. The characteristic Denbigh Flint complex tools at this level date to approximately 5,500–4, 000 ago. The makers of these tools are thought to be the ancestors of the present-day Inupiat of northern Alaska. J. Louis Giddings, who excavated at Iyatayet in the late 1940s and early 1950s, identified bones from an upper, 2,500-year-old level of the site (Norton culture) as predominantly “small seal.” He also identified bearded seal, walrus, and beluga in this Norton assemblage, along with a small number of caribou bones.

Since Giddings’ pioneering archeological fieldwork in northwest Alaska, our knowledge of the prehistoric cultures has increased enormously, in part because of the fieldwork and research carried out by the National Park Service in Bering Land Bridge National Preserve (BELA). As the result of surveys and excavations in BELA by archeologists Jeanne Schaaf and Roger Harritt, we now have extensive faunal collections from BELA sites at Cape Espenberg, the Ikpek Lagoon area, and the mouth of the Kitluk River. Besides the small ringed seal that appeared in collections made by Giddings, the spotted seal and the ribbon seal have been identified at BELA sites. Bearded seals or ugruk, walruses, belugas, and polar bears also occur in the assemblages. These species all thrive along the far northern coastline, locked during the winter in shore-fast ice. They are *not* out of place geographically but fit well within current distributions of sea mammals north of Bristol Bay.

South of Bristol Bay in Shelikof Strait and the Gulf of Alaska, an entirely different suite of sea mammals is usually found within faunal assemblages, even at sites dating back earlier than 6,000 years ago. The harbor seal is the only seal species of the genus *Phoca* (as opposed to fur seals in the genus *Callorhinus*) that currently inhabits Alaskan waters south of the Alaska Peninsula. Other commonly identified species are the sea otter, Steller sea lion, fur seal, and two species of porpoises. Again, these are species that would be expected in the region. Clearly out of place in southern coastal assemblages are the bones of the ice-loving polar bear, ringed seal, and walrus, so their presence in the faunal assemblage from the Margaret Bay site on Unalaska Bay in the Aleutians was a surprise to zooarcheologist Brian Davis.

An extensive zooarcheological collection was recovered from the Mink Island site on the coast of Katmai National Park and Preserve. Archeologists built this dome structure to protect fragile site stratigraphy and artifacts during excavation. Brown bears (see center of photo) were frequent visitors at the site.

The Margaret Bay site was noted by zoology professor Alvin Cahn, who was a Lt. Commander in the U.S. Naval Reserve stationed in Dutch Harbor in the early 1940s. Archeologists, working at the site in later decades, recognized the importance of this stratified (or many-layered) site, but it was not until excavations in 1996-97 by Richard Knecht of the Museum of the Aleutians that a dense shell midden with an abundance of animal bones was encountered and excavated. This midden was radiocarbon dated at 4,700–4,100 years before present. Brian Davis analyzed over 5,000 mammalian specimens from the midden, using the comparative collections housed at the University of Alaska Museum in Fairbanks, and he made some unexpected identifications. Harbor seal bones accounted from almost 50% of the identified specimens, but the ringed seal was also abundant at the site, contributing about 11% of the total bone count. Davis's most exciting finds were the mandible, forelimb, and hindlimb of a polar bear. The bones of this species are very rare, even within its current range on Alaska's far northern coastline. A few specimens of walrus were also found within the Margaret Bay assemblage. The age of this midden is congruent with the Neoglacial, a cooling period of glacial advance identified between 5,000 and 3,500 years ago in the Aleutians. The effect that these climatic conditions, and the resulting geographically displaced species, had on the hunting techniques and culture of the prehistoric Aleuts will be a subject of archeological study for many years.

We are undoubtedly in for more faunal surprises and out of place bones when identification and analysis of the enormous Mink Island site collection are completed. The Mink Island site, located in Amalik Bay off the coast of Katmai National Park and Preserve, was excavated by Jeanne Schaaf and her NPS crews in 1997–2000. It has two main components: the upper one dating to 370–2,010 years before present, and the lower one dating to 5,000–7,300 years old, making it one of the oldest known sites along the south-central coastline of Alaska. Well-preserved bones recovered from both components are currently under analysis by zooarcheologist Maribeth Murray at the University of Alaska Fairbanks. According to Murray and her colleague, S. Craig Gerlach, a neonatal walrus mandible was identified in the upper site component. According to modern species distributions, walrus are usually considered out of place in the Shelikof Strait region. The verdict on whether polar bear specimens are present among the Mink Island bear bones awaits Murray's final identification and analysis. These bones may date to a glacial period known as the Little Ice Age (1300–1850 A.D.), a global phenomenon of low temperatures that dramatically affected cultures around the world.

Walrus ivory artifacts have been found at sites farther east, in Prince William Sound, even more removed from the present-day species range. Zooarcheologist Linda Yarborough, who excavated the Palutat site, reports that ivory toggles and projectile points found at the site possibly date from between 2,000 and 1,400 years ago. There were no other skeletal elements of walrus identified at the site. Yarborough is unsure whether the ivory tusks were brought to the area in trade and the artifacts manufactured on-site, or whether these ice-adapted creatures were hunted nearby during a period of glacial advance in Prince William Sound.

Cultural Factors

Natural environmental conditions affecting past animal distributions explain the presence of some bones that appear to be out of place, but cultural factors are also important to consider. In analyzing the faunal collection from the protohistoric (about 1850 A.D.) Kitluk River site a few years ago with my colleague, Angela Demma, we came across a specimen that we simply could not identify. It took several visits to wildlife biologists in Anchorage before we were satisfied with a positive identification. The specimen was a horn core of a Dall's sheep, certainly not something we expected to find on the coastal margin of the Seward Peninsula, far from any mountainous habitat. We interpreted the horn core as either a trade item or a remnant brought back from a distant hunting trip, possibly far to the north in the hilly country around Cape Lisburne or the Baird Mountains north of Kotzebue.

Trade between coastal and inland people, particularly of caribou antlers and walrus ivory, is well documented in the ethnographic literature of the Arctic and appears to have deep roots in the past. Anthropologist Otto Geist studied the Siberian Yupik people of St. Lawrence Island in the Bering Sea during the 1930s and excavated their ancient sites, including the Kukulik Mound. He reported finding tool handles and scratchers fashioned from caribou or reindeer antlers deep within the mound. Caribou are not native to St. Lawrence Island, and reindeer were introduced as late as 1900. It therefore appears that the antlers from which these tools were fashioned must be prehistoric trade items the ancient St. Lawrence Islanders received from mainland caribou hunters. Large trade fairs, such as one held every summer at Sheshalik, near Kotzebue, in the 1800s, may have been the source of such trade goods.

Otto Geist also reported that the people of St. Lawrence Island spoke of hunting "the real walrus without tusks" in the past. Geist conjectured that they were referring to Steller's sea cow, an extinct relative of the manatee, hunted to extinction by Russian fur traders in the late 1700s and early 1800s in the Bering Sea and the Aleutians. Only recently have the bones of this species turned up in zooarcheological assemblages. Debbie Corbett, archeologist with the U.S. Fish and Wildlife Service, excavated a few fragments of what she believed to be sea cow bone from 1,000-year-old sites on Buldir Island in the western Aleutians. These bones, probably ribs, are very dense and distinctly different from bones of other sea mammals and walrus ivory. Corbett believes that the ancient Aleuts not only hunted these creatures for their meat but may have also made artifacts from their bones.

Out of place bones tease our imagination, whether they come from archeological contexts or from more recent surface finds. Notable in my experience is a foot bone brought to my office by Dale Vinson of Lake Clark–Katmai National Park and Preserve. Vinson's expertise as a zooarcheologist was called into play when, surveying on Takli Island, he stumbling upon an unusual bone he recognized as an animal not indigenous to the area. It was, in fact, part of a horse skeleton. With a bit of historic sleuthing, he was able to shed some light on this out of place bone. As the story goes, a bay gelding was the only horse that survived a shipping mishap in Amalik Bay on the Katmai coastline in 1956. The horse continued to survive in the hostile environment for the next 18 years and was known as a living legend to local fisherman. This bone, the subject of much discussion, is now properly accessioned as a historic specimen in the NPS collections at the Lake Clark–Katmai Study Center in Anchorage.

Zooarcheology and Biogeographic History

Although bettering our knowledge of prehistoric subsistence is often the rationale in zooarcheological analyses, the bones themselves sometimes force us to go beyond subsistence in our interpretations. Some bones simply cannot be identified on the basis of present-day animal distributions. Extinctions, shifts in range, trade, and long-distance hunting are all possible factors for explaining bones that appear to be out of place. These specimens challenge our assumptions and remind us that past landscapes were different than those of today and that cultural patterns were not what we might expect them to be. The integration of a wide variety of data—geological, biological, ethnographic, and historic—has proven successful for zooarcheologists. Now it's time to turn the tables and convince wildlife biologists that zooarcheological data can benefit them by providing the element of great time depth to their studies of species that may be threatened or endangered.

Listed in the 2002 program for the 67th annual meeting of the Society for American Archaeology was a symposium entitled "Zooarchaeology's Contribution to Conservation Biology." Included were papers addressing the interface between archeological perspectives and wildlife management of elk in Washington, black bears in Minnesota, pronghorn antelopes in Wyoming, freshwater fish in Virginia and North Carolina, and others. Perhaps the paper most relevant for Alaskan wildlife managers was the one presented by Michael Etnier on seal remains from the Ozette site in western Washington. He documented the differences between prehistoric and modern abundance and migration patterns of six North Pacific sea mammal species and discussed both anthropogenic and natural catalysts for behavior change. Work such as Etnier's may be the wave of the future for wildlife managers who want to expand the narrow time range of their studies—just a few decades or less—to centuries or even millennia by looking into the zooarcheologists' bags of bones.

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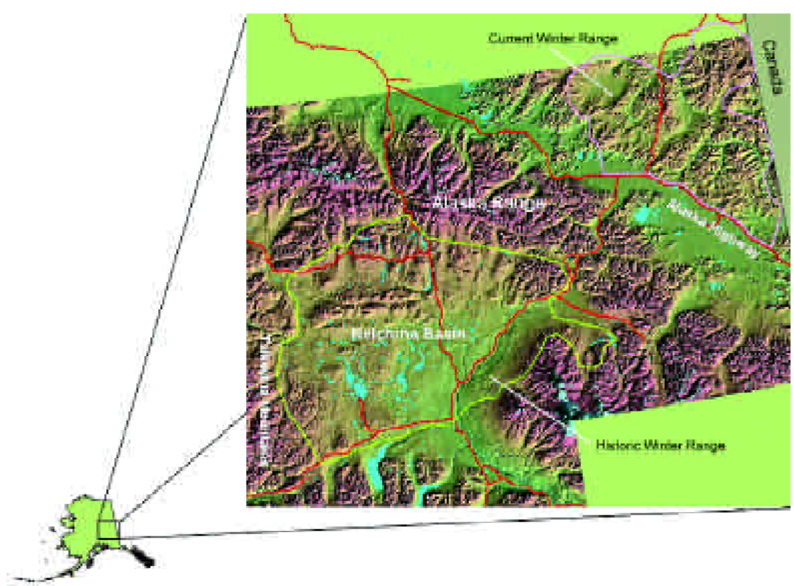
Evaluating the Impacts of Wildland Fires on Caribou in Interior Alaska

This article was prepared by Kyle Joly and Layne Adams, both of the Alaska Science Center, U.S. Geological Survey, and by Bruce Dale and William Collins, both of the Alaska Department of Fish and Game.

Caribou are found throughout the boreal forests of interior Alaska, a region subject to chronic and expansive wildland fires. Fruticose lichens, if available, constitute the majority of the winter diet of caribou throughout their range and are common in mature boreal forests but largely absent from early successional stages. Fire, the dominant ecological driving force, increases vegetative diversity and productivity across the landscape but may reduce the availability of caribou winter forage for decades.

Increasingly, wildland fire regimes are influenced by humans seeking to reduce fire hazards or mitigate the effects of years of fire suppression. Consequently, biologists have debated the importance of forage lichens to the dynamics of caribou populations, and land managers have questioned the importance of fire regime to wintering caribou. To better understand the impacts of wildland fire on caribou, we are simultaneously investigating the relationships between fire history, caribou movements, forage lichen availability, and caribou nutritional performance on their winter range.



The Nelchina Caribou Herd (NCH) provides an excellent research opportunity to investigate the effects of wildland fires on interior herds. Scientists have been studying this important herd for over 50 years, and it has been the focus of numerous recent research projects that provide extensive background information. Moreover, for the past ten years the majority of the herd has migrated northeast out of the Nelchina Basin over the Alaska Range in the fall to overwinter in the Ladue and Dennison Fork river drainages north of the Alaska Highway. The current winter range consists of gently rolling, continuous, and expansive stands of black spruce. Wildland fire has left a complex mosaic in this otherwise relatively homogeneous landscape. There are frequent and extensive wildland fires in the herd's current winter range, which provides an exceptional framework for evaluating the relationships between stand age and forage lichen abundance. Also, because the use of this area by the NCH is relatively recent, the region provides the opportunity to evaluate selection for lichen abundance driven by wildland fire.

The herd historically overwintered in the boreal forest in the heart of the Nelchina Basin, a region practically devoid of fires for the past 50 years. Assuming that wildland fire is detrimental to lichen abundance, it seems paradoxical that the herd has shifted its winter range north of the Alaska Range. Obviously, factors other than the age of the stand have influenced the selection of winter range. Grazing or trampling by caribou, competition from other species, or interactions of those factors may inhibit lichen abundance. Indeed, instead of limiting lichen abundance, under certain circumstances, fire may be required for recovery of overgrazed or over-mature range. Comparing the historic and current ranges provides a unique framework for evaluating these hypotheses.

Caribou present significant challenges for evaluating resource selection. The herd, which consists of approximately 30,000 individuals, calves in

Caribou congregating on Swede Mountain, October 2000.

the eastern foothills of the Talkeetna Mountains. Large aggregations form during the summer but then splinter and dissipate throughout the Nelchina Basin prior to the fall migration. The current winter range is located over 150 miles to the northeast of the calving grounds. Extensive, frequent, and unpredictable movements, as well as highly variable degrees of aggregation, make it difficult to estimate the used and available resources. The large geographic extent of the herd's range (approximately 69,000 square kilometers, or 27,000 square miles) and the various spatial scales that resource selection could operate on add to the complexity and require us to use a combination of methods to collect and analyze data.

We are investigating habitat selection at three spatial scales. At the broadest scale, we are comparing fire history, lichen abundance, and caribou distribution between the herd's historic and current winter ranges. In addition, we will compare these ranges to secondary wintering areas and summer range. Within the current winter range (intermediate scale), we are evaluating resource selection in relation to recent wildland fires (less than 50 years old). At the finest scale, we will be analyzing the role of lichen abundance for selection of specific feeding sites.

It is often noted that selection for a resource does not necessarily indicate that availability of that resource affects the fitness of individuals or the dynamics of populations. In other words, selection for a certain habitat may not be biologically relevant, as alternative habitats may be just as beneficial. Therefore, it is necessary to evaluate the benefits of a selected habitat as well as the consequences of loss of that habitat. In the case of fire–caribou relationships, the most likely consequence of fire-caused scarcity of forage lichens is poor overwinter nutrition. Consequently, we are evaluating the overwinter nutritional performance, as measured by changes in body size and weight, of both free-ranging and captive caribou on various ranges. These indices will be related to resource selection patterns to determine if differences in the caribou's choice of habitat result in quantifiable changes in body weight, a key index of reproductive potential. The study is in its third of five years, and some preliminary results are available.

Methods

Research Team

The U.S. Geological Survey's Alaska Science Center (ASC) and the Alaska Department of Fish and Game (ADFG) developed a cooperative research project to investigate a suite of questions that will help determine the role of wildland fire in caribou ecology. Personnel from the Alaska Fire Service (AFS), the Bureau of Land Management, the U.S. Fish and Wildlife Service, the National Park Service, and the University of Alaska Fairbanks have assisted the ASC in this research. Funding for this project was secured from the National Interagency Fire Center, ASC, and ADFG.

Resource Selection

We captured caribou by darting them from helicopters in the spring and fall during each year of the study. Approximately 100 caribou were fitted with either traditional VHF or GPS radiocollars. The GPS collars, programmed to obtain locations every seven hours, were equipped with VHF beacons as well. Monthly aerial surveys were used to collect data on caribou movements and distribution. We downloaded GPS data from the collars every six months during capture operations.

We used monthly aerial radiotelemetry data collected by the ADFG in the early 1980s to determine caribou use patterns on the historic winter range, which enabled us to compare broad-scale patterns of selection. Forage lichen biomass, which was determined from ground surveys, was then correlated to the percent coverage of lichens, which was determined for a large number of used and random plots throughout the NCH's range using digital aerial videography. This allowed us to analyze the broad-scale patterns of selection by comparing the historic versus the current winter ranges.

To analyze resource selection at an intermediate scale, we used our telemetry data to delineate the current winter range of the NCH. Data assem-

Authors weighing a young caribou on Sixtymile Butte. The caribou were weighed repeatedly to determine weight change over the winter months.

bled by AFS on fire perimeters dating back to 1950 were then incorporated into a geographic information system (GIS). Using these data, we calculated the proportion of area burned in the last 50 years. By comparing caribou distribution to wildland fire history in the region, we have been able to determine if the caribou select for or avoid these younger stands in the herd's current winter range.

To evaluate resource selection at the finest scale, vegetation plots were located at sites that were used by caribou, as determined from the GPS data. These data were compared to data from sites randomly distributed throughout the current winter range. Lichen biomass, stand age, and a suite of other characteristics were determined at each of the plots. We subcategorized lichen biomass by preference into primary and secondary caribou forage lichens, as well as other less preferred lichens.

Caribou are fitted with very high frequency (VHF) radiocollars during captures. Fixed-wing aircraft are used to track the collared caribou throughout the winter. Here, the author tracks caribou near the Clearwater Mountains.

Nutritional Performance

Free-ranging caribou had numerous morphometric measurements taken at the time of each capture, as well as being fitted with radiocollars. By measuring body weight at 4, 10, and 16 months of age, we obtained weight change over each caribou's first winter and first summer relatively free of maternal influence. This information will then be related to the individuals' use of habitat and distribution relative to other caribou.

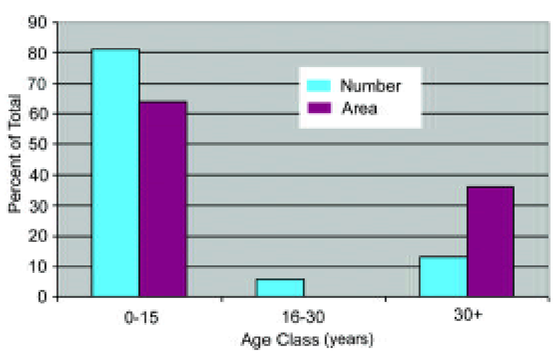
Evaluating the nutritional performance of free-ranging caribou is problematic because range use is confounded by the myriad of factors that influence the movements of caribou. To evaluate the effect of lichen abundance on nutritional performance under more controlled circumstances, we conducted feeding trials with hand-raised animals. Several NCH caribou calves were captured at one day of age and reared in captivity. During the fol-

Bill Collins loads a hand-reared caribou onto a trailer to transport it for feeding studies. The Alaska Pipeline is in the background.

lowing two winters, the calves were brought to enclosures on the herd's historic and current winter ranges. After a seven-day acclimation period, we determined activity budgets, diets, and weight changes during one-week feeding trials. We conducted these trials on one-hectare enclosures with lichen coverage ranging from 0 to 56%.

Results

Approximately 40 four-month-old calves and 12 sixteen-month-old yearlings were captured each fall, along with 20 adults that received GPS collars. All the calves and GPS-collared cows that survived the winter were captured again in the spring and the following fall. Over 800 VHF and 12,000 GPS relocations were collected in the current winter range during the first two winters of the project. GPS units successfully determined the locations on over 80% of attempts.



Number and area of fires on the current winter range.

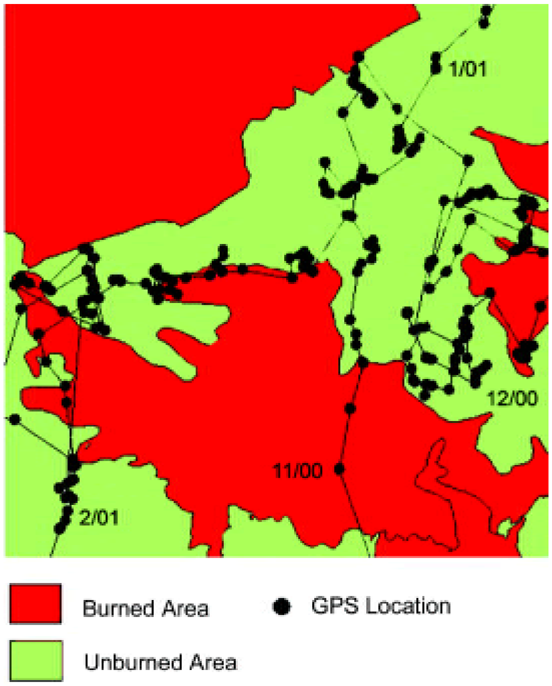
Broad-Scale Selection

The majority of the radiocollared caribou used the current winter range, which encompassed approximately 10,000 square kilometers, or 3,900 square miles. During the first two winters of this project, not a single captured caribou was located in the historic winter range in the Nelchina Basin. By comparison, a previous ADFG radiotelemetry study consisting of over 2,500 locations of NCH caribou between 1980 and 1985 clearly identified the Nelchina Basin area as the primary winter range. Evaluation of lichen availability on the historic range is not yet complete but it appears that, despite a paucity of recent fires, lichen is less abundant on the historic range than on the current winter range. However, lichen biomass is high within a series of wildlife exclosures (fences designed to keep large mammals out) constructed on the historic range in the 1950s, suggesting that grazing and trampling by caribou during the non-winter months keeps lichen abundance low. Furthermore, competition and shading by other species (primarily by mosses), in concert with grazing and trampling, may inhibit lichen growth and recovery. We have established new exclosures and "seeded" lichen fragments on a variety of burned and unburned substrates to evaluate these hypotheses.

Intermediate-Scale Selection

While less than 1% of the historic winter range is known to have burned in the last 50 years, AFS records indicate that recent wildland fires cover more than 20% of the current winter range. More than 80% of these fires have occurred in the last 15 years. Fires that are over 30 years old account for only about 10% of the total number of burns but nearly 40% of the total area. Vegetation plots examined within the current winter range support the fire scar data, revealing that few stands are over 200 years old and that sites between 60 and 100 years of age are the most common.

Less than 6% of the relocations, both VHF and GPS, in the current winter range fell within mapped fire perimeters during the winters of 1999-2000 and 2000-01. Given that over 20% of the range has burned within the last 50 years, caribou used these areas proportionately less than their availability. There were also indications that when caribou were relocated in burned areas, they tended to be near the perimeter or did not stay for long. We are investigating the possibility that some caribou located within mapped fire perimeters may have actually been using unmapped islands of unburned habitat within the fire perimeter.



Caribou used burned areas proportionately less than their availabilities. Caribou locations within burned areas tended to be towards the perimeter of the burn. Depicted here are the movements of one caribou, instrumented with a GPS collar, around a recent burn.

Fine-Scale Selection

Selection against using recent burns and for lichen-rich older stands was also readily apparent at the finest scale. A comparison of stand ages of 120 used and 120 random sites revealed that caribou used 80-year-old and older stands more than expected and used stands younger than 80 years less than expected within the current winter range. Forage lichen biomass was greatest in 80- to 220-year-old stands but virtually absent from stands less than 60 years old. Some lichens, such as *Cladonia rangiferina*, a primary forage species, were not detected in substantial quantities in stands that were younger than 150 years old. Forage lichen coverage was much greater at caribou locations (30%) than at random sites (10%). This translated into significantly greater primary and secondary forage lichen biomass at caribou locations versus random locations, as lichen coverage was strongly correlated with lichen biomass. Caribou locations had more than twice the mean primary forage lichen biomass than random locations had. Because some random sites may have been within stands selected for by caribou, the difference between used and random locations is only a conservative estimate of the potential differences between used and unused habitat.

Nutritional Performance

We measured changes in overwinter body measurements of free-ranging caribou each year. Calves, on average, lost about 5% of their total weight over the winter. During this period, however, skeletal growth did occur. Metatarsus and mandible lengths were both, on average, approximately 2 cm longer at the end of winter than at the beginning. Cows lost on average over 10% of their body weight during the first winter but only 5% during the second. Some individuals actually gained weight over the winter.

Analysis of the performance of individuals and cohorts (all the individuals born during a given year) of free-ranging radiocollared caribou in relation to habitat use has just begun. However, captive caribou grazing on the historic winter range spent more time ruminating (chewing their cud), which implies lower habitat quality, than when they were on the current winter range. The captive caribou resorted to changing their diet to include poor forage such Labrador tea when on the historic winter range. The results of grazing captive caribou on different plots with varying levels of lichen abundance are still pending but should provide specific data on the abundance of lichen required for caribou to maintain their body weight over winter.

Conclusions

In the NCH's winter range, the boreal forests of east-central Alaska, wildland fire is a key ecological factor increasing vegetative diversity and productivity. Wildland fires destroy lichen mats in the region, and replacement of the primary caribou forage species takes more than 50 years. Our data strongly reinforce the tenet that lichen abundance is related to stand age. These results imply that fire regime can have strong influences on lichen abundance. Moreover, factors influencing fire frequency, such as prescribed fire, fire suppression, or climate change, likely influence the availability of winter range for caribou, which avoid areas that have been burned within the past 50 years.

By limiting our analysis to older stands, we determined that caribou were specifically selecting for lichen abundance rather than some physical characteristic inherent in older stands. If forage lichen abundance affects winter weight loss, the frequency, distribution, and size of wildland fires may play a significant role in increasing vulnerability to predators, delaying maturity, and reducing the productivity of caribou. These consequences could be detrimental to the fitness of individuals and populations of caribou.

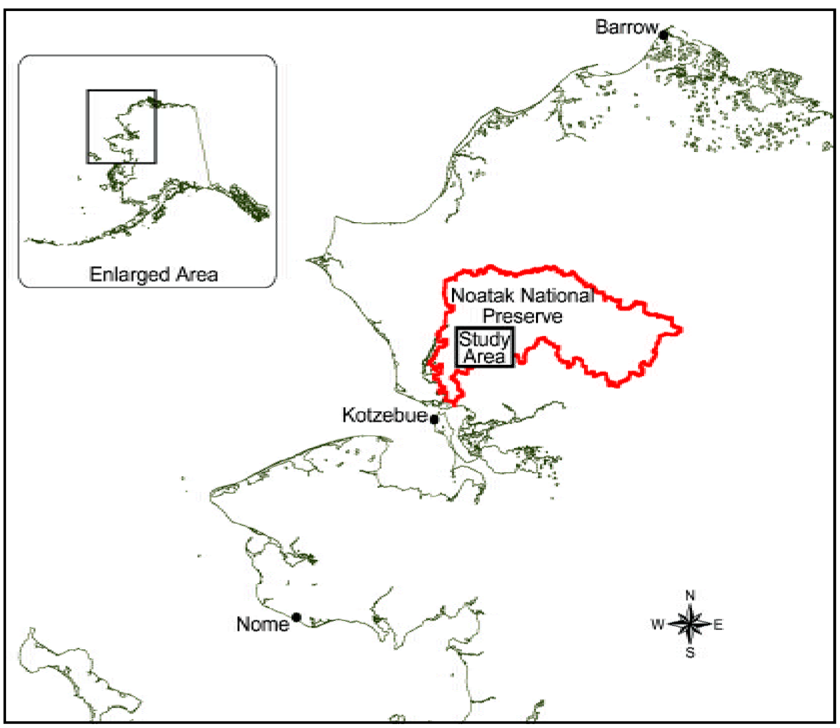
Demography of Dall's Sheep in Northwestern Alaska

This article was prepared by Christopher Kleckner, Mark Udevitz, and Layne Adams, all of the Alaska Science Center, U.S. Geological Survey, and by Brad Shults of the National Park Service, Kotzebue, Alaska.

Dall's sheep in northwestern Alaska declined in the early 1990s following the severe 1989-90 and 1990-91 winters. In the Baird Mountains of Noatak National Preserve, estimates of adult sheep declined by 50% from 800 in 1989 to under 400 in 1991. Population counts remained low throughout 1991 to 1996, reaching a minimum of 244 adult sheep in 1996. Few lambs were observed during annual midsummer aerial surveys in 1991 to 1994. We suspect that these declines resulted from a combination of poorer nutritional condition and increased vulnerability of sheep to predation resulting from severe winter conditions.

As a result of these declines, both subsistence and sport hunting seasons were closed by emergency order in 1991, resulting in substantial management controversy. The affected publics, although willing to accept the closures, questioned the validity of the sheep survey data and strongly emphasized their interest in restoring harvests as soon as populations increased sufficiently. In 1995 the Northwest Arctic Regional Advisory Council, the local advisory committee for the Federal Subsistence Board, passed a motion supporting efforts to initiate research on sheep populations in the region to better understand the factors limiting sheep populations and to evaluate sheep survey methodologies.

Location of the Baird Mountains Study Area, Noatak National Preserve, Alaska.



Currently estimates of Dall's sheep population size and composition in the western Brooks Range are based on intensive fixed-wing aerial surveys conducted annually since 1986 in areas including the Baird Mountains. The annual variation in recent Baird Mountains aerial counts cannot be explained with reasonable assumptions about reproduction and survival, suggesting that there is some variability in the proportion of the population observed each year or that a substantial number of sheep move during the survey. Prior to our research, no attempt had been made to estimate visibility bias or precision for these surveys.

Our understanding of Dall's sheep population biology comes largely from studies in central or southern Alaska and the southern Yukon. However, sheep in northwestern Alaska are at the northwestern extreme of their range and live in a less hospitable environment characterized by short growing seasons and long, severe winters. We expect patterns of productivity and survival for sheep in Noatak National Preserve to differ from the more southerly populations. To adequately manage sheep harvests in northwestern Alaska, we need a better understanding of sheep demography. Along with unbiased population estimates, understanding the dynamics of sheep populations in the region will allow population models to be developed that can provide focus for a useful dialog on management goals and strategies and facilitate a cooperative strategy for managing sheep harvests in northwestern Alaska.

Barry Minor hobbles a Dall's sheep. The sheep are captured from a helicopter with a shoulder-mounted netgun. Once a sheep is in a net, the net-gunner hobbles the sheep so that the biologist can collar and take samples from the animal.

In 2000 the U.S. Geological Survey's Alaska Science Center and the National Park Service's Western Arctic Parklands initiated a cooperative three-year study of Dall's sheep in the Baird Mountains. Our objectives are to investigate patterns of productivity, lamb recruitment, and adult survival of Dall's sheep; to compare aerial survey methods and assess the validity of their key assumptions; and to recommend a cost-effective procedure for monitoring Dall's sheep in the Baird Mountains.

Study Area

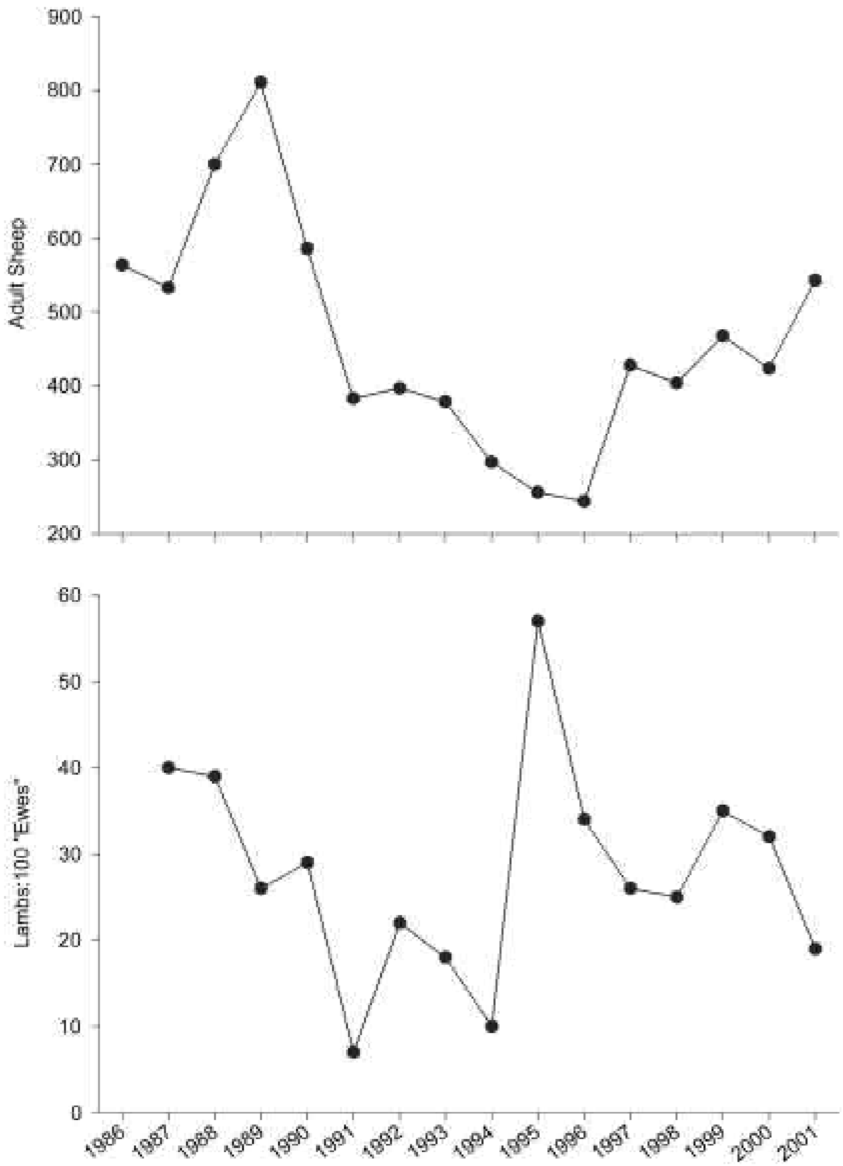
The Noatak National Preserve encompasses 26,600 square kilometers in the western Brooks Range and is bisected by the Noatak River valley. Dall's sheep inhabit most of the mountainous areas within the preserve. The Baird Mountains consist of approximately 2,000 square kilometers in the southern portion of the preserve and are characterized by rolling tussock tundra interspersed with ridges and knolls reaching 700 to 900 m in elevation. In addition to Dall's sheep, the area is inhabited by moose and is within the annual range of the large Western Arctic Caribou Herd. Predators in the area include gray wolves, grizzly bears, and wolverines.

Background

Population Demography

The published literature on Dall's sheep population dynamics is surprisingly sparse. The majority of information is derived from research conducted on Alaska's Kenai Peninsula, the central Alaska Range, and the southern Yukon Territory of Canada. Reports on the ages at which Dall's sheep ewes reach puberty are quite variable. A study on the Kenai Peninsula reported that three of four yearlings collected were pregnant, while a study in Kluane National Park in the Yukon Territory found that initial lamb production was delayed to as late as five years of age. Other studies have reported a minimum age for onset of reproduction at two years. If sheep are similar to other members of their family, we would expect that the variation in sexual maturation results largely from differences in nutrition, but other explanations are also possible.

Once they reach sexual maturity, ewes tend to be highly productive throughout the remainder of their lives. Estimates of pregnancy rates of sexually mature ewes derived from carcass analyses or intensive observations during lambing have varied from 78 to 87%. There is some evidence that productivity may decline for ewes greater than nine years old. These reproductive patterns are comparable to those reported for bighorn sheep. Many other studies have reported estimates of productivity based on mid-summer lamb:"ewe" ratios, but these counts are conducted after the period when lambs are highly vulnerable to predation and often include nonproductive yearling ewes and one- or two-year-old rams in the



Results of annual fixed-wing surveys of Dall's sheep in the Baird Mountains, Noatak National Preserve, Alaska, during July 1986 to 2001. The top graph shows the total number of adult sheep observed each year. The bottom graph shows annual lamb:"ewe" ratios. "Ewes" include all females more than one year old and young rams that have horn characteristics similar to females.

estimate of "ewes," resulting in underestimates of actual productivity.

Most published estimates of lamb survival are also based on comparisons of lamb:ewe and yearling:ewe ratios obtained during summer counts at licks or during aerial surveys. Lamb survival varies from year to year and is likely linked to the age and nutritional status of females and to winter severity.

Information on adult survival is also sparse. Wayne Heimer, formerly a researcher with the Alaska Department of Fish and Game, estimated adult survival for each sex based on observations of eartagged or visually collared individuals. Ewe survival averaged 94% for individuals greater than nine years old, then decreased to 82% for older ewes. Survival rates varied for rams depending on horn curl restrictions, but they generally followed a similar pattern, with high survival until individuals began actively participating in the rut.

Research on Dall's sheep in Alaska has been limited. Compared to other ungulate species, sheep are primarily managed with conservative harvest strategies aimed at removing fully mature males, and the management controversies have been minimal. However, with the large decline in sheep numbers in northwestern Alaska and the associated concerns raised by subsistence and sport hunters, we require a more thorough understanding of sheep population dynamics.

Survey Methodologies

It is widely recognized that aerial surveys of wildlife are subject to visibility bias. Dall's sheep tend to occur in relatively exposed habitats and may be less subject to visibility bias than many species. However, a variety of factors can affect the detectability of mountain sheep, including size and composition of groups, activity, habitat, and light conditions.

Four approaches have been used to account for visibility bias in aerial surveys of North American mountain sheep, including single observer mark–resight, double observer sight–resight, double sampling ratio, and covariate-based modeling methods. Single observer mark–resight methods require animals to be marked before the survey, and detection probabilities are estimated based on the proportion of the marked animals observed during the survey. Double observer sight–resight methods require two observers but have the advantage of not requiring marked animals and may detect more animals, reducing the overall visibility bias that must be corrected. Detection probabilities are estimated from the proportion of sheep seen by one observer that were also seen by the other observer. Double sampling ratio methods require two surveys, with the first flown at a relatively low intensity and the second flown at a higher intensity on a subset of the units covered by the first survey. Detection probabilities for the low-intensity survey are estimated based on ratios of low-intensity to high-intensity counts from double-sampled units. Although modeling of covariates can be used with any of the above survey methods to account for heterogeneity of detection probabilities, visibility models may also be developed as a separate activity and then applied in future surveys conducted under similar conditions. A function that relates detection probabilities to covariates such as group size and vegetation type is estimated during intensive preliminary surveys of radiocollared animals. This function is then used to adjust for effects of these covariates on detectability in subsequent surveys of uncollared sheep. We refer to those approaches that separate model development from application as covariate-based modeling methods.

All of the survey methods assume that the population is closed, with no movements between survey units during the survey. Sheep populations in the Noatak National Preserve are thought to be relatively discrete. However, little information is available about within-season movements for these populations. Surveys are usually designed to minimize the potential for movements among sampling units, but only a few studies have been designed to directly assess movements by mountain sheep during surveys.

Netgunner Barry Minor hobbles a Dall's sheep ewe.

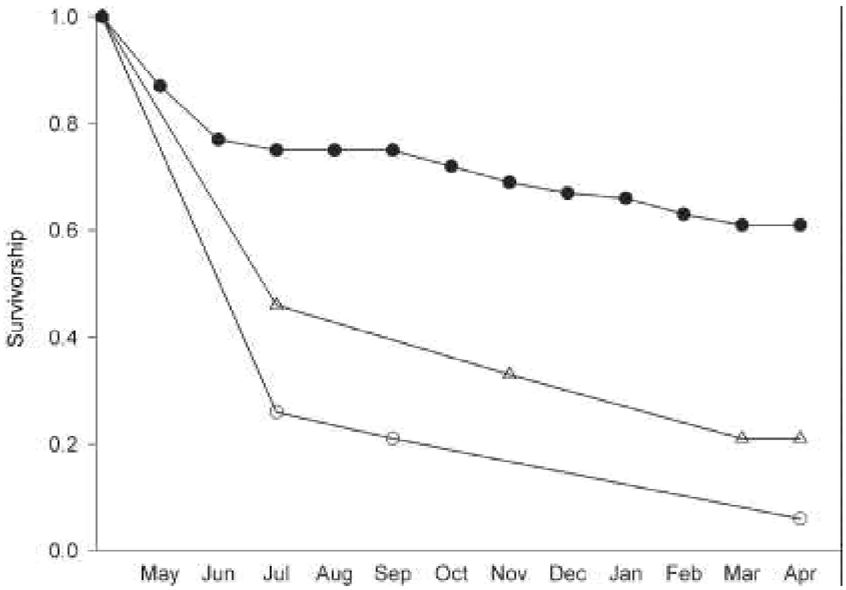
It is not clear which of these survey methods might be most appropriate for monitoring sheep populations in northwestern Alaska, or whether any would result in a cost-effective improvement over the unadjusted fixed-wing surveys currently in use. This study directly compares the basic aerial survey methods, using radiocollared sheep to assess the validity of key assumptions. Based on this evaluation, we will recommend a cost-effective monitoring protocol for the population.

Methods

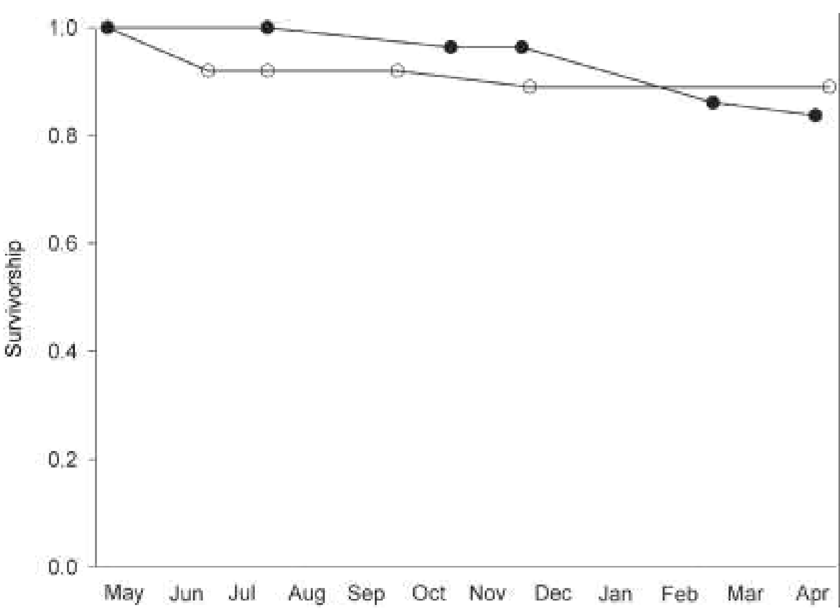
In March 2000 we captured 44 sheep by helicopter netgunning and fitted them with mortality-sensing radiocollars. The composition of the captured sheep—34 ewes and 10 rams—was representative of the population as determined from aerial surveys. While restrained, ewes were weighed and blood samples were taken to determine their reproductive status. We estimated each sheep's age by counting horn rings and, for ewes, by pulling a canine tooth for cementum analyses. In March 2001 and 2002, all surviving ewes were recaptured to be weighed and blood sampled for pregnancy detection. An additional 21 ewes and 6 rams were captured to maintain our sample size.

Currently, radiocollared sheep are located monthly, weather permitting, to determine their survival, group size and composition, and seasonal distribution. We are estimating lamb recruitment by monitoring the survival of lambs associated with radiomarked ewes known to have been pregnant. During summer aerial surveys, collared sheep are used to evaluate sightability and detect movements between survey units.

The annual aerial survey evaluation begins with a pre-survey period in late June to assess baseline movements and habitat selection of collared animals before any potential disturbance resulting from surveys. This is followed in early July by three simultaneous replicate surveys with Supercub airplanes, designed to provide the data for population estimation with each of the basic survey methods. Subsamples of units are surveyed by helicopter immediately following the fixed-wing surveys. During these surveys, collared sheep are monitored for movement between survey units. Survey fieldwork concludes each year with a post-survey period immediately following the aerial surveys to gather additional data on daily movements among survey units.



Estimates of lamb survivorship during May 2000–April 2001 (open triangles) and May 2001–April 2002 (open circles) for the Baird Mountains. Survivorship of lambs from a study by Brad Scotton is provided for comparison (solid circles). Scotton's estimates of lamb survival are from a more southerly population in the Alaska Range, and they are substantially higher.



Survivorship of Dall's sheep ewes during May 2000–April 2001 (solid circles) and May–April 2002 (open circles) for the Baird Mountains.

Results

Although our studies are ongoing and any conclusions at this point are preliminary, we have already made some interesting observations. The pregnancy rates of ewes were substantially different between the two years, with 90% of the ewes pregnant in March 2000, but only 58% pregnant in March 2001. The body weights of ewes averaged 2.00 kg less in 2001 than 2000 (54.2 kg and 52.2 kg, respectively) indicating that the sheep were in poorer nutritional condition in 2001, when pregnancy rates were low.

Observations of collared ewes with lambs at heel are being used to estimate lamb survival. Lamb survival to one year was 21% in 2000-2001 and 6% in 2001-2002.

Adult survival rates are being estimated from observations of collared ewes. Five of the ewes died between May 2000 and April 2001, resulting in an estimate of 84% annual survival for ewes. Between May 2001 and April 2002, four ewe mortalities were recorded, resulting in a survival estimate for this period of 89%.

We were largely unsuccessful during our 2000 field evaluation of survey methods because of unfavorable weather throughout the survey period. However, we were able to more fully implement our study design in the summer of 2001. The proportion of groups containing marked sheep detected by Supercub survey teams varied from 72 to 100%, whereas the helicopter crew detected 94% of the marked groups in 2001. Sheep that were not detected tended to be in smaller groups than on occasions when they were detected. We also detected movements by 12 of 45 (27%) marked sheep among survey units during the 2001 survey. It appears that we could minimize the effects of these movements on population estimates by redesigning survey units and conducting surveys simultaneously in adjacent units where movements are likely.

Research wildlife biologist Chris Kleckner prepares to release a Dall's sheep ewe as pilot Rick Swisher assists.

Research wildlife biologist Chris Kleckner releases a young Dall's sheep ram.

Summary

Our studies are well under way and will continue through April 2003. At that time, we expect to have gained a clearer view of vital rates that comprise the population dynamics of Dall's sheep in northwestern Alaska and to be able to provide recommendations for improving the annual monitoring of these sheep populations. We hope that by providing a better understanding of the status and trends of sheep populations in the region, we can help the public and wildlife managers develop reasonable strategies and goals for managing this important resource.

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Muskoxen in Northern Alaska

Restoration of an Arctic Animal

This article was prepared by Patricia Reynolds, U.S. Fish and Wildlife Service.

The coastal plain of the Arctic National Wildlife Refuge seems to be devoid of life in mid-winter, when snow, wind, and darkness dominate the landscape. Gone are the countless caribou and birds and insects that animate the coastal plain in summer. Colors are muted into monochromes of black and white. Wolves have moved to the mountains, and grizzly bears are curled in winter dens. But groups of dark-bodied animals move slowly across the frozen tundra foraging on dried sedges. Muskoxen have returned to Arctic Alaska after an absence of over 100 years.

The muskox is misnamed: it is not an ox and does not produce musk. This mammal is a member of the cow family, which includes large ruminating animals with hooves and horns. But muskoxen are more closely related to sheep and goats than to oxen or cattle. Their distinctive odor was likely experienced by the early explorers who encountered and named this animal.

Adult male muskox in late winter, Arctic National Wildlife Refuge, Alaska.

Muskoxen are arctic animals well adapted for life in cold climates. With a large head, short legs, and a stocky body, the muskox loses less heat than a lean, long-legged animal. At a distance, muskoxen appear to be massive, but the animals are relatively small, standing only 4–5 feet tall at the shoulder. However, a mature bull can weigh more than 900 pounds. Females captured in late summer in the Arctic National Wildlife Refuge weighed 300–560 pounds. The muskox has a heavy dark coat of long coarse hair that hangs in a skirt over its white-furred legs. Even its muzzle is covered with hair. In winter a thick layer of fine wool (called quivit) insulates the animal like a down parka. With a large gut and an efficient digestive system, the muskox can survive and maintain body fat on a winter diet of dried sedges that would starve a cow.

Both male and female muskoxen have long curved horns with sharp tips that are used to drive off predators and to discourage less-dominant members of their group from feeding in a favorite spot. Males also have a heavy helmet of horn that covers the forehead and protects the skull during fights for females. When males clash heads, the thick horn boss and the heavy bones of the skull protect the brain from concussion.

History of Muskox Populations

Originating in Asia, muskoxen were in western Europe almost a million years ago and appeared in Alaska in the late Pleistocene 150,00 to 250,000 years ago. As the ice sheets spread, muskoxen moved across Europe into the continental United States. They also expanded eastward into northern Canada and Greenland. Mammoths, bison, horses, and reindeer dominated the ice-age fauna in Europe, Asia, and North America, where several kinds of muskoxen also were present. But musk-

Mixed-sex group of muskoxen in summer, Arctic National Wildlife Refuge.

oxen may have been uncommon animals in the ice-age ecosystem.

About 9000 years ago, as ice sheets contracted and disappeared, muskoxen vanished from Europe. By 2000 years ago, they were gone from Russia. But one species of muskox survived in Arctic regions until recent times in Alaska, Canada, and Greenland.

Decline and Extinction

By the beginning of the 1900s, however, these remaining populations of muskoxen were in trouble. Muskoxen disappeared from northern Alaska by the 1860s and were gone from the rest of Alaska and possibly northwestern Canada by 1900. The extermination of muskoxen in Alaska was likely due to a combination of factors, including climatic conditions that influenced access to food and mortalities from predators and hunters. Humans with dogs were effective hunters of muskoxen, even before the arrival of firearms in Alaska.

Muskox populations in Canada also declined by the early 1900s. Commercial exploitation of the species occurred on a large scale. Between 1860 and 1915, 23,000 muskox hides were taken from the mainland of Canada and traded to the Hudson's Bay Company. Some Arctic explorers supported their expeditions by using muskoxen and caribou for food, clothing, and dogfood. At least 1400 muskoxen were taken from the Arctic islands of northern Canada between 1880 to 1917 by explorers. Whalers and local hunters took thousands more muskoxen in Canada during these years.

In Greenland, Arctic explorers, whalers, and sealers also killed muskoxen in the early 1900s. Muskoxen were used to support fox trapping and fox farming operations, as well as meteorological and radio stations. A few thousand adult muskoxen were likely killed during efforts to capture calves for zoos. Populations in East Greenland, however, survived in spite of years of exploitation.

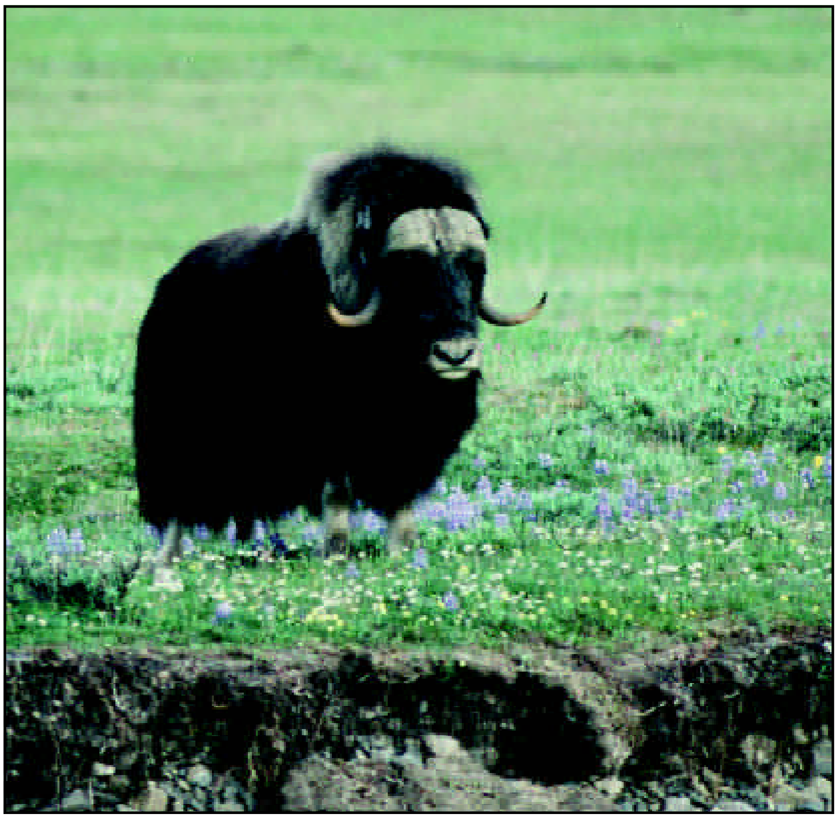
Conservation Actions

The disappearance of muskoxen from Alaska and the decline in numbers of muskoxen in Canada raised concerns that the species might become extinct. In 1917, killing muskoxen and trading muskox parts in Canada became illegal except in some areas where residents needed muskoxen for food. In 1927 the Thelon Game Sanctuary was established to protect remnant populations of muskoxen in Canada.

The United States government, also concerned about the disappearance of muskoxen from Alaska and the decline of the species in Canada, allocated money to acquire muskoxen and re-establish the species in Alaska. In 1930, 36 muskoxen, mostly calves and yearlings, were captured in East Greenland. During the next four months, these animals traveled halfway around the world from Greenland to Norway and New York by ship, across the United States to Seattle by train, up the inside passage to Seward by steamer, and finally to

Fairbanks, Alaska, by train. These well-traveled muskoxen were pastured at the Biological Survey Experiment Station in Fairbanks for five years. In 1935, four muskoxen from Fairbanks were taken to Nunivak Island, 25 miles off the coast of western Alaska. This island had nearly a million acres of grazing land and no large predators. In 1936 the remaining 27 muskoxen from Fairbanks were also moved to Nunivak Island after a journey down the Yukon River to the community of St. Michael in Norton Sound. The final leg of the trip by open barge to Nunivak Island almost ended in disaster when the barge began to take on water. But the animals landed safely and became the source of all wild muskoxen in Alaska today.

Adult male muskox in summer, Arctic National Wildlife Refuge.



Restoration of Vanished Populations

The 31 muskoxen released on Nunivak Island in the 1930s increased to several hundred by the 1960s. The island could only support about 500–600 muskoxen, and surplus animals were used to restore populations in regions of Alaska where they had disappeared. Between 1967 and 1981, 129 muskoxen from Nunivak Island were moved to four locations: Nelson Island east of Nunivak Island, northeastern Alaska near the Arctic National Wildlife Refuge, northwestern Alaska near Point Hope, and western Alaska on the Seward Peninsula. During the next two decades, muskoxen expanded into nearby areas and recolonized formerly occupied landscapes in Alaska. About 4000 wild muskoxen live in Alaska today, with about half of these animals living on the Seward Peninsula.

In northeastern Alaska, muskoxen returned to areas of former occupation with the release of 51 muskoxen near the community of Kaktovik on Barter Island in 1969 and 13 muskoxen on the Kavik River in 1970. Most of these animals quickly dispersed into the nearby wilderness of the Arctic National Wildlife Refuge, although some animals moved long distances or died. Within a few years, muskoxen were established in three locations in northeastern Alaska.

Muskox Studies

I have studied the population of muskoxen in the Arctic National Wildlife Refuge for the U.S. Fish and Wildlife Service for more than two decades. The studies began in 1981 as part of a larger investigation collecting biological information about the coastal plain of the refuge. Today, studies of muskoxen in northeastern Alaska are part of a long-term monitoring program of refuge resources and cooperative investigations with biologists from other agencies and organizations.

We estimate numbers of muskoxen and trends in animal abundance in the refuge during surveys flown in late March or early April, when the ground is still snow covered and animals are easy to see on the treeless tundra. Calves, subadults, and adult males and females are counted from the ground in late June. Surveys of muskoxen in the Arctic National Wildlife Refuge are coordinated with surveys in adjacent areas flown by colleagues with the Alaska Department of Fish and Game, Parks Canada, and the Yukon Territory Government.

I use radiocollared animals to find out where muskoxen live, how far they move, how long they live, how often females reproduce, and how they behave in social groups. Between 1982 and 2000, we radiocollared 114 muskoxen, mostly adult females. Some of these muskoxen also carried collars that sent a signal to an orbiting satellite. Locations and activity counts were relayed to computers in Fairbanks several times each week. From this information, I defined seasonal use areas, movement rates, and activity patterns. I also cooperated with several graduate students from the University of Alaska Fairbanks who were studying the habitats of muskoxen in and near the Arctic National Wildlife Refuge.

Social Behavior

Muskoxen are social animals. Females are almost always found in mixed groups of males, females, and young animals. Mixed groups of muskoxen in the Arctic National Wildlife Refuge range in size from 2 to 118 animals and are larger in winter and smaller during the summer breeding season. From October through May, 1982 through 1991, mixed groups had an average size of 20 to 24, compared with an average size of 12 in August.

Many adult males spend the winter in small groups of 2 to 12 bulls. In summer these bull groups dissolve, and most bulls become solitary or are associated with a breeding group. Males without females often linger on the edge of breeding groups and move from group to group.
Like wild sheep, one male muskox breeds several females. Large adult males acquire and defend groups of females from July through September. The peak of breeding occurs in August, and displays and fights among males over females are common during this time of year. Males roar, butt and push heads, use odor as a threat display, and tear up the ground with their horns. A dominant male walks stiff-legged, tilting its head toward a rival to "show off" its horns. Bulls face one another, swinging their heads from side to side as they back up slowly for several yards. Then they run toward one another at full gallop, at speeds of 30 miles per hour, and clash head on.

When disturbed or frightened, muskoxen run together and wheel around, shoulder to shoulder, forming a circle or crescent with their horns facing out. Each animal attempts to press its rear flanks against another muskox. Even a solitary animal, when disturbed, will back up against a rock, bank, or snowdrift to protect its hindquarters. If a predator approaches, it is faced with a wall of horns. Adult muskoxen often dart from a defensive formation and attempt to hook the predator with their horns. Muskoxen will also run in a tight group, sometimes for miles, leaving a wide track of trampled snow.

Numbers of Muskoxen in the Arctic National Wildlife Refuge

After their return to northeastern Alaska, the number of muskoxen rapidly increased from about 50 in 1976 to almost 400 in 1986. During this time, calf production and rates of animal survival also were high. By 1987, mixed groups of muskoxen were moving out of the refuge, as the population expanded into new regions.

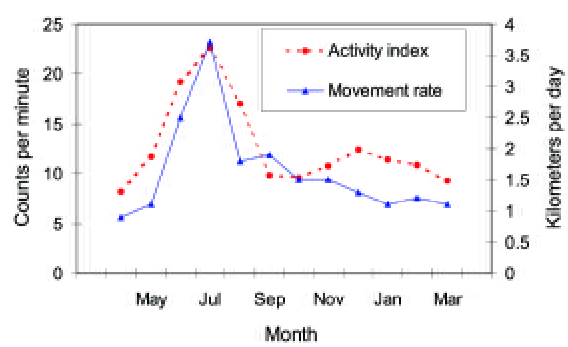
From 1987 to 1998, numbers of muskoxen in the Arctic Refuge were relatively stable at about 325. But from 1999 to 2002, numbers of muskoxen declined sharply. The changes in the abundance of muskoxen in the refuge over time occurred because of changes in births and deaths and shifts in distribution.

Calves

Most muskox calves in the Arctic National Wildlife Refuge are born from mid-April to mid-May. Unlike caribou, which produce calves in early June when high-quality food is available, muskoxen give birth when snow and freezing temperatures are present and green vegetation is not available for several weeks. A female muskox must be fat at the time she gives birth to have enough body reserves to make milk for a calf.

The number of calves varies from year to year because most female muskoxen in northeastern Alaska do not reproduce every year. Marked females in the Arctic National Wildlife Refuge have a calf every two or three years. When deep snow or icing conditions are present or winter conditions are prolonged, fewer calves are seen in June. In such years, muskoxen spend more energy digging and moving through snow, and by the calving season, reproducing females may be in poor condition and newborn calves may not survive.

In the Arctic National Wildlife Refuge the number of muskox calves declined over time. Very few calves were seen in 2000 and 2001 after winters of deep snow. Winter conditions persisted into June 2001, delaying the growing season for at least two weeks. Long winters not only deplete the body reserves of adult muskoxen but also result in a



Seasonal changes in the rates of movement and activity counts of satellite-collared female muskoxen in and near the Arctic National Wildlife Refuge, Alaska, 1986–1992.

shortened growing season, which may prevent females from fattening enough to successfully reproduce the following year. Predation by grizzly bears may also have contributed to the low numbers of calves in 2000 and 2001.

Deaths

The adult muskoxen die from several causes, inluding winter starvation, predation, hunting, and old age. Twelve (20%) of 61 marked muskoxen dying between 1982 and 2002 were in poor condition and died during winter. Five (8%) likely died of old age. Known-aged female muskoxen in the Arctic National Wildlife Refuge lived a maximum of 19 years. Hunters killed six (10%), and the cause of death was not determined for six marked muskoxen (10%). Grizzly bears likely killed 10 (16%) of the marked muskoxen and were seen feeding on 14 other carcasses (23%). By contrast, wolves and unidentified predators killed or scavenged eight marked muskoxen (13%).

About 3–4% of the estimated numbers of muskoxen in the Arctic National Wildlife Refuge are killed each year by hunters. Hunting of muskoxen was first permitted in 1982. Only residents of the community of Kaktovik have been allowed to hunt muskoxen in the Arctic National Wildlife Refuge since 1992. Hunting is regulated by permits, and most animals killed in the hunt are adult males.

Predation of muskoxen by grizzly bears in northeastern Alaska may be increasing. In 2000 and 2001, 19 muskoxen were killed and 5 were possibly killed or scavenged by bears in and near the Arctic National Wildlife Refuge. Sixteen of these died in multiple kills, events in which two to five muskoxen were killed from one group. Several marked bears were implicated in multiple kills of muskoxen, indicating that bears have become efficient predators of muskoxen in northeastern Alaska. Deep snow in 2000 and 2001 may have contributed to the high incidence of multiple kills in these years.

Preying on muskoxen is not without risk for grizzly bears. At least one marked bear was killed by a muskox, and other bears were badly injured when attacking muskoxen. Radiocollars were ripped off three different bears by muskoxen. These incidents show that muskoxen use their horns to defend themselves against predators.

Shifts in Distribution

As numbers declined in the Arctic National Wildlife Refuge, numbers of muskoxen increased in the Yukon Territory, Canada, east of the refuge, and in north-central Alaska, west of the refuge. Periodic pulses of mixed groups moving out of the refuge into adjacent areas have occurred several times since 1986. Movements of groups containing radiocollared muskoxen indicate that at least several muskoxen left the Arctic National Wildlife Refuge in 2000 and 2001.

Adult female muskoxen in winter, Arctic National Wildlife Refuge.

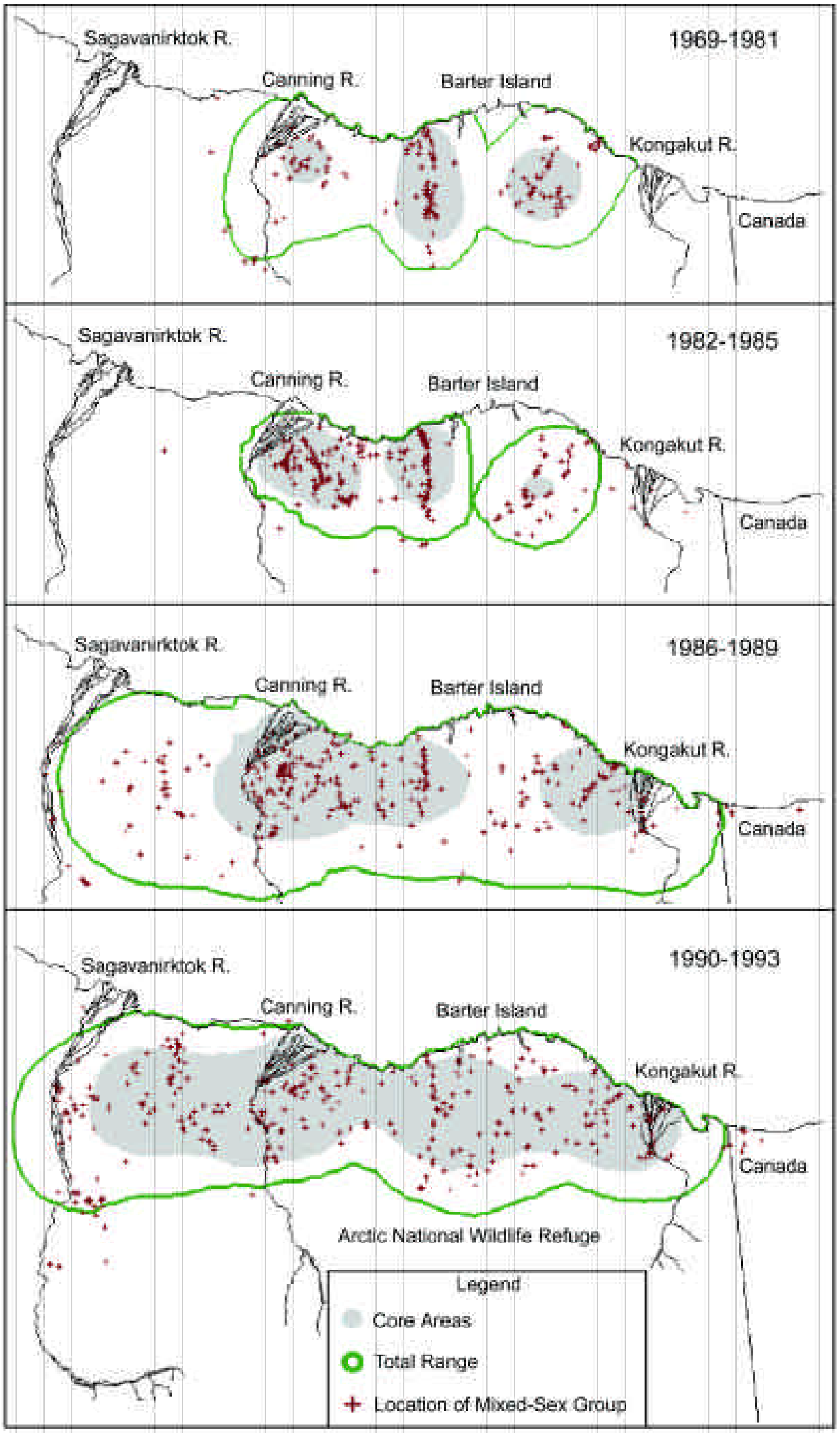
Ice, deep snow, an extended snow season, or a short growing season may limit access to food and force muskoxen to move. Muskoxen may also move long distances in response to predator attacks.

Seasonal Strategies

The lives of muskoxen on the coastal plain in northern Alaska alternate between the abundance of the short summer season and the dark and cold of the Arctic winter lasting eight to nine months. Seasonal shifts in physiology and behavior, as well as physical adaptations, allow muskoxen to live in these conditions year-round.

During the short summer, when green forage is available, muskoxen feed intensively to replenish body reserves lost the previous winter and calving period. The animals need to become fat enough to reproduce and to survive the next long winter. In summer, muskoxen in northern Alaska frequently forage along rivers, eating willows, sedges, and forbs. Muskoxen move longer distances and are more active in summer than in winter.

Throughout the long winter, muskoxen maintain their body condition while foraging on small amounts of poor-quality food. Energy conservation is a key. The warm, quivit-lined coat, the square body, and the short limbs of the muskox reduce heat loss. Muskoxen also slow down in winter, reducing their metabolic rate and food intake and decreasing their movements and activ-



Range expansion of muskoxen in mixed-sex groups in and west of the Arctic National Wildlife Refuge, Alaska, 1969–1993.

ity. Muskoxen generally stay in the same location most of the winter, selecting feeding sites with shallow soft snow on wind-blown ridges or uplands.

But winter conditions can affect muskox populations. In years when icing conditions, deep snow, or a prolonged snow season occur, muskoxen use more energy to dig for food or to move through snow and may not successfully reproduce or survive. Deep snow or other local conditions may influence rates of predation or cause muskoxen to move to new areas.

Outlook

Muskoxen have been returned to Alaska, and the numbers of muskoxen have increased dramatically in Canada and Greenland since 1900. Populations of muskoxen have been established in northern Russia, Scandinavia, and West Greenland. These trends indicate that muskoxen will continue to exist in northern areas of the world. Muskoxen are an important component of the Arctic environment. They fit into a space not occupied by other animals, with their abilities to conserve energy, to survive on poor-quality food in winter, to defend themselves against predators, and to live year-round in northern climates.

Although numbers of muskoxen in the Arctic National Wildlife Refuge have declined, the total population in northeastern Alaska and northwestern Canada continues to expand. About 600–700 muskoxen now live between the Colville River in Alaska and the Babbage River in Canada in areas where no muskoxen were found 100 years ago. Populations in other regions of Alaska also are stable or increasing. The return of muskoxen to Alaska has restored a key piece to the Arctic ecosystem and adds dimension and diversity to the landscape of the Arctic National Wildlife Refuge.

Suggestions for Further Reading

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