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# ARCTIC RESEARCH

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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 and the Arctic Research Commission. Both the Interagency Committee and the Commission were authorized under the Arctic Research and Policy Act 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;
- Summaries of other current and planned Arctic research, including that of the State of Alaska, local governments, the private sector and other nations; and
- A calendar of forthcoming local, national and international meetings.

*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 22203.

## Covers

*The Mesa, a sliver of igneous rock that sits 60 m above the surrounding valley floor just north of the Brooks Range. This site was used by Paleoindians as a hunting lookout, and archaeological research being conducted here is shedding new light on the lives of these people and the appearance of humans in North America. See page 55 for more information about this research.*

# ARCTIC RESEARCH

## OF THE UNITED STATES

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# *The Department of the Interior in the Arctic*

*This introduction was prepared by Mark Schaefer, Deputy Assistant Secretary for Water and Science, Department of the Interior, 1849 C Street NW, Mail Stop 6640, Washington, DC 20240.*

The mission of the Department of the Interior is to encourage and provide for the appropriate management, preservation and operation of the Nation's public lands and natural resources for use and enjoyment both now and in the future; to carry out related scientific research and investigations in support of these objectives; to develop and use resources in an environmentally sound manner and provide an equitable return on these resources to the American taxpayer; and to carry out the responsibilities of the U.S. Government with respect to American Indians and Alaska Natives.

The Arctic Region of Alaska offers enormous challenges and opportunities for the Department to demonstrate the value of accomplishing this mission. The challenges range from the protection of the great biodiversity, both onshore and offshore, to providing equitable treatment to the Native communities. The opportunities include the unique laboratory for scientific research on matters such as climate change, volcanic eruptions and Arctic land management. The Department's activities are performed by bureaus, each with administrative and technical offices located in Alaska, including the U.S. Geological Survey (which now includes a new Biological Resources Division, the former National Biological Service), Minerals Management Service, U.S. Fish and Wildlife Service, National Park Service, Bureau of Land Management (which includes parts of the previous Bureau of Mines) and the Bureau of Indian Affairs.

In FY 96 the DOI spent approximately \$33 million fulfilling its responsibilities in the Arctic. Most of this was used for research-related activities. This represents approximately 20% of all Federal money spent on Arctic research activities.

Articles published in this edition of *Arctic Research of the United States* cover a variety of topics describing the diversity of programs managed by Department of the Interior bureaus. The fact that the Arctic is an international resource and that international cooperation is important to Arctic science is reflected in papers on international cooperation in the Beringia region and the Shared Beringian Heritage Program by the National Park Service, on global partnerships and an international environmental data directory by the U.S. Geological Survey, and in a paper by the U.S. Fish and Wildlife Service on the polar bear and Pacific walrus bilateral conservation agreements between the U.S. and Russia. Emphasis on traditional biology and management of biological resources is

reflected in papers from the National Park Service and Bureau of Land Management on the migration of shorebirds and waterfowl at Carter Spit, the ecology of yellow-cheeked voles along the Kobuk River, and the environmental dimensions of seabird distribution and utilization on St. Lawrence Island and nearby Russia. Prehistoric life and its relationship to past climate and geography are explored in papers related to a Paleoindian archaeological site in the northern foothills of the Brooks Range and in a paper on the Cretaceous dinosaur fauna along the Colville River. Continuing to explore the problem of ecological contamination of Arctic ecosystems (a focus of the Fall/Winter 1966 issue of *Arctic Research of the United States*), two articles by the U.S. Geological Survey discuss radioactive contamination in Arctic marine systems and contaminants in Arctic waterfowl.

Three articles relate to oil and gas resources in Arctic Alaska and adjacent waters. A paper by the Minerals Management Service summarizes the Minerals Management Service 1995 assessment of the quantities of undiscovered oil and gas that lie beneath submerged Federal lands offshore of Alaska. For onshore Alaska the U.S. Geological Survey provides a history of oil and gas exploration, information on known resources and recent increasing interest in oil and gas prospects on Federal lands. In a paper on "Melding Science and Traditional Ecological Knowledge for Future Offshore Oil and Gas Development Decisions," the Minerals Management Service provides information on its Alaska Environmental Studies Program and how it defines information needs and implements studies to assist in minimizing potential effects of oil and gas exploration and development on human, marine and coastal environments of the Outer Continental Shelf and nearby coastal areas.

Four articles in this issue illustrate the use of new technologies for mapping and understanding the Arctic environment. The U.S. Geological Survey has produced a unique digital shaded relief map of Alaska, which reveals a number of Alaskan geologic features that have not been depicted before and, therefore, provides earth scientists with a new "look" at fundamental geologic features of Alaska. A copy of this map is featured in this edition as our first fold-out illustration. The U.S. Fish and Wildlife Service discusses how satellite technology and remote sensing are being used as part of an international effort to produce a new circumpolar Arctic vegetation map depicting



the distribution and boundaries of Arctic vegetation north of the Arctic treeline, and the U.S. Geological Survey describes how these technologies have been used to assess caribou habitat selection at a landscape level. The Bureau of Land Management provides a paper illustrating how a combination of historic photography and modern technology have been combined to understand surges and changes in the Bering Glacier, the largest and longest glacier in continental North America.

Finally, two researchers from the University of Alaska describe their work in collaboration with the National Park Service on the Kobuk Sand Dunes, remarkable geologic features that rise to 30 m in height and cover approximately 100

square km in northern Alaska. The Kobuk Dunes are a globally unique desert ecosystem existing as an island within the boreal forest. They persist in a tension zone between desert and forest and may be important as a future indicator of global change.

After reading the articles in this edition of *Arctic Research of the United States*, one is left with the sense of the Department of the Interior's oftentimes conflicting and varied responsibilities in the Arctic. We are proud of our research results in the Arctic and are pleased to be able to describe some of these in this *Arctic Research of the United States* edition devoted exclusively to the Department of the Interior. We will continue to have a significant role in the Arctic.

# MMS Alaska Arctic Environmental Studies

## Melding Science and Traditional Ecological Knowledge for Future Offshore Oil and Gas Development Decisions

*This article was prepared by Michael Buffrey, Cleveland Cowles, Valerie Elliott, Timothy Holder, Warren Horowitz, Thomas Newbury and Stephen Treacy of the Alaska OCS Region, Minerals Management Service, 949 East 36th Avenue, Anchorage, Alaska 99508-4302.*

The Minerals Management Service (MMS) Alaska Environmental Studies Program (ESP) was initiated by the U.S. Department of the Interior in 1974 in response to the Federal government's decision to propose areas of Alaska for offshore gas and oil development. The purpose of the ESP is to define information needs and implement studies to assist in predicting, assessing and managing potential effects on the human, marine and coastal environments of the Outer Continental Shelf (OCS) and coastal areas that may be affected by gas and oil development. Lease-management decisions are enhanced when current, pertinent and timely information is available. To attain ESP goals, data on specific environmental, social and economic concerns arising from offshore leasing are sought. The ESP may then monitor effects during and after oil exploration and development.

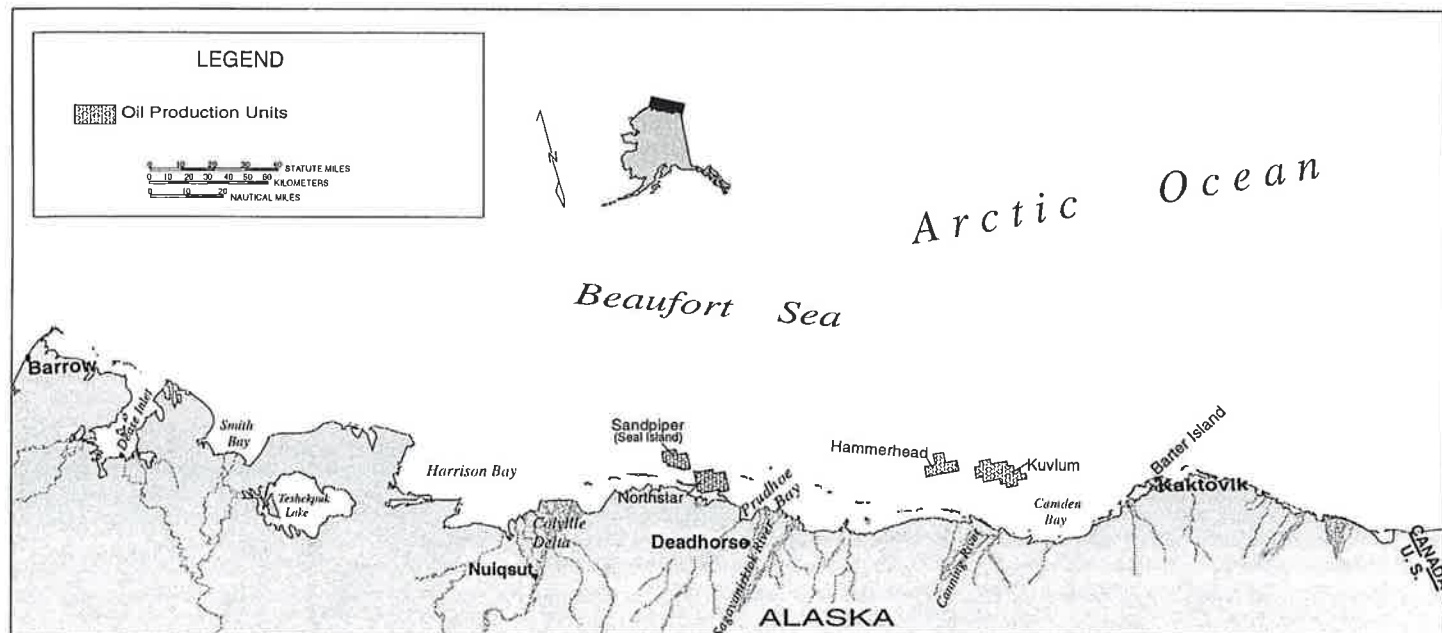
Beaufort Sea studies have been an important program component since the ESP was established and will be especially important for the foreseeable future. Not only has the area been the focus of several previous offshore oil and gas lease sales, but industry interest in the Beaufort Sea OCS was re-affirmed in 1996 by the leasing of 29 additional tracts. Also expected to increase interest in the area is the Northstar prospect proposed for development by BP Exploration. This site is on the continental

shelf less than 16 km north of Prudhoe Bay. The Northstar Unit lies on both sides of the boundary that separates State of Alaska offshore waters from Federal OCS waters and will be undergoing environmental reviews in the near future.

As proposals for development continue to evolve, Alaska's coastal communities on the Beaufort Sea are expecting increased involvement in project reviews and decisions that may affect their subsistence lifestyle. Since the peoples of Alaska's remote Arctic communities rely so heavily on subsistence resources of the marine environment, they are especially concerned about industrial activities that may directly or indirectly affect hunting success or the habitats of species important to subsistence. Just as local peoples expect to be involved in policy decision making, they also desire to participate in project-level decision making related to research activities that seek to understand the interactions of human activities and the natural environment.

Over the years the ESP has involved Alaskans and others in its research planning and execution in a number of ways. For example, direct solicitation of comments on Regional Environmental Study Strategic Plans (MMS 1995) has long been used to seek and make use of the knowledge of coastal communities and other residents in plan-

*Beaufort Sea and North Slope of Alaska, showing OCS oil production units.*



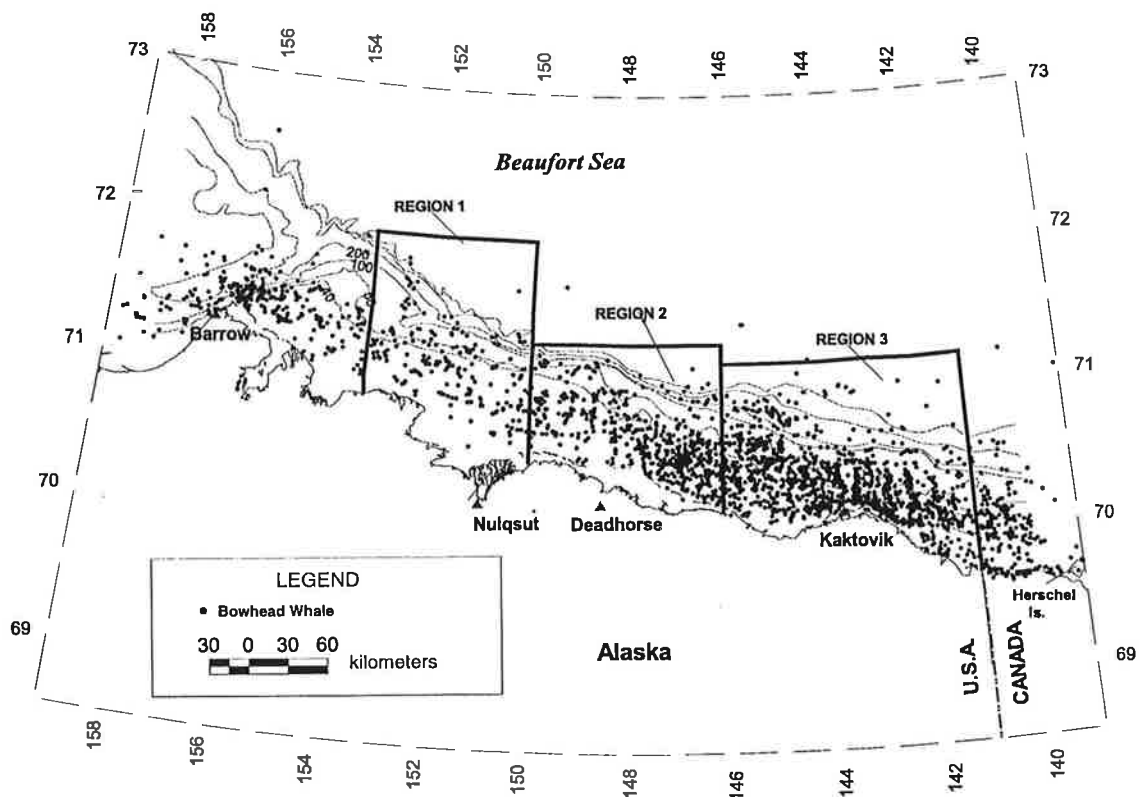


ning. Other public involvement, such as participating on project management or scientific review boards of certain studies, has been utilized. In all MMS field-oriented studies, researchers coordinate directly with local communities to discuss their plans, seek advice, and assure that interested people learn about the project and its results. Recently the MMS has incorporated traditional knowledge of Alaskan residents directly in the preparation of its environmental impact statements and other decision documents.

Always a strong point, public input in planning and execution of the ESP has remained a cornerstone of the program's success. The process of melding traditional information with MMS scientific activities varies from project to project, but the outcome of better information for decision making is a common goal. Three Arctic studies that present examples of how scientific and traditional information sources can be successfully melded are presented below. Two are ongoing biological studies focusing on key subsistence species, the bowhead whale and the ringed seal, and the third is an upcoming project that will synthesize scientific and traditional information on the socioeconomic effects of oil and gas industry activity on the entire Alaska OCS.

## Aerial Surveys of Bowhead Whales in the Beaufort Sea

One of the most important focuses for scientific study in the Alaska OCS is the bowhead whale. Distinctive for its huge, comb-like baleen and thick blubber, the bowhead migrates annually between the Bering and the Canadian Beaufort Seas. This large whale is vital to Inupiat subsistence hunters and coastal villages in Alaska that are located along the migration route. Each year since 1979 the ESP has funded aerial surveys of bowhead whales in Arctic waters. Since 1987 the MMS Bowhead Whale Aerial Survey Project (BWASP) has used staff scientists to monitor the progress of bowhead migrations across the Alaskan Beaufort Sea during the fall. This project is an important component in mitigating the potential effects of offshore exploration on bowheads by helping to determine the timing and geographic distribution of the migration. Monitoring occurs during September and October when seismic exploration and offshore drilling may occur and when the fall subsistence hunt for bowhead whales takes place. Study results help to determine the need for adjustments to offshore operations during the migration and to assess any regional changes.



*Bowhead whale sightings, showing selected isobaths (in meters) and bathymetric regions, September and October, 1982-1995.*

The annual migrations are described in a 17-year series of published reports, the most recent of which covers the fall of 1995 (Treacy 1996).

#### *Coordination with Alaskan Native Groups*

Each year the Alaska Eskimo Whaling Commission (AEWC), North Slope Borough (NSB) and Indigenous People's Council for Marine Mammals (IPCOMM) review draft annual reports that analyze the previous fall's sightings. The AEWC, NSB and IPCOMM, as well as several whaling captains' associations and the mayors of Barrow, Nuiqsut and Kaktovik, Alaska, receive annual project management plans and final reports. Results of the aerial surveys have also been presented at village meetings, NSB-sponsored bowhead whale conferences, and MMS-sponsored Arctic Synthesis Meetings. These interactions have been valuable sources of information for the MMS in obtaining the benefit of experience offered by whale hunters in comments on plans, projects and reports.

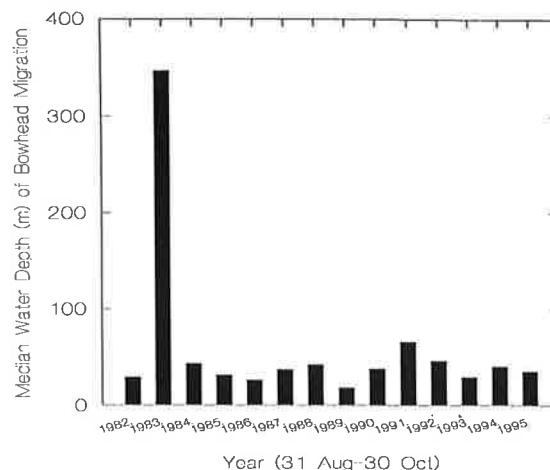
Also, the BWASP is coordinated with subsistence whale hunters through the Whalers Communication Group to avoid aircraft disturbance of the fall bowhead hunt. Following each day's survey, data collected by the project are telefaxed to the Alaska Eskimo Whaling Commission (AEWC) for their use in managing the whaling season. Members of the AEWC and the Barrow Whaling Captains Association have accompanied project surveys to observe survey methodology.

#### *Aerial Survey Design*

The aerial surveys are based out of Deadhorse, Alaska, using a Twin Otter aircraft equipped with bubble windows for downward visibility. Survey flights are targeted at an altitude of 458 m above sea level along randomized northerly-southerly transect grids within each survey block. The project records all bowhead (and beluga) whales observed, including date, time, geographic position, initial behaviors and angle of the sighting relative to the horizon. Emphasis is placed on providing information to assess fine-scale shifts in the migration pathway of bowhead whales in this area and on coordinating the effort and management of data necessary to support seasonal offshore-drilling and seismic-exploration regulations.

#### *Median Water Depth of Bowhead Migration Corridor*

For this survey the Beaufort Sea is divided into three regions to analyze east-west components of the known fall migration corridor. Because of the bathymetry of the Alaskan Beaufort Sea, if there was a seaward shift of the fall migration, it would be represented as a shift to a greater median water



Median water depth (in meters) at random sightings of bowhead whales, by year, 1982-1995.

depth at which whales are sighted. The annual area-wide median water depth of bowhead whale sightings ranges between 18 and 347 m. The area-wide median for the years 1982 through 1995 ( $n = 568$ ) is 37 m. For the same period the median water depth is 131 m for Region 1, 31 m for Region 2, and 42 m for Region 3 (Treacy 1996).

The difference between the 1983 median value (all three regions combined) and the median values for other years except 1991 is highly significant; the difference is also highly significant, in some instances, in Regions 2 and 3. The bowhead may have chosen the offshore (deep-water) migratory route in 1983, instead of the shallower route followed in other years, because of the general ice cover, including shorefast ice. The most severe ice year since 1975 was 1983 (Naval Ice Center 1996). Ice cover probably has the greatest potential for interacting with environmental conditions that may have biological significance to migrating bowhead whales (net primary production, availability of leads, water temperature). Differences in human activity levels, oceanographic conditions and the possible indirect effect of heavy ice cover on prey availability are additional potential factors (Treacy 1996).

### *Monitoring the Distribution and Abundance of Ringed Seals in Northern Alaska*

In 1996 a monitoring study on the distribution and abundance of ringed seals in northern Alaska was initiated through a cooperative agreement with the Alaska Department of Fish and Game (ADF&G). The ADF&G previously conducted an MMS-funded study on ringed seal distribution and abundance from 1985 through 1987. After review-



ing the previously established aerial survey protocol, the three-year effort will provide additional information on current ringed seal distribution and abundance in the Beaufort Sea. This will help the MMS and subsistence hunters learn about the possible effects that OCS oil and gas leasing and development activities may have on ringed seal distribution and abundance. Of particular interest will be the analyses of relationships between ringed seal distribution and sea ice characteristics, as well as the seal distribution relative to general levels of exploration and development, such as near the Northstar or other industry activities.

#### *Incorporation of Traditional Knowledge and Dissemination of Results*

Ringed seals are part of the subsistence economy of the Inupiat people. These seals are harvested by Native peoples in Russia, Canada and the United States, where they are traditionally hunted on the shorefast ice. This study will help to assure that government agencies and residents of coastal villages along the Alaskan Beaufort Sea have information on factors potentially affecting subsistence resources. As part of interpretation of the scientific results, the project cooperators will informally assess and compile information available from local information sources. Possible contacts will include informal networks established through marine mammal committees or co-management groups established by indigenous peoples. Working in collaboration with the ADF&G, the North Slope Borough's Department of Wildlife Management will assist in communicating study plans and results to people residing in the study

area. All cooperators will have input to the study design and will have access to, and be able to make use of, all data collected.

#### *Study Methods*

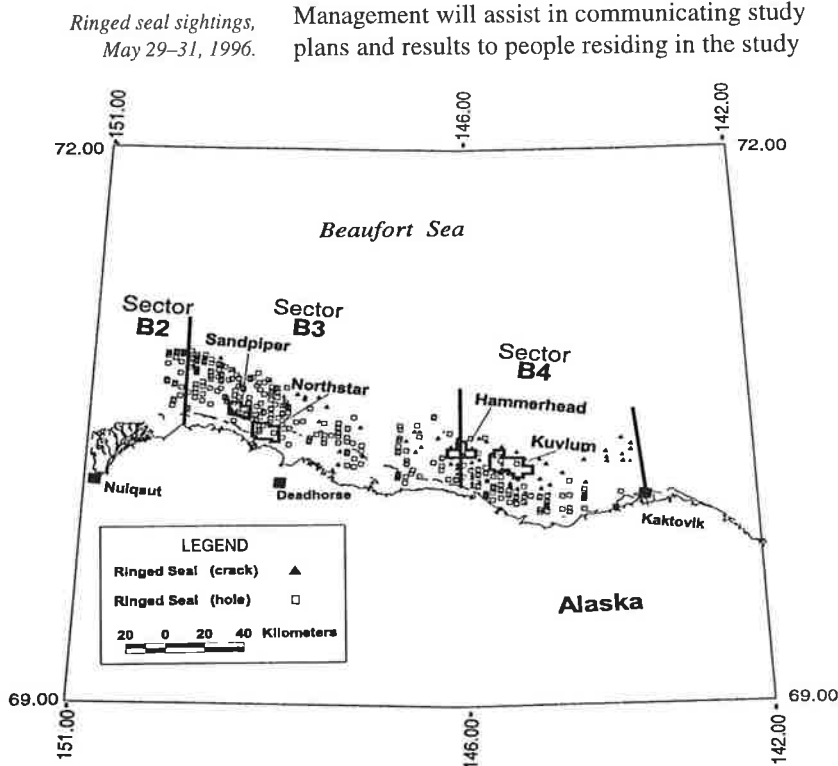
The survey area for this study is in the Alaskan Beaufort Sea. The survey completed in May 1996 concentrated on an anticipated "industrial area" and on adjacent areas to the east and west. Survey lines were flown between Barter Island and the Colville River Delta. The industrial area includes the Northstar and Sandpiper Units. Oil development activities are planned to be initiated in the Northstar Unit in 1997. The survey of this industrial area establishes a baseline using both previously and newly collected (1996) data. "Control areas" surveyed were in Sectors B2, B3 and B4. In 1997 and 1998, aerial surveys will be conducted throughout the Alaskan Beaufort Sea with emphasis on areas of industrial activity. Aerial surveys will be completed using a chartered twin-engine high-wing Aero Commander aircraft equipped with nine bubble windows for downward visibility. The aircraft is also equipped with two global positioning systems. The flights will be flown at 91 m along randomly selected north-south transects. Seal sightings and ice conditions are entered directly into an onboard computer.

During the survey completed in May, two observers used previously established strip-transect protocols to count ringed seals, and they observed whether the seal was located at a breathing hole or at an ice crack. Ice condition observations and seal counts were entered directly into laptop computers. The observations were linked with latitude, longitude and time through computer linkage with the aircraft's global positioning system. The north-south lines in the industrial area were flown at 1.85-km intervals. Transect lines in the Kuvlum and Hammerhead Units and in the control areas east and west of the industrial area were flown at 3.7-km intervals. Similar methods will be used in later surveys.

#### *1996 Study Preliminary Results*

Flights for 1996 were conducted from May 28 through 31, in clear, sunny weather. The surveys were flown between 10:00 a.m. and 4:00 p.m. at an altitude of 91 m. A total of 64 transects and 2381 km were flown in 1996. No oil development activities occurred in the industrial area at the time these survey flights were conducted.

Preliminary ringed seal densities were estimated for the entire length of the transects for all types of ice types combined (fast, pack and unknown). Seal densities at breathing holes—0.5 to 0.6 seals/km<sup>2</sup>—were similar in all sectors except



B2 (1.08 seals/km<sup>2</sup>), where only three transects were surveyed. However, seal densities at cracks increased from west to east, with the lowest densities in Sector B2 and the industrial area (0.02 and 0.05 seals/km<sup>2</sup>, respectively), a higher density in Sector B3 (0.18 seals/km<sup>2</sup>), and the highest in Sector B4 (0.52 seals/km<sup>2</sup>). The highest densities for all observed seals were in Sectors B2 and B4. Of the four surveyed areas (Sectors B2, B3 and B4 and the industrial area) the industrial area had the lowest observed density of seals overall. Density estimates calculated separately for fast and pack ice are forthcoming.

The study results will be compared with the ringed seal data collected in 1985 through 1987. Preliminary comparisons of seal densities for all ice types combined in 1996, and the 1985–1987 density estimates for fast ice only, indicate that densities of seals at breathing holes in Sectors B3 and B4 were similar in 1985 and 1996 (about 0.5–0.6 seals/km<sup>2</sup>). For all seals combined, at holes and cracks, the 1985 density estimates were slightly higher than the 1996 estimates in Sector B3 and lower in Sector B4. However, the 1986 seal densities on fast ice were more than double, and the 1987 densities more than triple, the preliminary 1996 density estimates in Sectors B3 and B4. More in-depth analysis of ice characteristics and the timing of surveys relative to breakup will be needed for further comparisons.

The results of the 1996 ringed seal surveys described above are considered preliminary, and they will be subjected to additional analysis and interpretation. Additional aerial surveys to be conducted in 1997 and 1998 will involve continued review and refinement of the previously established protocol for monitoring ringed seals. The additional data will provide a means for comparing the abundance and density of winter-resident ringed seals on shorefast ice in the Beaufort Sea area for 1985 through 1987 and 1996 through 1998, and for determining and comparing seal abundance and density near industrial areas with those of non-industrial areas.

### *Synthesis of Socioeconomic and Traditional Information*

Not only is traditional knowledge being incorporated into specific study planning, field work and interpretation of results such as described in the above efforts, but the synthesis of information from many projects into a broader, multi-disciplinary view of research results is continuing. Past efforts such as MMS Information Transfer Meetings have helped us guide the design of future

studies toward a more encompassing involvement of traditional information with scientific activities and results. Also of particular importance is the sharing of information between social and economic disciplines and other scientific fields. Since 1975 the MMS has sponsored more than 160 social and economic studies, with many directly related to Arctic issues and concerns of local residents. Methodological approaches of the ESP reports have included case studies, institutional profile analyses, analyses of secondary-source materials, modeling and econometric analyses, and survey research.

In recent years, socioeconomic studies have become more focused and issue-oriented, emphasizing the critical linkages between OCS development and social systems. These studies have collected time-series information and measures of community and regional well-being as bases for monitoring social indicators.

#### *Arctic Information Transfer Meetings*

The ESP regularly organizes conferences to share all of the ESP results with other Federal, state and local governments; other Arctic scientists; and the general public. An additional purpose of the conferences is to integrate MMS ESP information with other sources of environmental information. In the past, speakers and participants have included, for example, representatives of the AEWG, the NSB, the U.S. Geological Survey's National Biological Research Division, the National Marine Fisheries Service, the National Ice Center, the Environmental Protection Agency, the ADF&G and Alaska Department of Natural Resources, the University of Alaska Fairbanks, the Marine Mammal Commission, and the U.S. Arctic Research Commission. At the 5th MMS Arctic Information Transfer Meeting held in January 1993, a special workshop was held titled "Social and Economic Studies in the Northern and Northwest Arctic: Assessing Methodological Approaches, Strengths in the Knowledge Base, and Information Needs" (MMS 1993). This meeting helped to define constructive approaches to cross-cultural communications and led to discussions by the MMS Scientific Committee in June 1995 on how to integrate traditional knowledge into administration of an environmental studies program.

#### *Planning Workshop for Alaska OCS Socioeconomic Book/Synthesis*

In part as a result of such meetings and discussions, it became clear that a more comprehensive synthesis of MMS-sponsored and traditional information on Arctic social and economic information was needed. In 1995 the Alaska ESP proposed to



design and implement such a synthesis project, with the goal of developing a cooperatively sponsored book synthesizing peer-reviewed scientific results of past studies and other pertinent social and economic information. Since this project is in its inception, specific methods are under development and products are not currently available. However, it exemplifies the melding sought between scientific and traditional information sources.

Recently a planning workshop was held to consider the synthesis of the socioeconomic reports and associated publications produced by MMS since 1975. The workshop considered the costs and benefits of synthesis and identified a tentative outline, chapter integration and potential co-sponsors for the Alaska OCS Socioeconomic Book/Synthesis.

Workshop participants were invited for their expertise on a wide range of socioeconomic topics and their potential as cosponsors of the resource document. Topics ranged from the state economy and the importance of continued oil and gas production to the economics associated with coastal communities and their dependence on a subsistence-based lifestyle. Participants possessing traditional knowledge, particularly Alaskan Natives, were invited. It is anticipated that the

resulting synthesis of scientific and traditional knowledge will benefit local communities as well as participants in the workshop.

The workshop was held in April 1997, and the resulting Alaska OCS Socioeconomic Book/Synthesis will be made available to the public and government decision makers.

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# *Undiscovered Oil and Gas Potential of the Alaska Federal Offshore*

## *1995 National Resource Assessment*

*This report was prepared by Kirk W. Sherwood, James D., Craig and Larry W. Cooke, all geologists with the Alaska Region of the Minerals Management Service, U.S. Department of the Interior, 949 E. 36th Ave., Room 308, Anchorage, Alaska 99508-4302. This work is based on studies by the authors and present and former Alaska Regions staff, including James Scherr, Peter Johnson, Susan Zerwick, Susan Banet, Sally Hurlbert, Steve Haley, Dorothy MacLean, John Larson, Drew Comer, Bruce Herman, John Parker, Richard Newman, Warren Horowitz and Gary Martin.*

This report summarizes the Minerals Management Service's 1995 assessment (based on data available as of January 1995) of the quantities of undiscovered oil and gas that lie beneath submerged Federal lands offshore of Alaska. Estimates include both undiscovered conventionally recoverable resources, unconstrained by economics, and undiscovered economically recoverable resources. Conventionally recoverable resources are oil, natural gas and natural gas liquids recoverable from a discrete subsurface pool into a well by natural flow or pumping, or addition of pressure, using modern extraction technologies. Resources not assessed include gas in geopressed brines, tar deposits, oil shales, coal gas or gases in clathrates (gas hydrates). Economically recoverable resources are the undiscovered resource volume in each province which, if discovered, could be produced profitably given realistic estimates for costs of exploration, development, production and transportation.

The Alaska offshore is estimated to offer a mean potential for undiscovered conventionally recoverable oil of 24 billion barrels, with a 5% chance of the oil potential exceeding 34 billion barrels. The undiscovered gas potential (mean value) is estimated at 126 trillion cubic feet, with a 5% chance of the gas resources exceeding 230 trillion cubic feet. Approximately 90% of the undiscovered conventionally recoverable oil in offshore Alaska occurs within the Chukchi shelf (13 billion barrels) and Beaufort shelf (9 billion barrels) provinces, which lie adjacent to the onshore Arctic Alaska oil and gas province, the latter with a discovered oil endowment of 70 billion barrels (commercial reserves, 16.4 billion barrels) and presently producing about 1.5 million barrels per day.

Most of the undiscovered oil and gas in the Alaska offshore occurs in accumulations too small to warrant commercial exploitation at this time. Only about 15% of the undiscovered oil offshore Alaska could be profitably recovered at prices approaching those that exist today. Most of the economically recoverable oil resources occur beneath the Beaufort shelf (2.27 billion barrels of oil) and Chukchi shelf (1.14 billion barrels of oil). Elsewhere in the Alaska offshore, only Cook Inlet offers any economically recoverable oil, here estimated at 0.27 billion barrels.

Most of the conventionally recoverable gas resources occur beneath the Beaufort and Chukchi shelves, but gas in these provinces is considered uneconomic because of the lack of an infrastructure for transporting gas to markets outside Alaska.

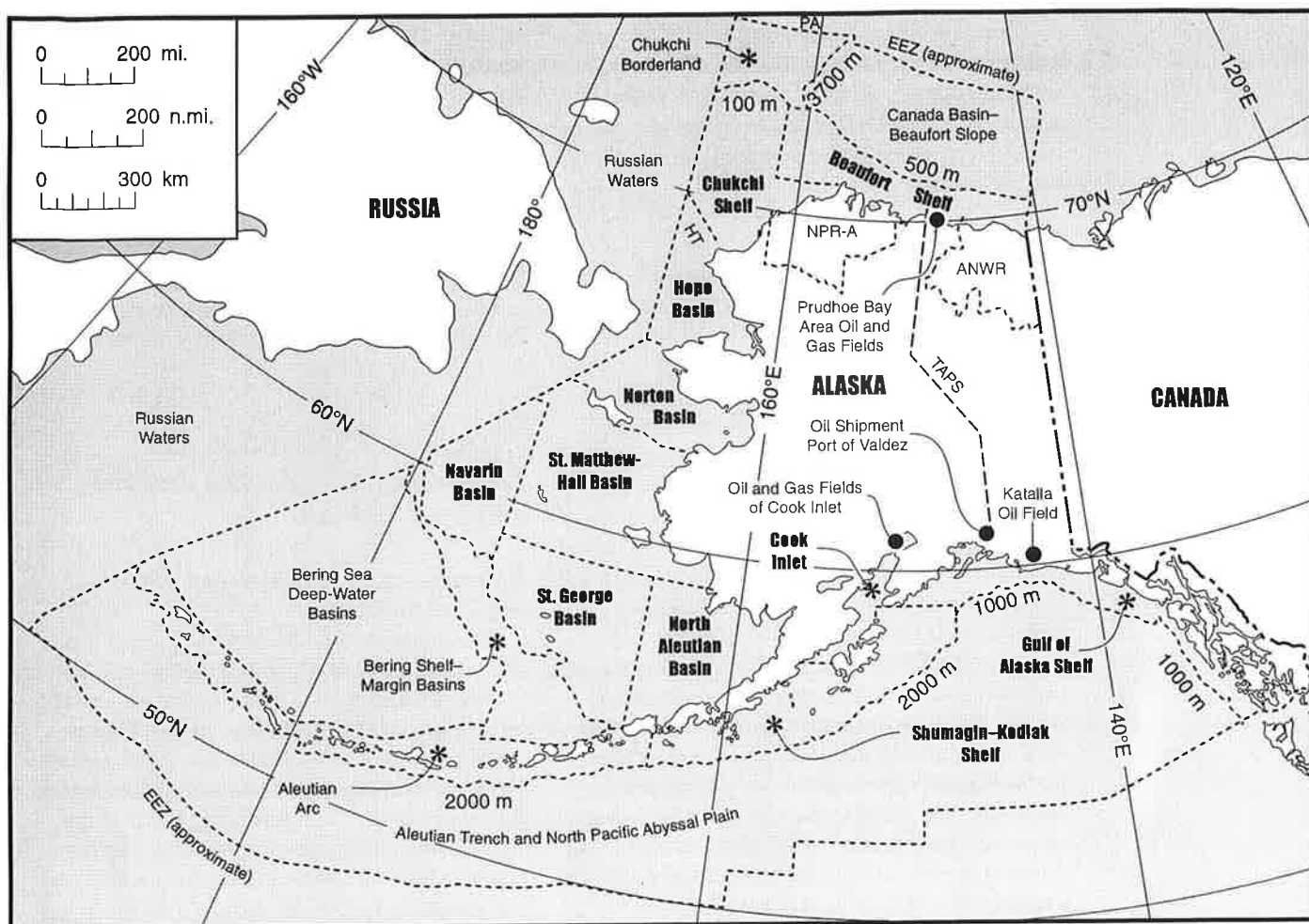
### *Purpose of Assessment and Assessment Areas*

This assessment of the Alaska Federal offshore was conducted as part of a national appraisal of all Federal offshore lands in the U.S. performed by the Minerals Management Service (MMS) concurrently with a U.S. Geological Survey (USGS) assessment of all onshore lands and submerged lands in State waters (USGS 1995). The MMS assessments are conducted periodically (Cooke 1985, 1991, Cooke and Dellagiarino 1989, MMS 1996, Sherwood et al. 1996), and the results are used to guide management of leasing and exploration policies and programs in the Federal offshore.

Federal jurisdiction in Alaska offshore waters extends seaward from the limit of State of Alaska waters, generally three miles offshore, to the farther of two limits as defined by either Federal Outer Continental Shelf (OCS) planning areas or the 200-mile Exclusive Economic Zone. Canadian or Russian international maritime boundaries limit several offshore assessment provinces.

Because submerged Federal lands may extend 200 miles or farther offshore, they include all of the continental shelves as well as large areas of the continental slopes and deep abyssal plains of the north Pacific Ocean and the Bering, Chukchi and Beaufort Seas. Six of the 17 offshore assessment provinces embrace areas of deep water or unpromising geology that offer only negligible geologic potential for conventionally recoverable oil or gas. The five deep-water assessment provinces are the Canada Basin-Beaufort Slope, the Chukchi Borderland, the Bering Shelf-Margin Basins, the Bering Sea Deep-Water Basins, and the Aleutian Trench and North Pacific Abyssal Plain. A sixth assessment province, the Aleutian Arc, consists of an intra-oceanic volcanic arc of Tertiary age and is considered to have negligible potential for oil and gas.





*Alaska offshore assessment provinces, 1995 National Resource Assessment. The provinces with undiscovered conventionally recoverable resources are shown in bold type; the others have negligible oil or gas. Some province boundaries are defined by the Exclusive Economic Zone (EEZ), some by bathymetric contour, and one by the OCS planning area (PA). HT refers to Herald Thrust, and TAPS refers to the Trans-Alaska Pipeline System.*

The 11 assessment provinces that offer any realistic potential for undiscovered conventional or economic oil and gas are confined to the continental shelves surrounding Alaska. These provinces are grouped into three subregions. The Arctic subregion includes the Beaufort Shelf, Chukchi Shelf and Hope Basin assessment provinces. The Bering Shelf subregion includes the Norton Basin, St. Matthew-Hall Basin, Navarin Basin, St. George Basin and North Aleutian Basin assessment provinces. The Pacific Margin subregion includes the Shumagin-Kodiak Shelf, Cook Inlet and Gulf of Alaska Shelf assessment provinces.

## *Geologic Settings of Alaska Offshore Assessment Provinces*

### *Pacific Margin Subregion*

The assessment provinces located offshore southern Alaska overlie the modern Pacific convergent margin, where the oceanic crust of the Pacific plate moves northward and is subducted beneath the Aleutian volcanic arc and the Shu-

magin, Kodiak and Gulf of Alaska continental shelves. The compression and uplift resulting from the convergence of plates along this zone has controlled the geological development of the Pacific margin of Alaska.

The Aleutian volcanic arc, of Tertiary age and constructed entirely upon oceanic crust, extends eastward 1300 km from Russian waters into a continental setting where it meets the Bering Sea continental margin (at approximately the southeast limit of the Bering Shelf-Margin Basins assessment province). From the Bering margin northeast to the interior of southern Alaska, the modern volcanic arc is superposed upon older volcanic-arc systems ranging up to Jurassic [145–200 million years ago (Ma)] in age (Reed and Lanphere 1973). East of Cook Inlet the volcanic arc and convergent-margin tectonics gradually give way to the strike-slip fault tectonics that dominate the eastern Gulf of Alaska, where the Pacific plate moves northwest and laterally past the North American continental plate.

Most of the undiscovered oil and gas resources in the assessment provinces of the Pacific Margin subregion are associated with forearc basins and

shelf-margin wedges of Tertiary age (66 Ma and younger). Except in Cook Inlet these Tertiary rocks are superposed on a deformed "basement" consisting of older volcanic-arc complexes and accretionary terranes that generally offer negligible hydrocarbon resource potential.

#### *Bering Shelf Subregion*

Western offshore Alaska is dominated by the 600-km-wide Bering Sea continental shelf. From Jurassic to earliest Tertiary time, the Bering shelf hosted one segment of a larger system of volcanic arcs extending from southeast Alaska to the Russian Sea of Okhotsk. This volcanic-arc system marked the northward descent of a southern oceanic (proto-Pacific) plate encroaching from the south. Continental fragments and volcanic arcs borne along with the southern oceanic plate collided with both Russian and Alaskan elements of the volcanic-arc system in earliest Tertiary time (Worrall 1991). The collision(s) strongly deformed the rocks of most parts of the Bering shelf segment and other parts of the volcanic-arc system. Rocks deformed by these collisions, typically of Cretaceous age or older, offer only negligible potential for undiscovered oil and gas resources. The Aleutian arc was also established as a new plate boundary at this time, trapping fragments of an old volcanic arc and oceanic crust that formerly were part of the southern oceanic plate of Marlow et al. (1982). Subduction of a spreading ridge that lay within the southern oceanic plate reorganized plate interactions in the north Pacific and caused strike-slip faulting throughout southern Alaska in early Tertiary and later time (Atwater 1970). Most of the Bering Shelf basins (Norton, St. Matthew-Hall, Navarin, St. George and North Aleutian Basins) began to subside at this time as pull-aparts or related features along strike-slip fault systems passing through the Bering Shelf. Most of the undiscovered oil and gas resources offshore western Alaska are associated with Tertiary rocks deposited in the Bering Shelf basins formed during this period of strike-slip faulting.

#### *Arctic Offshore Subregion*

Offshore areas north and northwest of Alaska are dominated by the broad (400-km) continental shelf of the Chukchi Sea and the narrow (70-km) continental shelf of the Beaufort Sea. In Paleozoic and Mesozoic time (ca. 360–115 Ma), these shelf areas and onshore Arctic Alaska shared petroleum-rich geologic basins that were broken up or restructured in Early Cretaceous time (ca. 115 Ma) by continental breakup and rifting along the Beaufort Shelf margin and the elevation of the Brooks Range (Craig et al. 1985, Moore et al. 1992, War-

ren et al. 1995). The fragmentation of the crust in northern Alaska and mountain-building in the Brooks Range gave rise to several new basins that received many thousands of meters of sediments during Cretaceous and Tertiary time (115 Ma to present). These events also created the geologic structures that later trapped the vast oil reserves (70+ billion barrels, in place) found in the Prudhoe Bay area of Arctic Alaska, as well as the undiscovered oil and gas resources thought to underlie the neighboring continental shelves of the Beaufort and Chukchi Seas.

### *Petroleum Exploration and Development in Alaska and the Alaska Offshore*

#### *Exploration of the Pacific Margin Subregion and Southern Alaska*

Petroleum exploration in Alaska began in the late nineteenth century, and the first field (Katalla) was discovered in 1902 by drilling at the site of oil seeps along the coast of the eastern Gulf of Alaska (AOGCC 1994). In the late 1950s and the 1960s, several commercial oil and gas fields were discovered in the Cook Inlet area. Many of the commercial-sized fields discovered during this time remain in production today (seven oil fields and seven gas fields). Altogether, 8 oil fields and 22 gas fields have been discovered in Cook Inlet, with the total discovered oil resources of about 1.34 billion barrels of oil (BBO) and 9.33 trillion cubic feet of gas (TCFG) (AOGCC 1994, *Oil and Gas Journal* 1993, AKDO&G 1995). Oil production from Cook Inlet fields peaked at 236,000 barrels of oil per day (BOPD) in 1970 but declined to 43,500 BOPD by 1994 (AOGCC 1994). The total cumulative production from Cook Inlet by the end of 1994 was 1.19 BBO and 7.44 TCFG (AOGCC 1994). Of the 7.44 TCFG produced in Cook Inlet, 2.73 TCFG were re-injected to aid oil recovery (and remain a future resource), with 4.70 TCFG, or 50% of discovered resources, actually delivered to market and consumed. Cook Inlet also hosts a liquefied natural gas (LNG) facility, which ships about 144 million cubic feet of gas per day to power utilities in Tokyo, Japan (AOGCC 1994, *Oil and Gas Journal* 1993). No commercial production has occurred on Federal submerged lands in the Cook Inlet area.

The first explorations of the Alaska Federal offshore began in the early 1970s with the scheduling of lease offerings in the Gulf of Alaska and Cook Inlet. A stratigraphic test well was drilled in the Gulf of Alaska in 1975, and a second stratigraphic test was drilled in Federal waters of Cook Inlet in

1977. The first Federal offshore lease sale in Alaska waters was held in 1976 in the Gulf of Alaska. Three sales in the Gulf of Alaska from 1976 to 1981 leased 0.6 million acres for total high bonus bids of \$670 million. Twelve exploratory wells on Gulf of Alaska leases in the period from 1977 to 1983 failed to locate commercial quantities of oil or gas. Two lease offerings in Federal waters of Cook Inlet in 1977 and 1981 leased 0.57 million acres for total high bonus bids of \$403 million. Thirteen exploratory wells drilled on Cook Inlet leases in the period from 1977 to 1985 failed to find commercial quantities of oil or gas.

#### *Exploration of the Bering Shelf Subregion and Western Alaska*

Petroleum exploration has been conducted since early this century in various parts of western Alaska and the Alaska Peninsula. These efforts all failed to locate any significant petroleum accumulations.

Petroleum exploration offshore western Alaska began in the early 1970s with the scheduling of lease sales on the Bering Shelf. Seismic data were gathered across large parts of the Bering Shelf, and six stratigraphic test wells were drilled from 1976 to 1983 in the St. George, Norton, Navarin and North Aleutian Basins. Four lease sales were held in these same basins in the period from 1983 to 1988, and 1.9 million acres were leased for total high bonus bids of \$1.36 billion. Twenty-four exploratory wells were drilled in the Navarin, Norton and St. George Basins. None encountered significant shows of oil or gas. Except for a stratigraphic test well drilled in 1983, no exploratory drilling has occurred in the North Aleutian Basin.

#### *Exploration of the Arctic Offshore Subregion and Northern Alaska*

Petroleum exploration in Arctic Alaska began with the reporting of oil seeps in the Cape Simpson area near the northernmost tip of Alaska by Leffingwell of the U.S. Geological Survey in 1917. In 1923, based on the presence of these seeps and prompted by fuel shortages in World War I, President Warren Harding established Naval Petroleum Reserve No. 4, later renamed the National Petroleum Reserve-Alaska (NPR-A). Fuel shortages during World War II prompted the first intensive, publicly funded exploration program in the NPR-A from 1944 to 1953, resulting in the discovery of several subcommercial oil and gas fields.

With passage of Alaska statehood in 1959, exploration shifted to the lands selected by the State of Alaska in the corridor between the NPR-A on the west and the Arctic National Wildlife Ref-

uge (ANWR) on the east. State of Alaska lease sales in 1964 and 1965 were followed by the 1968 discovery of the 12.4-BBO Prudhoe Bay field, the largest oil field ever found in North America. The ultimate reserves recoverable from known commercial fields in the Prudhoe Bay area are approximately 16.4 BBO, and Prudhoe-area gas reserves are estimated at 28.2 TCFG (AOGCC 1994, AKDO&G 1995).

Construction of the Trans-Alaska Pipeline System (TAPS) began in 1974, and the first oil pumped through the pipeline arrived at the ice-free port of Valdez, Alaska, in 1977 for tanker shipment to the U.S. mainland. Pipeline throughput peaked at 2.0 million barrels of oil per day (MMBOPD) in 1988. By May 1996, production was 1.5 MMBOPD and a total of 11.2 BBO had passed through the pipeline.

In response to concerns about oil shortages related to the 1973 embargo of the United States by the Organization of Petroleum-Exporting Countries, government-sponsored exploration of NPR-A resumed in 1975 after a 22-year hiatus. This second program resulted in 28 exploration wells and 14,800 miles of seismic data but no significant discoveries. The first offerings of leases for private exploration occurred in 1981, followed by a single well drilled and abandoned in 1985. This well concluded the most recent cycle of petroleum exploration in the NPR-A.

The first lease sale in the Arctic Alaska offshore, offering mostly submerged lands of the Beaufort Sea near known fields in the Prudhoe Bay area, was conducted jointly by the State of Alaska and the Federal government in 1979. Since 1979 most continental-shelf areas of the Arctic Alaska offshore were offered in four additional lease sales in the Beaufort Sea and two lease sales in the Chukchi Sea. In all seven sales, a total of 5.5 million acres of Federal lands were leased for total high bonus bids of \$4.03 billion. An eighth sale, held in September 1996, attracted \$14.6 million in high bids on 29 lease blocks (100,000 acres). A total of 32 exploratory wells were drilled in Arctic Federal waters between 1980 and 1993, resulting in the discovery of several subcommercial pools of oil.

Northstar (Seal Island) field, estimated by BP-Alaska to contain up to 145 million barrels of recoverable oil, straddles State of Alaska and Federal offshore lands about 5 miles north of the Prudhoe Bay field and will provide the first-ever commercial production of oil from the Alaska Federal offshore. Commercial production from Northstar field could enter the trans-Alaska pipeline as early as 1999 (*Anchorage Daily News* 1996).

## *Computer Models Used to Calculate Oil and Gas Potential*

The assessment of the undiscovered oil and gas potential of the Alaska offshore involved two tasks. The first was to develop estimates of the undiscovered resources irrespective of any economic constraints. The second was to determine how much of the undiscovered oil and gas would be economic (profitable) to produce under a range of possible commodity prices.

The primary assessment unit in models constructed for both tasks was the geologic play, which is a population of pools or prospects having a common history of hydrocarbon generation, migration, reservoir development and trap configuration. (A pool is a discovered or undiscovered accumulation of hydrocarbons, typically within a single stratigraphic interval, that is hydraulically separated from any other hydrocarbon accumulation; a prospect is an untested geologic feature having the potential for trapping and accumulating hydrocarbons.) In the Alaska offshore, a total of 74 plays were identified and individually assessed for undiscovered, conventionally recoverable quantities of oil and gas. Conventionally recoverable and economically recoverable oil and gas potentials for individual plays are reported in Sherwood (1996).

To accomplish the first task, MMS used a computer program called GRASP (Geologic Resource ASsessment Program). [GRASP was adapted by MMS from a program called PETRIMES (PETroleum Resource Information Management and Evaluation System), originally developed by the Geological Survey of Canada.] To use GRASP, assessors constructed a subjective database in which ranges of values with varying probabilities of occurrence were estimated for geologic variables such as pool area, pay thickness, porosity, hydrocarbon saturation and recovery efficiency. Ranged values were used rather than fixed values to reflect uncertainty about the true quantity of a geologic variable at any particular site. GRASP uses these ranged variables to calculate probability distributions for sizes of recoverable pool volumes, both oil and gas, within each play. Separately a probability distribution for the numbers of pools is calculated by combining geologic risk factors with a probability distribution for the numbers of prospects within the play. (Estimates for prospect numbers were generally developed from the prospect count obtained by geophysical mapping and some estimates of additional prospects missed or not mapped in areas of no data.) A Monte Carlo process statistically combines the probability distribution of the possible sizes of

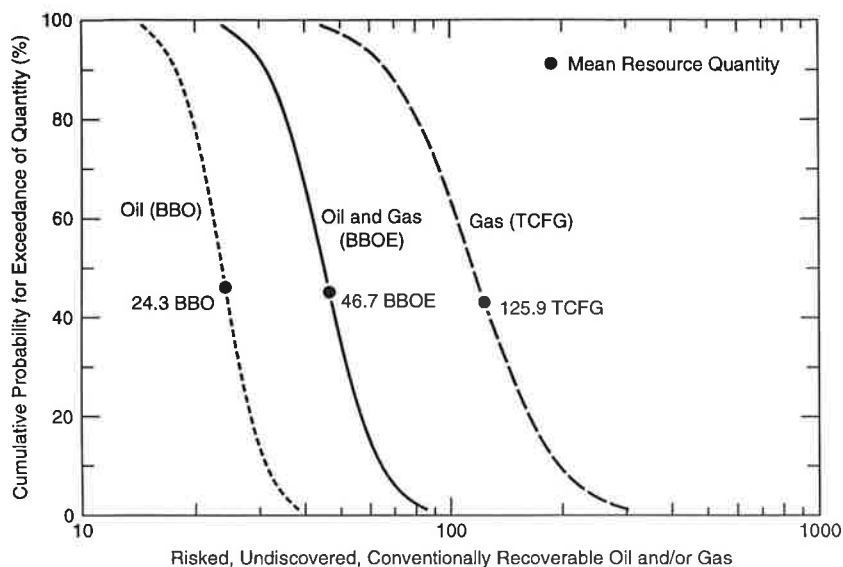
pools with the probability distribution of the possible numbers of pools to compute probability distributions for the oil and gas volumes of individual pools. The pools are then ranked from largest to smallest and are summed to calculate the overall play resource endowment. Outputs from GRASP include pool-size rank plots, cumulative probability curves and tabulated results. GRASP separately calculates the volumes of crude oil, solution gas, nonassociated and associated gas, and condensate but only reports oil (all liquids), natural gas (all gases) and total hydrocarbon energy (oil summed with gas in oil-equivalent units).

To calculate the oil and gas potential of the Alaska offshore provinces, the probability distributions for oil and gas potentials of individual plays were statistically aggregated using a computer program named FASPAG, developed by Robert Crovelli of USGS. The oil and gas potentials of subregions and the entire Alaska Federal offshore were similarly obtained by FASPAG aggregations.

To accomplish the second major task—determining the quantities of undiscovered economic resources—the MMS used a computer program named PRESTO (Probabilistic Resource ESTimates—Offshore). PRESTO simulates the exploration, development, production and transportation of the pool resources for all plays within a geologic province. The geologic data used by GRASP for pool and play modeling are translated into a format usable by PRESTO. A Monte Carlo process samples the ranges of values input for engineering and economic variables. For each pool the program models numbers and costs of wells, schedules installation of development platforms and wells, estimates annual production, schedules production costs and revenues, develops a risk-weighted discounted cash flow, and calculates a present economic value. Results for all pools are summed to the play level to determine whether economic resources are sufficient to justify development of the play. Similarly the results from all of the plays are summed to determine whether sufficient resources are available to justify a transportation infrastructure for the entire geologic basin or province. This process is repeated for a large number of trials, resulting in a distribution of possible economic resources under the given conditions. Economic conditions are then modified and the entire process is repeated many times (typically 1000 trials), finally yielding a series of possible results under many economic scenarios.

Although numerous tables of various play and province results are available from PRESTO, the primary output is the price–supply curve. Inspection of price–supply curves allows interpretation





Cumulative probability distributions for risked, undiscovered, conventionally recoverable oil, gas and total hydrocarbon energy for the Alaska Federal offshore (BBOE = billion barrels of oil-equivalent, 1 barrel of oil = 5260 cubic feet of gas).

of economically recoverable volumes of oil or gas at any commodity price. Increases in price drive corresponding increases in the volumes of oil and gas that can be economically recovered, primarily by allowing profitable development of additional small fields. At very high theoretical prices the price-supply curve approaches a limit that equals the resource endowment estimated by GRASP.

## Undiscovered Oil and Gas Potential of the Alaska Offshore

Federal submerged lands offshore Alaska offer up to 34 billion barrels of oil and 230 trillion cubic feet of gas. (This refers to the risked, undiscovered, conventionally recoverable oil and gas resources reported at a 5% probability for exceedance in a cumulative probability distribution.) On average, though, the resource expectation is rather less, 24 billion barrels of oil and 126 trillion cubic feet of gas.

The Arctic subregion contains 90% of the undiscovered oil and 79% of the undiscovered gas (compared at mean values) of the entire Alaska offshore. The high proportion of offshore oil and gas resources estimated to be present in the Arctic subregion is consistent with the fact that 92% of Alaska's original commercial oil reserves were found in Arctic Alaska. Arctic dominance of both offshore undiscovered resources and proven on-shore reserves simply reflects the rich endowment of Arctic Alaska and adjoining continental shelves with the key ingredients for oil and gas accumulations—prolific source rocks, excellent reservoir rocks and numerous potential traps covering large areas.

### Risked, undiscovered, conventionally recoverable oil and gas.

Area	Oil (BBO)			Gas (TCFG)			BOE (BBO)			MPhc
	F95	Mean	F05	F95	Mean	F05	F95	Mean	F05	
Alaska offshore	16.85	<b>24.31</b>	33.57	58.01	<b>125.93</b>	229.53	28.68	<b>46.72</b>	70.61	1.00
Arctic subregion	14.68	<b>21.96</b>	31.18	38.02	<b>99.41</b>	201.13	22.52	<b>39.65</b>	63.25	1.00
Bering Shelf subregion	0.36	<b>0.91</b>	1.81	6.98	<b>18.80</b>	38.64	1.65	<b>4.26</b>	8.57	1.00
Pacific Margin subregion	0.72	<b>1.44</b>	2.49	2.12	<b>7.72</b>	18.34	1.15	<b>2.81</b>	5.50	1.00
Arctic subregion										
Chukchi Shelf	6.80	<b>13.02</b>	21.94	9.81	<b>51.84</b>	141.75	8.59	<b>22.24</b>	44.75	1.00
Beaufort Shelf	6.28	<b>8.84</b>	11.96	20.10	<b>43.50</b>	79.15	10.29	<b>16.58</b>	24.84	1.00
Hope Basin	0.00	<b>0.11</b>	0.34	0.00	<b>4.06</b>	12.67	0.00	<b>0.83</b>	2.59	0.61
Bering Shelf subregion										
Navarin Basin	0.00	<b>0.50</b>	1.21	0.00	<b>6.15</b>	18.18	0.00	<b>1.59</b>	4.41	0.88
N. Aleutian Basin	0.00	<b>0.23</b>	0.57	0.00	<b>6.79</b>	17.33	0.00	<b>1.44</b>	3.62	0.72
St. George Basin	0.00	<b>0.13</b>	0.41	0.00	<b>3.00</b>	9.72	0.00	<b>0.67</b>	2.14	0.94
Norton Basin	0.00	<b>0.05</b>	0.15	0.00	<b>2.71</b>	8.74	0.00	<b>0.53</b>	1.70	0.72
St. Matthew-Hall	0.00	<b>&lt; 0.01</b>	< 0.01	0.00	<b>0.16</b>	0.69	0.00	<b>0.03</b>	0.13	0.44
Pacific Margin subregion										
Cook Inlet	0.32	<b>0.74</b>	1.39	0.40	<b>0.89</b>	1.65	0.39	<b>0.90</b>	1.68	1.00
Gulf of Alaska	0.18	<b>0.63</b>	1.43	0.94	<b>4.18</b>	10.59	0.36	<b>1.37</b>	3.27	0.99
Shumagin-Kodiak	0.00	<b>0.07</b>	0.29	0.00	<b>2.65</b>	11.35	0.00	<b>0.54</b>	2.30	0.40

BBO, billions of barrels;

TCFG, trillions of cubic feet;

BOE, total oil and gas in billions of energy-equivalent barrels (5620 cubic feet of gas = 1 energy-equivalent barrel of oil);

Reported **Mean**, resource quantities at the mean in cumulative probability distributions;

F95, the resource quantity having a 95% probability of being met or exceeded;

F05, the resource quantity having a 5% probability of being met or exceeded;

MPhc, marginal probability for hydrocarbons for basin, that is, chance for the existence of at least one pool of undiscovered, conventionally recoverable hydrocarbons somewhere in the basin.

Resource quantities shown are risked, that is, they are the product of multiplication of conditional resources and Mphc. Mean values for provinces may not sum to values shown for subregions or region because of rounding.

### Risked, undiscovered, economically recoverable oil and gas.

Area	Oil (BBO)			Gas (TCFG)			BOE (BBO)			E/C
	F95	Mean	F05	F95	Mean	F05	F95	Mean	F05	
<b>Alaska offshore</b>	1.41	<b>3.75</b>	7.65	0.02	<b>1.11</b>	4.33	1.43	<b>3.95</b>	8.20	0.08
<b>Arctic subregion</b>	1.15	<b>3.41</b>	7.25	0.00	<b>0.12</b>	0.00	1.15	<b>3.44</b>	7.31	0.09
<b>Bering Shelf subregion</b>	0.00	<b>0.02</b>	0.22	0.00	<b>0.99</b>	10.82	0.00	<b>0.19</b>	2.11	0.04
<b>Pacific Margin subregion</b>	0.00	<b>0.32</b>	0.79	0.00	<b>negl</b>	0.01	0.00	<b>0.32</b>	0.80	0.11
<b>Arctic subregion</b>										
Chukchi Shelf	0.00	<b>1.14</b>	4.48	N/A	N/A	N/A	0.00	<b>1.14</b>	4.48	0.05
Beaufort Shelf	0.72	<b>2.27</b>	4.44	N/A	N/A	N/A	0.00	<b>2.27</b>	4.44	0.14
Hope Basin	0.00	<b>negl</b>	0.00	0.00	<b>0.12</b>	0.00	0.00	<b>0.03</b>	0.00	0.04
<b>Bering Shelf subregion</b>										
Navarin Basin	0.00	<b>negl</b>	0.00	0.00	<b>0.04</b>	0.00	0.00	<b>negl</b>	0.00	<b>negl</b>
N. Aleutian Basin	0.00	<b>0.02</b>	0.20	0.00	<b>0.88</b>	7.71	0.00	<b>0.18</b>	1.77	0.13
St. George Basin	0.00	<b>negl</b>	0.00	0.00	<b>0.05</b>	0.00	0.00	<b>0.01</b>	0.00	0.02
Norton Basin	0.00	<b>negl</b>	0.00	0.00	<b>0.02</b>	0.00	0.00	<b>negl</b>	0.00	<b>negl</b>
St. Matthew–Hall	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E
<b>Pacific Margin subregion</b>										
Cook Inlet	0.00	<b>0.27</b>	0.71	N/A	N/A	N/A	0.00	<b>0.27</b>	0.71	0.30
Gulf of Alaska	0.00	<b>0.05</b>	0.30	0.00	<b>negl</b>	<b>negl</b>	0.00	<b>0.05</b>	0.30	0.04
Shumagin–Kodiak	0.00	<b>negl</b>	0.00	0.00	<b>negl</b>	0.00	0.00	<b>negl</b>	0.00	<b>negl</b>

*Economic Assumptions:* 1995 base year, \$18 per barrel oil price, \$2.11 per thousand cubic feet (MCF) gas price, 0.66 gas value discount, flat real prices and costs, 3% inflation, 12% discount rate, 35% Federal tax rate;

BBO, billions of barrels;

TCFG, trillions of cubic feet;

BOE, total oil and gas in billions of energy-equivalent barrels (5620 cubic feet of gas = 1 energy-equivalent barrel of oil).

Oil resources include crude oil and natural gas liquids (NGL). Gas resources include nonassociated dry gas and associated solution gas. All provinces analyzed on a stand-alone basis.

N/A refers to Not Available (lacking transportation infrastructure and/or market).

N/E refers to Not Evaluated because of very low resource potential.

Negl refers to negligible (less than significant figures listed).

E/C is ratio of risked, mean economically recoverable BOE to risked, mean conventionally recoverable BOE. Mean values for provinces may not sum to values shown for subregions and region because of rounding.

Among the provinces of the Arctic subregion, the sparsely explored Chukchi shelf offers the highest potential for undiscovered resources, with a 5% chance for recoverable oil resources as high as 21.94 BBO. Navarin Basin, because of its large size and abundance of large potential traps, offers the greatest potential of the gas-prone provinces of the Bering Shelf subregion. Among provinces of the Pacific Margin subregion, Cook Inlet offers the greatest potential for undiscovered oil.

Very small quantities of liquid hydrocarbons are reported in the assessments of Norton Basin, St. Matthew–Hall Basin and Shumagin–Kodiak Shelf provinces. These three provinces were modeled as offering potential for gas only. The volumes reported as oil are therefore actually natural-gas liquids or condensate derived as a byproduct of gas production.

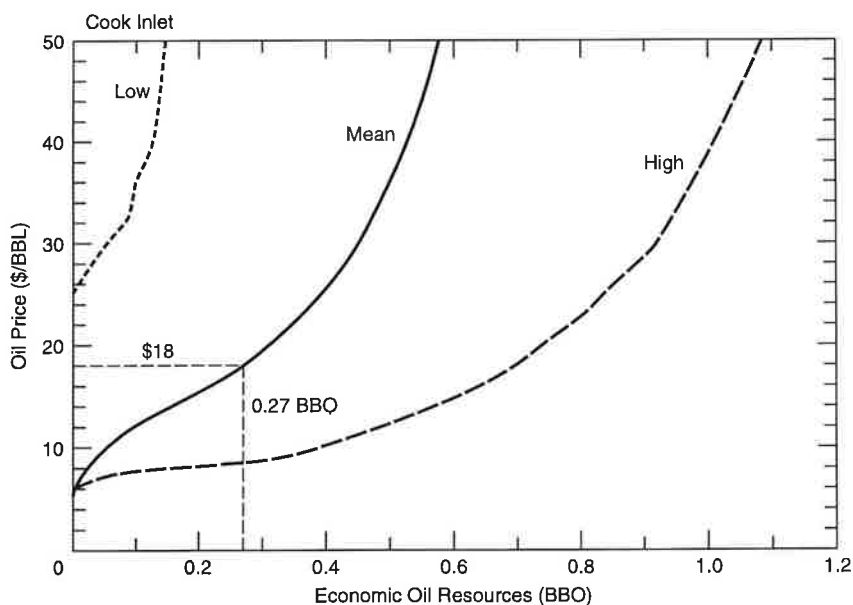
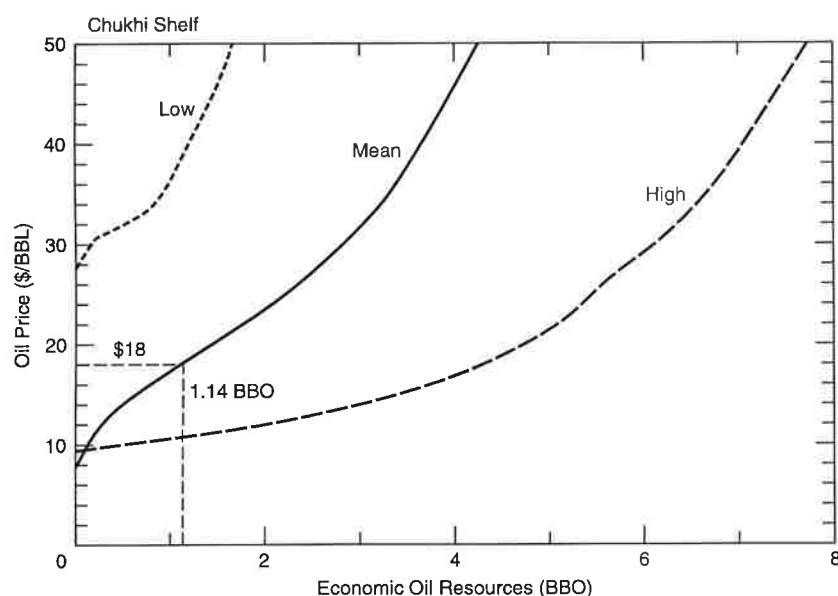
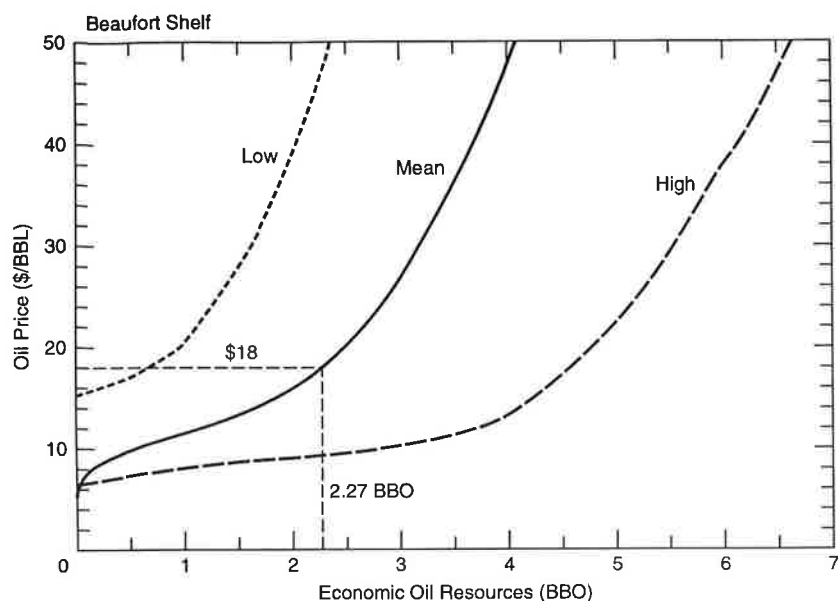
### *Undiscovered Economic Oil and Gas Potential of the Alaska Offshore*

The quantities of economically recoverable resources are generally some minority fraction of the much larger estimates for conventionally recov-

erable resources. Only 8.5% of the conventionally recoverable resources on a barrels-of-oil-equivalent (BOE) basis, or 15% of oil resources, are estimated to be economically recoverable at current oil prices.

Ninety-one percent of the economic oil of the Alaska offshore occurs in the Beaufort and Chukchi Shelf assessment provinces. (This refers to the risked, mean, undiscovered, economically recoverable oil at a price of \$18 per barrel.) The other nine provinces account for the remaining 9%.

Most of the undiscovered offshore gas also occurs in the Arctic, but none of this gas is considered economic at this time. No gas transportation system exists to carry gas from Arctic Alaska to a southern market, and several gas fields (about 28 trillion cubic feet of gas reserves) near the head of the existing oil pipeline transportation corridor already await development. These huge onshore gas fields will surely fill any newly constructed gas line for some years or decades following the commencement of production. Therefore, it is very unlikely that new offshore gas fields will be developed in the foreseeable future. For these reasons we conclude that the Beaufort and Chukchi Shelf assessment provinces offer no economic gas resources at the present time.



Other than the Beaufort and Chukchi Shelf provinces, only the Cook Inlet province is likely to contain economically viable oil resources at current prices. Although the geologic resources are modest compared to the Arctic, the proximity to existing infrastructure and potential markets contributes to reduced development costs in the Cook Inlet province. As in the Beaufort and Chukchi provinces, the economic assessment for the Cook Inlet considered only oil production, largely because all of the undiscovered accumulations were modeled as oil pools overlain by gas caps. To optimize oil recovery, produced gas would be reinjected for reservoir pressure maintenance and no gas would be extracted for sale from the gas cap. Only decades later, after exhaustion of the oil reserves, would offshore oil production platforms be converted to allow recovery of the gas reserves.

The remainder of the Alaska offshore provinces are generally gas-prone and lack production and transportation infrastructure. The small volumes of oil listed for most of the gas-prone provinces are largely condensate liquids recovered as a byproduct of gas production. Because potential markets are in the western Pacific Rim, the gas must be shipped to market as liquefied natural gas (LNG). The substantial costs of constructing an LNG infrastructure typically cannot be supported by the relatively small gas fields in these remote, high-cost locations. Of the gas-prone assessment provinces in the Bering Shelf subregion, the North Aleutian Basin is estimated to contain the majority—79%—of the economically recoverable gas of the entire Alaska offshore.

An indicator of the relative chances for economic success among the Alaska offshore provinces is the ratio of economically recoverable BOE (oil and gas combined) resources to conventionally recoverable BOE resources, known as the E/C value. The BOE E/C values range from 0.30 in Cook Inlet to negligible (less than 0.01) in the Navarin Basin. This suggests that many undiscovered pools in Cook Inlet are large enough to support relatively low-cost development, whereas the undiscovered hydrocarbon pools in the Navarin Basin, though large, are typically too small to support the relatively high costs of development in that remote area. The Navarin Basin offers essentially no economic potential, even though it offers the highest total geologic endowment outside the Arctic (1.59 BBOE). The BOE E/C ratios identify the Cook Inlet, Beaufort Shelf and North Aleutian Basin

*Price-supply curves for oil at low (F95), mean and high (F05) resource cases for the three provinces that offer economic oil at current (\$18) oil prices. Price-supply graphs for 10 Alaska offshore provinces are provided by Craig (1996).*

assessment provinces as those offering the highest reward/risk opportunities.

All provinces were assessed on a stand-alone basis, with no sharing of development infrastructure between adjacent provinces. For some provinces (Beaufort, Chukchi and Cook Inlet) at least some existing infrastructure was utilized for the simulated development of undiscovered fields. Otherwise, new infrastructure was constructed and entirely supported by production from each province in the economic models. Sensitivity tests, where several provinces shared infrastructure costs (for example, LNG facilities), generally resulted in improved economic viability. Despite shared infrastructure strategies, most of the gas-prone provinces nevertheless remain subeconomic at mean resource volumes and current commodity prices. However, in any of these subeconomic provinces, economic resources could be recovered from unusually large pools (less likely to exist than mean sizes) or at commodity prices above current levels.

Economic results are summarized in price-supply graphs produced by the PRESTO computer program. These graphs illustrate the volumes of resources that could be profitably recovered (if discovered) across a range of commodity prices. The three curves shown on each price-supply graph illustrate the range of risked economic potential, with exceedance probabilities ranging from 95% (low-side potential) to 5% (high-side potential). These estimates are risked, that is, they include both the geologic probability that resources are present and recoverable as well as the economic probability that the simulated development model leads to profitable production at the prices shown.

The Beaufort Shelf results for the low case (F95, or 95% probability for occurrence) predict that at least 0.72 billion barrels of oil (BBO) are economically recoverable at an oil price of \$18 per barrel. The high case (F05, or 5% probability) predicts an undiscovered economic potential (at \$18) of at least 4.44 BBO, or six times larger than the low case. The mean case represents the average or expected economic potential (2.27 BBO at \$18).

The ratio of economic to conventionally recoverable oil in the Beaufort Shelf province is 0.26, second only to Cook Inlet oil at 0.36. The Beaufort Shelf assessment province clearly offers good opportunity for future commercial developments at reasonable levels of risk.

The Chukchi Shelf price-supply curves support the widely held perception that higher prices will be required to overcome higher development costs in that remote and forbidding corner of the Arctic

#### Comparison of conventionally and economically recoverable oil.

<i>Resource type</i>	<i>Mean oil (BBO)</i>	<i>Mean gas (TCFG)</i>
<b>Beaufort Shelf Province</b>		
Conventionally recoverable	8.84	43.50
Economically recoverable (\$18)	2.27	N/A
Ratio economic/conventional	0.26	N/A
<b>Chukchi Shelf Province</b>		
Conventionally recoverable	13.02	51.84
Economically recoverable (\$18)	1.14	N/A
Ratio economic/conventional	0.09	N/A
<b>Cook Inlet Province</b>		
Conventionally recoverable	0.74	0.89
Economically recoverable (\$18)	0.27	N/A
Ratio economic/conventional	0.36	N/A

offshore. For example, in the low case (F95, or highly probable resource volumes), any commercial development in the Chukchi Shelf will require oil prices above \$27 per barrel (1995 dollars). A broad envelope surrounds the mean case, with a high case (4.48 BBO) nearly four times larger than the mean case (1.14 BBO) at \$18 per barrel. The high-case oil potential of the Chukchi Shelf (4.48 BBO) is nearly the same as the high-case potential for the Beaufort Shelf (4.44 BBO). However, the fraction of economic to conventionally recoverable oil for the Chukchi Shelf is 0.09, only about a third of that for the Beaufort Shelf (0.26), suggesting that commercial discoveries are much less likely in the Chukchi Shelf. Despite the large potential rewards, the comparatively low chance for economic success on the Chukchi Shelf, mostly owing to greater costs, must surely dampen exploration interest.

The mean case for Cook Inlet indicates 0.27 BBO of economic oil potential, much more modest than either the Beaufort (2.27 BBO) or Chukchi (1.14 BBO) shelf assessment provinces. The high-case potential for Cook Inlet exceeds 1.0 BBO at theoretical prices approaching \$50 per barrel. The ratio of economic to conventionally recoverable oil is 0.36, suggesting that a very significant fraction of the oil resources occurs in commercial-sized fields.

Eventual development and production of these modeled economic resources will require extensive exploration drilling programs. Given the low chance of commercial success in many provinces and the high cost of exploration wells, most of these provinces are not likely to be thoroughly tested for some decades. The few wells that may be drilled in these immense geographic areas may easily fail to locate the few commercial-sized pools. Estimates of economically recoverable resources should be viewed, therefore, as province-wide opportunities, rather than as readily available



reserves awaiting only a sufficient rise in oil prices to spark development work.

This summary of the economic assessment for the Alaska offshore has focused on provinces likely to have recoverable oil at current commodity prices. However, many Alaska Federal offshore provinces contain no economically recoverable resources at the mean level and current commodity prices. Future offshore leasing and exploration in these subeconomic provinces will be driven by perceptions of high-side potential, which assumes greater reward potential at higher risk, significantly higher prices and perhaps innovative technology to reduce development costs.

### *Comparison of 1987 and 1995 MMS Resource Assessments for the Alaska Offshore*

The 1995 MMS assessment of the Alaska offshore produced results very different from the last comparable study in 1987 (Cooke and Dellagiario 1989). The difference in results from the 1987 and 1995 surveys cannot be easily traced to some simple cause. Besides major amendments to the basic database, there were also numerous changes in methodology (new computer programs), definitions and quantitative economic assumptions. Each of these changes may have independently contributed to an increase or decrease in the estimates for oil and gas potential, with the contribution from any source differing in each assessment province. The changes observed between 1987 and 1995 assessments in any given province represent the net effect of all of these independent changes.

However, because it is only natural to compare assessments, we have tried to qualitatively identify some of the key differences in the databases driving most of the changes between the assessments. Estimates for risked, mean, undiscovered, conventionally recoverable resources for the Alaska offshore increased dramatically, from 1987 values of 3.84 BBO and 16.75 TCFG, to 1995 values of

24.31 BBO and 125.93 TCFG. The Chukchi Shelf and Beaufort Shelf provinces show the largest increase, and it is the database changes in these provinces that are primarily responsible for the overall increase in Alaska offshore resources (resource estimates actually declined in some other provinces). The increases in resource estimates in the Beaufort and Chukchi Shelf provinces result mostly from increases in the numbers of prospects and increases in the fractions of prospects believed to be "successful," or filled with recoverable petroleum. Estimates of the fractions of "successful" prospects that lie among the larger populations of prospects in plays are determined by risk. The fractions of successful prospects increased in 1995 because of a major shift in the risking philosophy that resulted in increased chances for success in most areas of play analysis. This effect is important here because we are comparing the risked estimates that were reported in 1987 and 1995. Potential oil and gas volumes are discounted by risk to reflect the chance that the province may fail to contain any (conventionally or economically) recoverable hydrocarbons, and statistically valid comparisons between provinces (or any other entities) must be made using risked volumes.

The increase in the number of prospects in all provinces is related to three factors: more seismic mapping; the addition of subeconomic prospects precluded from the 1987 study; and the inclusion in the inventory of mapped prospects of additional numbers of "speculative" prospects that have not yet been identified because of lack of data or other causes.

In 1995 a "success" was defined as any pool of hydrocarbons recoverable into a wellbore. This was done to help account for both the economic and subeconomic fractions of the total hydrocarbon endowment. This definition of success generally resulted in much higher overall chances of success at the prospect, play and province levels. A much more conservative risking approach was taken in the 1987 assessment, such that the general effect was the finding of smaller risked volumes of oil and gas.

Estimates for risked mean economically recoverable resources for the Alaska offshore increased dramatically, from 1987 values of 0.92 BBO and no (0.00) economic gas, to 1995 values of 3.75 BBO and 1.11 TCFG. The most significant increases among economic resources are the estimates for economic oil in the Chukchi Shelf and Beaufort Shelf assessment provinces.

The key geologic factors affecting the overall increase in economically recoverable resources are the increase in prospect numbers and the higher chances of success. However, the 1995 and 1987

#### **Comparison to previous MMS assessment, total Alaska Federal offshore, risked mean resources.**

<i>Assessment</i>	<i>Year</i>	<i>Oil (BBO)</i>	<i>Gas (TCFG)</i>
Conventionally recoverable	1995	24.31	125.93
Conventionally recoverable	1987	3.84	16.75
Economically recoverable	1995	3.75	1.11
Economically recoverable	1987	0.92	0.00

1987 data from Cooke and Dellagiario (1989, p. 34 and p. 43). BBO, billions of barrels of oil.

TCFG, trillions of cubic feet of gas.

economic results poorly reflect changes in the geologic models because the quantitative economic assumptions (discount rates, commodity price paths, etc.) used in the 1987 and 1995 computer studies are so different. Significant differences between the economic parameters used in 1987 and 1995 reflect the different financial climates of those times and include flat real prices (rather than ramped), revised costs, full-cycle analysis (includes exploration costs), revised discount and inflation rates, and revised gas discount factors.

The economic results for 1995 are more completely described by price-supply curves. In the 1987 assessment, only two economic cases, a "primary" case (\$18 per barrel oil price) and an "alternative" case (\$30 per barrel oil price) were reported (Cooke and Dellagiarino 1989). In the 1995 assessment, instead of just two cases, the price-supply curves report a spectrum of economic resources as continuous functions of commodity prices ranging from \$0 to \$50 (or more) per barrel. (At very high prices, perhaps greater than \$50 per barrel of oil, economically recoverable volumes approach the undiscovered conventional resources calculated by GRASP.) The price-supply graphs allow readers to devise their own present or near-term commodity prices and then find the potential economic resources offered at that price by an offshore province of interest. (Because the graphs are in 1995 dollars, future prices must be discounted to 1995 to use the graphs.) The price-supply curves provide a much more complete summary of the ranges of economic potential and highlight the high-risk, high-reward potential that actually attracts exploration investment in frontier areas.

## Conclusions

The Alaska Federal offshore is estimated to contain risked, mean, undiscovered, conventionally recoverable resources of 24 billion barrels of oil and 126 trillion cubic feet of gas. Approximately 90% of these resources occur in areas offshore of Arctic Alaska, specifically the Chukchi Shelf (13 billion barrels of oil, 52 trillion cubic feet of gas) and the Beaufort Shelf (9 billion barrels of oil, 44 trillion cubic feet of gas).

Most of the undiscovered oil and gas occurs in pools that are too small to justify economic development. Only about 15% of the conventionally recoverable oil resources could be profitably extracted at current oil prices. Three assessment provinces offer significant quantities of undiscovered, economically recoverable oil: the Beaufort Shelf (2.27 billion barrels), the Chukchi Shelf (1.14 billion barrels) and Cook Inlet (0.27 billion bar-

rels). These provinces might also offer economically recoverable gas under certain future conditions. However, the lack of transportation infrastructures designed for the export of liquefied natural gas may deter significant gas production from these areas, and from the greater Alaska offshore, for many years.

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# *Oil Resources and Federal Lands on the North Slope of Alaska*

*This article was prepared by Dave Houseknecht, U.S. Geological Survey, Reston, Virginia 20192, and Ken Bird, U.S. Geological Survey, Menlo Park, California 94025.*

For more than a decade the North Slope of Alaska has accounted for 20–25% of the Nation's domestic crude oil production. However, the average output from this prolific region peaked at about 2 million barrels per day in 1988 and has steadily declined to a present 1.4 million barrels per day. So significant is this decline that production from North Slope oil wells could fall below the minimum required for continued operation of the trans-Alaska pipeline within 10–15 years unless the trend of declining production is slowed or reversed.

Like a lit fuse the declining margin between daily North Slope production and minimum capacity for the trans-Alaska pipeline adds urgency to the Nation's most volatile debate between advocates of resource development and proponents of environmental protection in the one region of the U.S. that contains both huge onshore oil potential and vast pristine wilderness. The U.S. Geological Survey (USGS) is conducting geological research and assessing undiscovered oil and gas resources of the North Slope to provide Federal policy makers and land managers with scientific information on which to base decisions that will surely weigh heavily in this debate.

## *The Evolving Search for Oil on the North Slope*

The prodigious output of oil from Alaska's North Slope has flowed primarily from the Prudhoe Bay field, which was discovered in 1968 and has produced more than 9 billion barrels of oil since production began in 1977. Prior to the discovery of Prudhoe Bay, only about 50 exploration wells had been drilled on the North Slope, and only a few tiny oil and gas fields had been discovered, none of which were economic discoveries.

During the two decades following the discovery of the Prudhoe Bay field, a few hundred exploration wells were drilled on the North Slope and in State and Federal waters offshore. Although this exploration effort resulted in the discovery of several oil fields that would be considered huge by "lower 48" standards, only a few were large enough to be developed considering the harsh economic realities of operating on the North Slope. Four relatively large fields currently are producing:

- Kuparuk (discovered in 1969; 2.5 billion barrels of recoverable oil);
- Milne Point (1970; 220 million barrels);
- Endicott (1978; 600 million barrels); and
- Point McIntyre (1988; 340 million barrels).

Also producing are Prudhoe Bay satellite fields Niakuk (50 million barrels), North Prudhoe Bay (6 million barrels), West Beach (12–65 million barrels) and Cascade (50 million barrels). In addition, several fields, each containing oil reserves of 50–350 million barrels, await development should economic factors become more favorable.

The Trans-Alaska Pipeline System was completed in 1977, and crude oil from the North Slope started flowing southward immediately. As "satellite fields" around Prudhoe Bay were developed during the 1980s, the Trans-Alaska Pipeline System was extended from Prudhoe Bay westward as far as the Kuparuk field and eastward to the Endicott field.

Although exploration proceeded at a modest pace during the past decade, significant technological innovations in drilling, completing and operating wells have redefined the economics of North Slope oil exploration. In essence, these advances have reduced the minimum size of an oil accumulation that is now considered economically feasible to develop into a producing field.

The most tangible evidence of the changing economics of North Slope oil production is the recent announcement that a new oil field (Alpine) containing 250–300 million barrels of recoverable oil will be developed on the Colville Delta, just outside the northeastern boundary of the National Petroleum Reserve-Alaska (NPR-A). Plans were announced in 1996 to develop the Alpine field and to build an extension of the Trans-Alaska Pipeline System from Kuparuk to Alpine.

News of the Alpine field development, and particularly the economic feasibility of extending the pipeline system approximately 30 miles westward to produce oil from a field of this size, truly redefines the oil potential of the North Slope. These events heighten the likelihood that a number of fields discovered east of Prudhoe Bay also may prove to be of sufficient size to warrant development. These include Badami, Point Thomson and Flaxman Island, all located onshore or in State waters, and Hammerhead and Kuvlum, located in Federal waters. Although specific reserve esti-



mates are either vaguely defined or confidential, each of these fields likely contains at least 100–300 million barrels of recoverable oil. In addition, the Sourdough exploration well drilled near the northwestern boundary of the Arctic National Wildlife Refuge (ANWR) in 1994 has been classified as “capable of producing in paying quantities,” and the Stinson well, drilled in State waters near the northwestern corner of ANWR, apparently is an oil discovery but information remains confidential. It appears only a matter of time before an extension of the Trans-Alaska Pipeline System eastward from Endicott is proposed so that development of oil fields can proceed.

### Exploration on Federal Lands

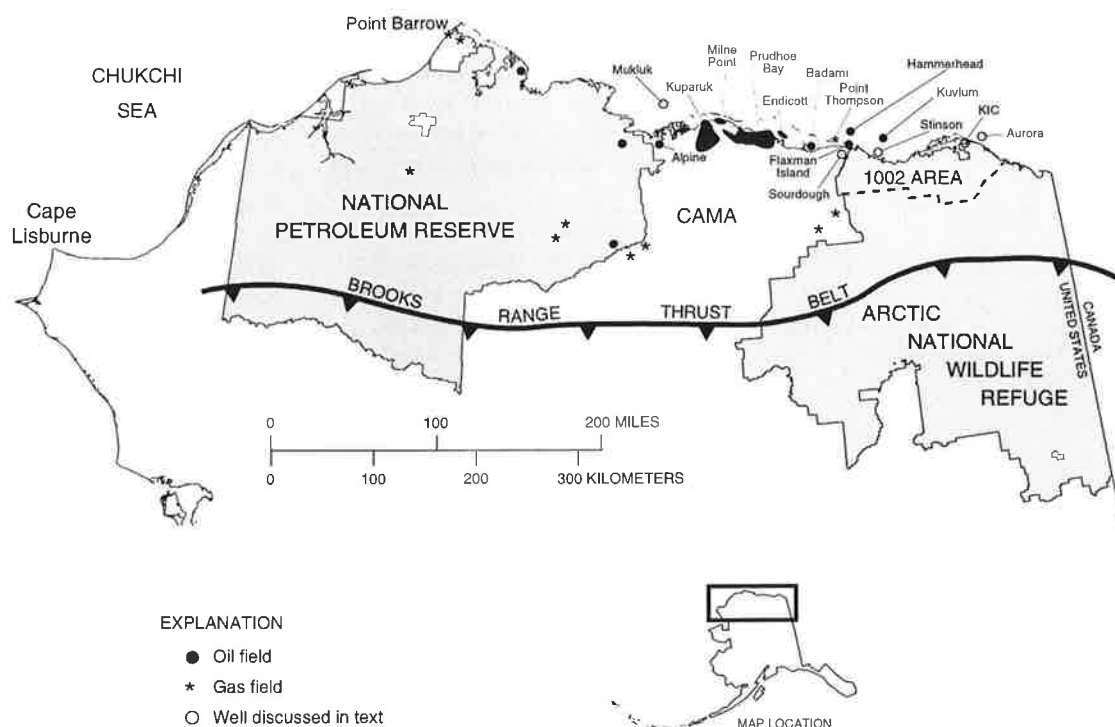
All North Slope oil production to date has been derived from areas under State jurisdiction, both onshore and offshore (the boundary between State and Federal stewardship for offshore areas is located three miles from the coast of the mainland). Areas under Federal stewardship have been tested to varying degrees. The NPR–A, an area the size of Indiana, was tested with 36 exploration wells and 45 core tests drilled by the Navy during an early appraisal effort from 1943 to 1953 and with an additional 28 exploration wells drilled by the Navy and the USGS during a second phase of Federal exploration from 1974 to 1982. The entire Federal exploration effort resulted in the discovery

of three sub-economic oil fields and several gas fields. Although natural gas fields are not economic on the North Slope, a few discovered during the Federal exploration were developed to provide a source of energy for local villages. Lease sales were held in NPR–A in the early 1980s, and a single exploration well was drilled by industry in 1985. That well was not successful.

The coastal plain (the 1002 Area) of ANWR has been of tremendous interest to the oil industry since its creation by the Congress in 1960 because it is considered to have the best potential to contain giant oil accumulations of all *onshore* areas of the U.S. Although the Congress permitted the collection of a large seismic data set during 1984–85, no lease sales or exploration drilling have been authorized by the Federal government, and the opening of the ANWR coastal plain to exploration is the subject of intense debate. The only onshore exploration well east of the Canning River, which forms the western boundary of ANWR, was drilled in 1985 on Native lands along the northern coast of ANWR; however, information regarding the KIC (Kaktovik Inupiat Corporation) well continues to be confidential, and there is no public knowledge of whether petroleum was encountered.

The Federal offshore area has been tested sparsely. The first exploration wells in Federal waters were drilled during the early 1980s as industry stepped out from Prudhoe Bay seeking to discover similar giant fields. In fact, an explora-

North Slope of Alaska, showing Federal lands, State lands (CAMA = Central Arctic Management Area), locations of selected oil and gas fields, and locations of specific wells discussed in text.



tion well drilled in Federal waters in 1983, the Mukluk, to test a geologic structure considered to be a Prudhoe Bay "look-alike" holds the dubious distinction of being the world's most expensive dry hole. The Mukluk well, drilled at a cost of \$120 million, encountered a favorable reservoir but only traces of oil. One well drilled in Federal water in 1988 is particularly important because of its proximity to the ANWR coastal plain; however, the Aurora well failed to encounter petroleum in more than trace amounts. A number of exploration wells have been drilled in Federal waters offshore from ANWR. At least two of these tests (Hammerhead and Kuvlum) discovered oil, although the reserves appear to be marginally economic, particularly considering the expense of developing offshore fields.

### *Increasing Interest in Federal Lands*

Two main factors are placing increased emphasis on the availability of Federal lands for oil exploration on the North Slope. First, industry has tested the most promising oil prospects in areas that have been available through lease sales (mostly State lands and waters plus the Federal offshore) and are now seeking access to lands that have not been available. No lease sale has been held in the NPR-A for nearly 15 years. Significant innovations have been made in geological science (for example, sequence stratigraphy), exploration technology (for example, seismic data processing) and drilling technology (for example, directional drilling from pads constructed of ice) during that time, and it is likely that these advances will cast a new light on the oil potential of the NPR-A. The ANWR coastal plain has always been off limits to exploratory drilling under Federal law, so the oil potential of that promising area has never been tested (except for the KIC well).

Second, the recent reduction in the size of an oil field that is considered economic to develop on the North Slope has already started to result in expansion of the existing infrastructure. The

announced extension of the Trans-Alaska Pipeline System westward to the doorsteps of the NPR-A and the possibility of an eastward extension to the threshold of the ANWR coastal plain significantly redefines the economic feasibility of exploration on those Federal lands. Clearly requests to the Federal government to make those lands available for exploration have been increasing during the past few years, and this trend is likely to continue.

### *USGS Information as a Scientific Basis for Decision Making*

As part of its mission to evaluate the energy resources of the Nation, the USGS periodically conducts an assessment of the oil and natural gas resources of the onshore and State water areas of the United States. In February 1995 the USGS released the results of the most recent oil and gas assessment, an intensive four-year study. The Minerals Management Service (MMS) conducts a parallel study of the oil and gas resources of Federal offshore areas.

Based on the results of the latest USGS national assessment of oil and gas resources (released in 1995), the North Slope of Alaska is believed to have the greatest oil potential of any onshore area of the U.S. Pertinent information from that national assessment has been provided to Federal policy makers and land managers to support pending decisions regarding a lease sale in the NPRA.

The USGS also is conducting an intensive re-examination of the geology and petroleum potential of the eastern North Slope, which includes the ANWR coastal plain. The objectives of this work are to produce the most up-to-date and comprehensive analysis of the oil and gas potential of the ANWR coastal plain and to produce a digital base of information that will facilitate policy and land-use decision making by the Federal government. This information also will be useful to State agencies, industry and environmental organizations involved in evaluating the competing demands for use of Federal lands on the North Slope.

# Monitoring Lead and Other Contaminants in Arctic Waterfowl

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The Alaska Science Center (ASC) has been engaged in waterfowl research on the Yukon-Kuskokwim (Y-K) Delta since the early 1980s. The primary focus of ASC research has been on declining populations of geese and seaducks managed by the U.S. Fish and Wildlife Service (FWS). Priorities for research on the Y-K Delta are established through coordination with the FWS in Region 7, Anchorage. The FWS provides funding for ASC research and conducts companion surveys and studies through the divisions of Migratory Bird Management and Refuges.

Waterfowl that nest in and migrate through the highly productive Y-K Delta are an important source of protein for indigenous Yupik Eskimos, especially in the spring when their food resources are usually low. In the 1970s, dramatic population declines in four species of geese that nest on the Y-K Delta prompted wildlife agencies from

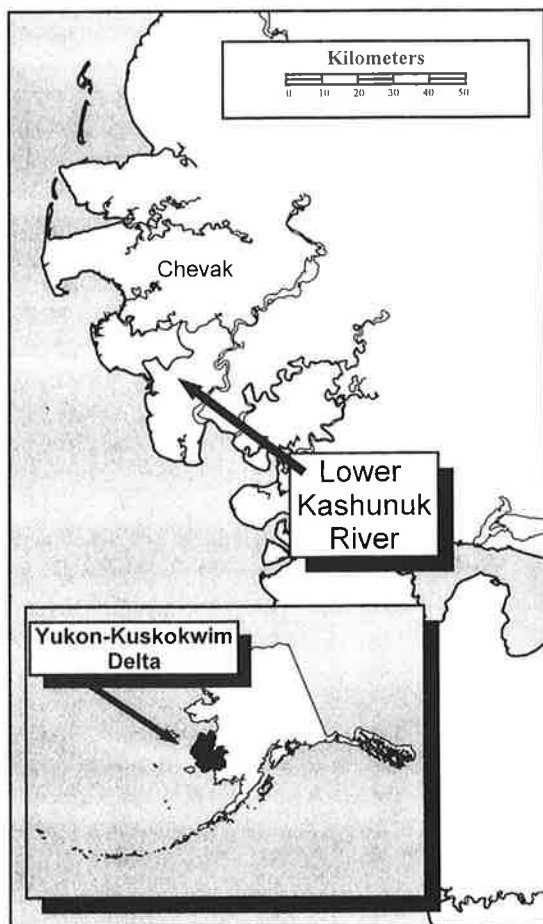
Alaska, Washington, Oregon and California to form an alliance with local Yupik people to improve management and increase waterfowl populations so that hunting could be resumed.

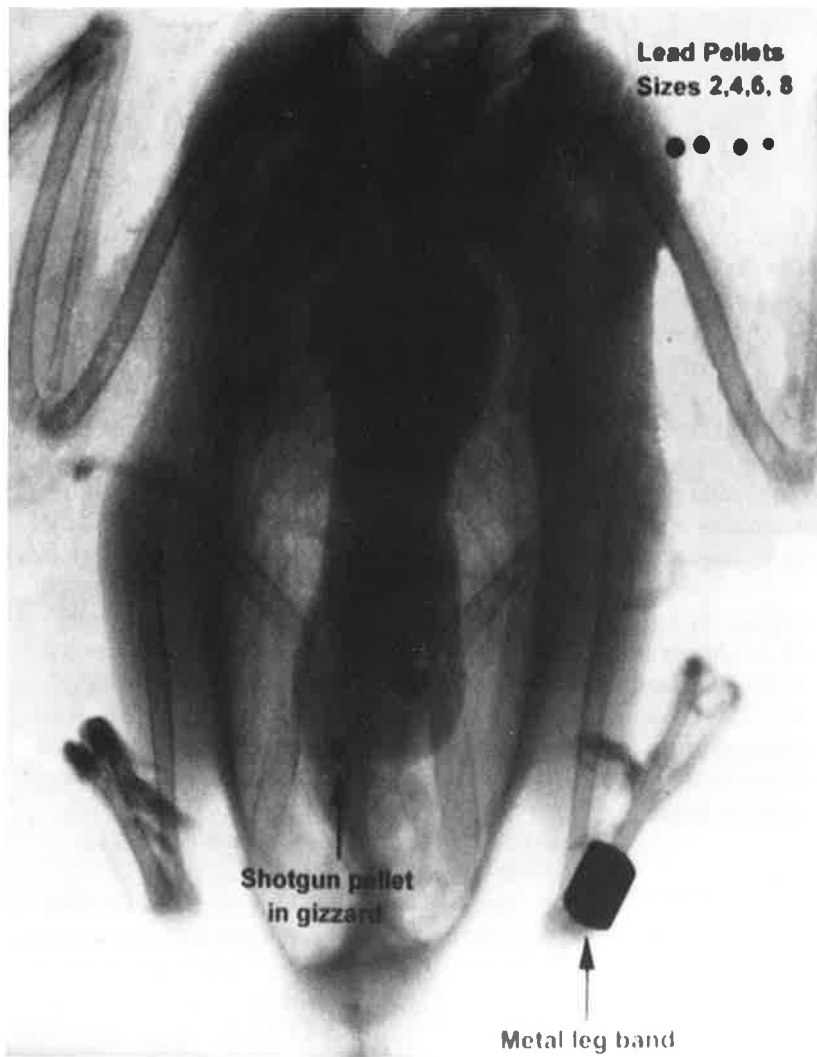
More recently FWS and ASC biologists working on the Y-K Delta documented a major, sustained decline in nesting spectacled eider ducks. The spectacled eider population nesting on the Y-K Delta declined from 50,000 pairs in 1971 to about 1,700 pairs in 1992. The FWS reviewed all available information about spectacled eiders and in 1993 listed the species as threatened under the Endangered Species Act. A recovery team was established that included expertise in spectacled eider and population biology, marine ecology, Native Alaskan culture and wildlife management. The recovery team developed a plan that, among other components, identified research necessary to evaluate potential causes for the nearly 96% decline in the nesting population on the Y-K Delta.

The ASC initiated studies of spectacled eider reproductive ecology, adult and duckling survival, habitat associations, and post-nesting distribution on the Y-K Delta in 1992. During the field work in 1992–1994 ASC and FWS biologists discovered a few spectacled eiders and closely related common eiders that were dying. These birds were examined by scientists at the National Wildlife Health Center (NWHC) in Madison, Wisconsin. The necropsies and analysis of blood and tissue samples showed that lead poisoning was the cause of death. Lead shot was recovered from the lower esophagus of one spectacled eider and the gizzard of a common eider. Lead concentrations were 26–38 ppm wet weight in the livers of the spectacled eiders and 52 ppm wet weight in the liver of the common eider, levels considered toxic in waterfowl. These were the first records of lead poisoning in spectacled eiders, and it signaled the need to focus research on this potential limiting factor.

Sampling of spectacled eiders for evidence of exposure to lead was expanded to include important nesting and brood-rearing habitats along the Kashunuk River near the village of Chevak. Female spectacled eiders were trapped on their nests 0–5 days before hatch, and broods were captured in ponds using mist nets. Adult female greater scaup, common eiders and oldsquaws were also captured to compare lead exposure rates

*Alaska Science Center study  
areas along the Kashunuk  
River in western Alaska.*





*X-ray made in the field with a portable machine. Note the presence of a single shotgun pellet in the gizzard of this adult female spectacled eider. The bird was released after the x-ray was made.*

among species. Blood samples were analyzed for lead using atomic absorption spectrophotometry; concentrations of 0.2 ppm or higher were considered evidence of exposure to lead above normal background levels. Additionally a sample of birds was examined in the field with a portable x-ray machine to identify ingested shot. Although the Kashunuk River corridor is an important subsistence hunting area for residents of Chevak and neighboring villages, the results of the lead analysis were unexpected, considering the large number of ponds and lakes in the area. Shot was detected in the gizzards of 11.6% of spectacled eiders x-rayed. During the period from arrival through incubation, 13.0% of adult females and 6.6% of adult males had elevated blood lead levels when captured. During the brood rearing period, 35.8% of adult females and 12.2% of ducklings were exposed to lead when captured.

An important finding was that adult females that had been in the area longer were more likely to have been exposed. Logistic regression was

used to assess the probability of exposure to lead in relation to date of capture for adult females. This analysis predicted that 50% of the successful breeding hens were likely exposed to lead, and 25–35% of the spectacled eider breeding population was exposed to lead.

Exposure rates of greater scaup (less than 5%) were significantly lower than for spectacled eiders. Common eiders and oldsquaws had exposure rates of 12% and 20%, respectively. These differences in exposure rates among species are likely related to differences in foraging behavior. Greater scaup feed in large sloughs and rivers on the Y–K Delta, where lead shot availability may be reduced by sedimentation and tidal action. By comparison, eiders and oldsquaws forage in small ponds where lead shot may persist for many years.

The ASC initiated “seeding” experiments in tundra ponds on the Y–K Delta to better understand how long lead shot may be available to waterfowl. Preliminary results after two seasons show that there is very little downward movement of shot through pond sediments, perhaps because of the presence of permafrost and the shallow active layer during the relatively short summer.

The high level of exposure to lead in spectacled eiders nesting along the Kashunuk River established the need to assess exposure levels throughout their breeding range on the Y–K Delta. Therefore, in 1995 the ASC and FWS consulted with Yupik Eskimo elders, area Native corporations, and individuals that own lands on the Y–K Delta about the results from the Kashunuk River and the desirability of understanding the geographic extent of lead poisoning in Y–K Delta waterfowl. Accordingly the ASC proposed a sampling protocol for most of the spectacled eider nesting habitat on the Y–K Delta. A total of 107 one-square-mile plots were examined with the aid of a helicopter, resulting in 142 blood samples. The blood samples were collected with the field assistance of a Yupik village corporation member who accompanied the principal investigator during surveys on Native-owned lands. Analyses of these data are in progress and will be comparable to data from the Kashunuk River, as well as spectacled eider blood samples ASC biologists collected from the only other nesting areas along the coast of Siberia and the North Slope of Alaska. As expected, preliminary results from the Prudhoe Bay area in Alaska show no evidence of lead exposure in spectacled eiders.

The discovery of lead poisoning in Y–K Delta ducks encouraged the FWS to fund the ASC and NWHC to evaluate exposure in emperor geese, a grazing species that has declined by about half their historic population. In 1996, blood samples





*Nasal-marked female  
spectacled eider ready for  
release.*

were collected from 235 emperor geese along the Kashunuk River. No lead was detected in 82% of the birds sampled, and 17% had blood lead concentrations at normal background levels. Only one bird had a blood lead concentration that was within the range considered toxic for waterfowl. Although more sampling would be desirable, it appears that emperor geese are less likely to consume lead pellets during feeding in upland areas than diving ducks do while foraging in Y-K Delta wetlands.

The results of research on lead poisoning in the threatened spectacled eider and exposure in other ducks on the Y-K Delta stimulated a cooperative

effort between wildlife agencies, Native groups and local residents to examine management alternatives that will enhance waterfowl survival rates and increase nesting populations. The Alaska Department of Fish and Game and the FWS have sponsored workshops and clinics in Y-K Delta villages to discuss the problem of lead poisoning in waterfowl from spent shot and to train local hunters how to use non-toxic steel shot effectively.

Recognition of the importance of lead shot as a factor limiting the recovery of spectacled eiders on the Y-K Delta has resulted in funding to monitor other heavy metals known to be toxic to waterfowl. ASC researchers have recovered over 100 dead eggs from spectacled eider nests on the Y-K Delta over the past few years. The number of addled eggs is much higher than in other ducks studied on the Y-K Delta and is cause for concern. Exposure to heavy metals has been linked to low hatchability in eggs of some species of ducks; however, there is little information available regarding the rates or effects of exposure on reproduction by eiders and other seaducks. Exposure to selenium is potentially lethal to adult waterfowl and may impair survival of eggs and ducklings. Mercury exposure may also result in lower reproductive success and poor survival in ducks. In 1996 the ASC and NWHC began work to evaluate these eggs and blood samples from adult females for the presence of selenium, mercury, cadmium and arsenic.

# Global Partnership Workshop

## Connecting the Russian Arctic to the Russian Far East

*This report was prepared by  
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On June 14 and 15, 1996, 42 Japanese, Korean, Russian and American representatives from academia, industry, government and nongovernmental organizations met in Niigata, Japan, to discuss issues related to radioactive waste treatment, storage and disposal. A key theme of the meeting was that existing cooperation and solutions to radioactive waste problems in the Arctic could be applied to similar problems in the Russian Far East. The meeting was titled "Global Partnership: A Multi-National Workshop on Nuclear Waste in and around the Sea of Japan, Sea of Okhotsk, and the North Pacific." The workshop was organized by the U.S. Geological Survey on behalf of the Inter-agency Arctic Research Policy Committee, the Center for International Security Studies of Mississippi State University, and the Center for United States-Japan Studies and Cooperation at Vanderbilt University. In-country support was provided by the Economic Research Institute for Northeast Asia, located in Niigata. The workshop was supported by the U.S. Navy Office of Naval Research's Arctic Nuclear Waste Assessment Program, the Japan Foundation Center for Global Partnership, the Japan-United States Friendship Commission, Babcock and Wilcox Company, Mitsubishi International Corporation, and Toman Corporation.

The Niigata meeting was the follow-on to a January 12-13, 1995, workshop, held in Biloxi, Mississippi, titled "Japan-Russia-United States Study Group on Dumped Nuclear Waste in the Sea of Japan, Sea of Okhotsk, and the North Pacific Ocean." (The proceedings of the Biloxi workshop were published in the Fall/Winter 1995 issue of *Arctic Research of the United States*.) At the Biloxi workshop, participants from government and industry from Japan, Korea, Russia and the United States discussed the history of, and possible environmental consequences resulting from, the ocean dumping of nuclear waste in the Asian eastern marginal seas and the northwest Pacific Ocean. In Niigata the focus progressed to solving the complex problem of radioactive and toxic waste storage and management. Many of the participants who came to Niigata were also in Biloxi. Their familiarity with each other assisted greatly in enhancing mutual understanding of national environmental concerns.

One theme—how international cooperation in the Arctic reduced the volume of low-level liquid

radioactive waste—surfaced many times. Many speakers, including Norwegian Embassy First Secretary Gerd Peterson, described specific aspects of this cooperation and suggested how Arctic successes could be implemented in the Far East. The first day's plenary session concentrated on policy formulation issues. The second day was reserved for discussing new opportunities for technical cooperation and information sharing. Yoshiaki Hasagawa, Mayor of the City of Niigata, opened the workshop and stressed the importance of the meeting for the conservation of the environment for the human race. Michael E. Kokeev, Director of International Scientific and Technical Cooperation at the Russian Federation's Ministry of Foreign Affairs, reiterated Russian President Boris Yeltsin's pledge, made at the April 19-20, 1996, Moscow Summit, that by the end of 1996, his country would formally accede to the London Convention, which banned radioactive waste dumping at sea. Teruyoshi Inagawa, Deputy Director-General of the Arms Control and Scientific Affairs Bureau of the Japanese Foreign Ministry, expressed great satisfaction for Russian adherence to this 1993 accord. The Chairman of the American delegation, William A. Nitze, Assistant Administrator for International Activities at the Environment Protection Agency, was also gratified that at the 1996 Moscow Summit, President Yeltsin advised Japanese Prime Minister Hashimoto about Russia's commitment to permanent cessation of all dumping of radioactive waste in the Sea of Japan.

Nitze outlined his vision for continued cooperation with Japan and Russia. He drew attention to the urgency of finding solutions to the management of radioactive waste in and around the Russian coastline. Nitze expressed hope that the Niigata workshop can provide a springboard for broader international cooperation between Russia and both its Arctic and western Pacific neighbors, particularly Norway, Japan and the United States. Expanded international cooperation would allow a wider range of environmental security problems, derived from the legacy of the Cold War era, to be addressed.

Nitze's remarks prompted Valery A. Danilian, Chief of the Russia's Pacific Fleet Chemical Service, to appeal for international assistance and cooperation in reducing the volume of high-level waste remaining in the Russian Far East. In the

Russian Arctic, a well-established system of interrelations already exists between Russia, Norway and the United States for expanding radioactive waste treatment, he said. But in the Primorsky Kray and Kamchatka, the Russians must deal with a similarly grave problem alone.

The Far East government's interest in cleaning up the environment was underlined by E.S. Stomatyuk, Chairman of the Primorsky Kray Committee on Natural Resources. He frankly admitted that a difficult situation occurred in the Far East after the prohibition of dumping of radioactive waste into the seas was implemented in 1993. Since then, increasing quantities of radioactive waste have created hazardous situations in and around navy bases where decommissioned submarines, many with spent nuclear fuel and radioactive reactor cores, are stored. As did previous speakers, Chairman Stomatyuk urged international cooperation for dealing with radioactive waste disposal. In addition he suggested undertaking a feasibility study for creating storage facilities for radioactive waste in Primorsky Kray.

Several speakers described a Japanese-sponsored, United States-designed floating treatment plant, informally known as "the floating barge." When completed in mid-1997, it will travel to a number of sites where Russian nuclear submarines are being decommissioned and dispose of low-level liquid waste.

During the closing session, ten recommendations were presented:

1. Hold a specialized workshop to establish a Japanese Data Node for the International Arctic Environmental Data Directory (ADD). The focus of the Japanese node would be radioactive waste and the marine environment of the Sea of Japan, the northwest Pacific Ocean and the Sea of Okhotsk. (The Japanese delegation promised to study the ADD and host a workshop to begin the cooperative process.)
2. Establish a joint expert group to visit radio-

active waste storage sites in the Russian Far East and in the U.S.

3. Investigate potential financial support from the International Monetary Fund and other international financial institutions for processing and storing Russian radioactive waste.
4. Discuss opportunities for technical and scientific cooperation on sorbent technology and development of a processing methodology for solid radioactive waste arising from the concentration of liquid waste.
5. Conduct a joint Russian-Japanese-American feasibility study for developing options for the disposal of nuclear waste (low level and high level) from Russian submarines in the Vladivostok area.
6. Establish an international commission, working jointly with Global Legislators for a Balanced Environment (GLOBE), to assess the problems of waste storage in Russia on a national and regional level.
7. Study other solid waste storage problems, including volume, improved stable waste forms and better containment systems.
8. Carry out joint investigations on the effects of radioactivity on the marine environment in the northwest Pacific region, the Sea of Japan and the Sea of Okhotsk, including the coastal zone.
9. Include the U.S. in existing environmental assessment activities.
10. Seek funding for a joint U.S.-Russian-Japanese-Korean-IAEA (International Atomic Energy Agency) expedition to study the ecological situation in Peter the Great Bay.

In conclusion, participants agreed that these recommendations should be the starting points for continued interaction and possibly a new workshop. The date, location and financing of a follow-up workshop are being studied. Chairman Stomatyuk suggested that the next workshop be held in Vladivostok.

# Apical Predators in the Arctic Marine System and Potential Radioactive Contamination

## Walrus and Polar Bear

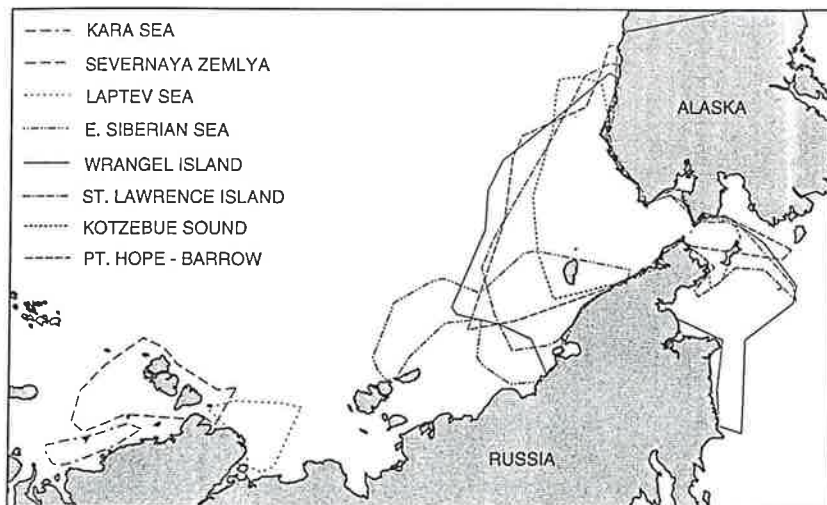
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The Alaska Science Center has conducted research on the ecology of polar bears and Pacific walruses in western Alaska since 1985. The initial effort on polar bears was in Alaskan waters but was expanded into the Chukchi Sea of eastern Russia in the early 1990s after satellite tracking data indicated that the western Alaskan population of polar bears was shared with Russia. Recently the cooperative U.S.-Russian polar bear research program was further extended to the Laptev, Kara and Barents Seas in western Russia to define population bounds and examine the use of sea ice habitats by polar bears in these regions. This research is also cooperative with Norwegian scientists. The research on Pacific walrus was cooperative between U.S. and Russian cooperators, and efforts during the late 1980s were focused on refining existing population survey methods to account for various biases. Current research on Pacific walrus focuses on the feeding ecology of walruses in Bristol Bay and developing suitable telemetry technology for use in a future study of industrial disturbance to walruses in ice edge habitats of the Chukchi Sea.

### *Polar Bear and Walrus Populations*

*Polar bear population areas  
in western Alaska and  
Russia identified by  
satellite telemetry.*

Satellite telemetry data from adult female polar bears captured in western Alaska and eastern Russia indicate extensive movements between the Chukchi Sea and the Bering Seas in both areas.

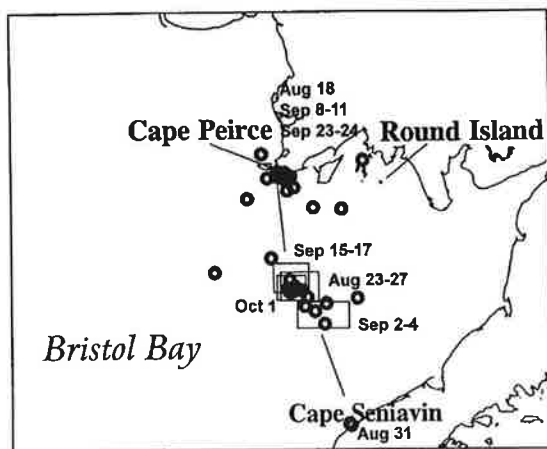


The majority of maternal denning for this population occurs on Wrangel and Herald Islands and the northern coastline of the Chukotka Peninsula in Russia. Maternal denning has been rarely documented along the coastline of western Alaska. Annual movements of individual adult females are extensive, with minimum distances traveled of 4,000–6,000 km and areal extents of 300,000–600,000 km<sup>2</sup> common. Satellite data from western Russia (the Laptev, Kara and Barents Seas) indicate a more limited pattern of movement that is closely associated with seasonal variations in the distribution of sea ice. In all cases, adjacent populations of polar bears exhibit movement between adjoining populations.

The walrus is holarctic in distribution and comprises at least six apparently geographically isolated populations around the Northern Hemisphere, including one population in the Bering and Chukchi Seas. The Bering and Chukchi walruses are regarded as the Pacific walrus, and walruses within the other regions are regarded as the Atlantic walrus. The Pacific walrus frequents the waters, ice and coasts of the Russian and U.S. Bering and Chukchi Seas. The seasonal distribution of the Pacific walrus population is generalized primarily from a compilation of reports of sightings from land, ships and aircraft. Because walruses prefer to haul out onto ice to rest, their distribution is strongly influenced by the seasonal distribution of pack ice. In winter, females and young migrate southward from the Chukchi Sea with the developing pack ice to join adult males in the Bering Sea. In spring, females and young migrate back to the Chukchi Sea, where they spend the summer, while most adult males remain behind in the Bering Sea. The males summer in Bristol Bay, Alaska, and at Big Diomedes and Arakamchechen Islands, on Rudder and Meechken Spits, and possibly along the southern Koryak coast and in the northern Karagin Gulf of Russia.

The Alaska Science Center has used radiotelemetry since the mid-1980s to track the movement of walruses. More recently, satellite transmitters and short-range VHF transmitters were deployed on adult male walruses in Bristol Bay to understand the importance of walrus movements in population assessments and to identify summer feeding areas

*Preliminary location information from a single tagged walrus within Bristol Bay. Dots indicate individual locations of the animal, and boxes indicate the general location of probable feeding bouts.*



that may be important to their survival. Most walrus were tracked from one to three months while they moved between haulouts and feeding areas at sea. Several feeding areas were identified, including one in the middle of Bristol Bay.

### *Apical Predators and Radioactive Contamination*

Russia, Norway and the United States share a number of biological resources of the Arctic Ocean, including the holarctic polar bear and walrus, both apical carnivores in the Arctic marine ecosystem. Radioactive contamination of the Arctic Ocean from Russian military nuclear tests sites on Novaya Zemlya has been reported (for example, in the Kara and Barents Seas), and riverine inflow from other inland Russian military and industrial centers may contain radioactive contaminants. This contamination may impact not only site-specific biological resources of Russia, but also critical biological resources of Arctic and sub-Arctic regions of the United States and Norway, either through transport by currents or through bioaccumulation in apical predators of the marine ecosystem and subsequent transport of the contaminants by extensive movements of contaminated predators. Ongoing cooperative research activities of American, Russian and Norwegian scientists have documented that several populations of both walrus and polar bears move extensively between the three countries. A pilot study was recently completed with Russian and Norwegian cooperators on using analyses of teeth enamel to determine historic exposure of polar bears to radiation.

The environmental community has expressed concern that the radioactive contamination of the Russian Arctic will spread throughout the Arctic. Polar bears and walrus can function as unique biological indicators of radioactive contamination in the Arctic because of their extensive movement

patterns, their potential for accumulating radioactive pollutants from military activity in western Russia, and their potential to act as biological transport mechanisms as they move between the Arctic regions of Russia, Norway and Alaska and into sub-Arctic zones of the Bering Sea. Polar bears are at the top of the marine pelagic food chain, feeding primarily on seals, while walrus are a top predator on the benthic food chain and may more directly integrate radioactive contaminants from contaminated benthic food sources. Therefore, these two species can serve as biological indicators for two distinct marine food chains and provide independent windows for delineating pathways of radioactive contamination and subsequent monitoring of these contaminants in the Arctic environment.

The Alaska Science Center has completed research that suggests that twelve sites representing four groups of polar bears and walrus in Alaskan, Russian and Norwegian waters could be studied to monitor relative radionuclide loads and to examine transport potential. Bears of eastern Alaska would serve as controls since they rarely move into Russian waters believed to be contaminated by radionuclides. Walrus at the Round Island Haulout and north Kamchatka Haulout Complex do not move through the Bering Straits and represent animals with the least likelihood of direct exposure to radionuclides. Western Alaska and Wrangel Island animals show significant movement patterns and would have the greatest likelihood of transporting contaminants of concern into U.S. waters. East Siberian and Laptev Sea walrus and polar bears have relatively restricted movement patterns and would likely show the most impacts from site-specific exposure. The existing cooperative work, primarily with Norwegian scientists at the Norsk Polar Institutt and Norsk Zoologisk Museum and Russian scientists at the All-Russia Research Institute for Nature Conservation and the Russian Academy of Sciences, is located in the area of the highest concentration of suspected radionuclide contamination and represents the immediate exposure areas of the Barents and Kara Seas.

The need for a research program to define pathways that exist for movement of radioactive contaminants resulting from past Russian military activity in western Russia is apparent. Future cooperative international research on the apical predators of the Arctic will determine the extent of existing radioactive contamination in two separate marine food webs by examining the bioaccumulation of these radionuclides in top marine predators. The project would also delineate the area of concern for monitoring radioactive contamination from Russian military activity in the western Arctic of Russia.



# Polar Bear and Pacific Walrus Bilateral Conservation Agreements Between the U.S. and Russia

*This report was prepared by David McGillivray, Scott Schliebe and Dana Seagars of the U.S. Fish and Wildlife Service, Marine Mammals Management Office, 1011 E. Tudor Rd., Anchorage, Alaska 99503.*

The U.S. Fish and Wildlife Service (FWS) is working on two major international conservation initiatives with Russia. These initiatives—a proposed bilateral conservation agreement for the shared population of polar bears and another proposed bilateral conservation agreement for the shared population of Pacific walruses—have been discussed for many years. However, the need for these conservation agreements and the effort being expended to develop them has increased significantly in recent years. Following the break-up of the U.S.S.R. in 1992, Russia entered into a free market economy. As a result, there are reports of increased illegal hunting and sale of wildlife parts in Russia.

On April 30, 1994, President Clinton signed amendments to the Marine Mammal Protection Act. Section 113(d) states "...the Secretary of the Interior, acting through the Secretary of State and in consultation with the Marine Mammal Commission and the State of Alaska, shall consult with the appropriate officials of the Russian Federation on the development and implementation of enhanced cooperative research and management programs for the conservation of polar bears in Alaska and Russia..." Since Pacific walruses are also shared with Russia and this population shares many of the same conservation issues as do polar bears, the FWS has proposed a separate similar agreement for walruses.

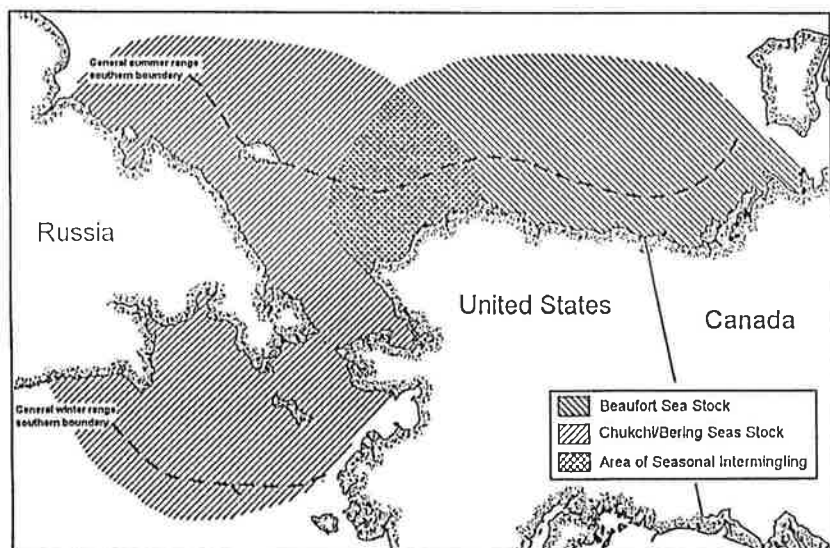
Protocols of Intentions between the U.S. and Russia were signed for the shared population of

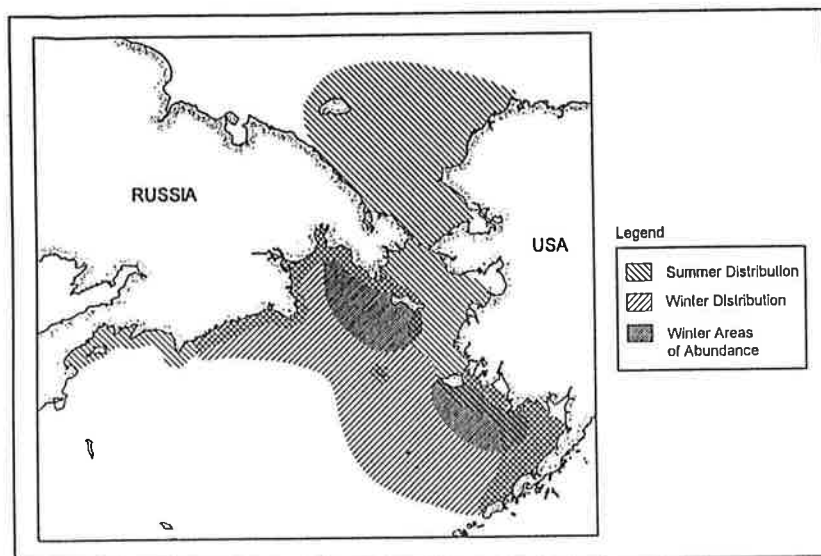
Pacific walruses in Nome, Alaska, and in Petropavlovsk, Kamchatskiy, Russia, in September 1995. During the talks in Russia, Native-to-Native discussions were held, and in June 1996 a draft Native-to-Native agreement was agreed to by indigenous people of both sides. Walrus and polar bear talks have progressed at a different pace, with progress on a polar bear agreement now about a year further along. Walrus talks are expected to follow as the polar bear agreement proceeds toward completion.

Discussions regarding development of a unified management approach between Russia and the U.S. for the shared Alaska-Chukotka polar bear population were initiated in Sochi, Russia, in October 1988 at the International Union for Conservation of Nature and Natural Resources (IUCN) Polar Bear Specialists Group Meeting. Further talks occurred in May 1990, and correspondence supporting the development of a bilateral agreement followed. Between 1992 and 1995, Protocols of Intentions were developed between natural resource agencies of the respective countries and the Native users of Alaska and Chukotka. During this period numerous discussions between FWS and Native representatives occurred on the possible development of a government-to-government conservation agreement and a companion Native-to-Native agreement. In April 1994 a "Protocol of Intentions Between the Indigenous People of Chukotka and Alaska on the Conservation, Protection, Management, and Study of the Bering and Chukchi Seas Shared Polar Bear Population" was signed by indigenous people on both sides.

In 1996 the FWS prepared a draft Environmental Assessment (EA) on the proposed "Development of a U.S./Russia bilateral agreement for the Conservation of Polar Bears in the Chukchi/Bering Seas." This document, developed in coordination with the

*Distribution and range of Chukchi/Bering Sea and Beaufort Sea stock of polar bears.*





*Distribution and range of the Pacific walrus.*

Department of State, Alaska Department of Fish and Game, Alaska Nanuq Commission, National Audubon Society, Department of the Interior's Solicitor's Office, North Slope Borough, Inuit Circumpolar Conference, and RurAL CAP, provided the mechanism for public review and comment on the proposed bilateral agreement for polar bears. Public meetings were held in Anchorage, Alaska; Washington, D.C.; and several villages along the coast of Alaska. A final EA was expected to be completed in early 1997.

The preferred alternative of the EA is the development of a government-to-government agreement with a companion Native-to-Native agreement. The government-to-government agreement provides an organizational framework and support for the Native-to-Native "implementation" agreement on subsistence harvest management. An international joint commission would be established to provide the coordination and consultation necessary for carrying out the terms of the agreement. This joint commission would be the primary decision-making body responsible for effective management of the shared Chukotka population of polar bears. This coordinated management would remedy deficiencies of current unilateral efforts and expand opportunities to obtain comprehensive information on population size and status of the Alaska-Chukotka polar bear population needed for conservation and management.

Implementation of an Alaska-Chukotka polar bear harvest limit, allocation and quota system in Alaska based on harvest guidelines would result in proactive management. Wildlife managers would have the flexibility to recommend harvest level adjustments to the joint commission. Enforcement of harvest quotas in Russia would presumably curb illegal take; however, without adequate enforcement, an increase in total take



(legal and illegal) could result. Monitoring of harvest and enforcement on both sides would need to be required and verified. Joint international research and monitoring programs for the study and conservation of the Alaska-Chukotka polar bear population would be enhanced and conducted between the governments and Natives of Russia and the U.S.

Following completion of a final EA on the proposed polar bear bilateral agreement, the FWS plans to work with the Department of the Interior's Solicitor's Office in preparing a "Circular 175" request for authority to negotiate a bilateral agreement with Russia. The Circular 175 document and supporting information will then be submitted to the U.S. Department of State. Draft bilateral agreement language will then be prepared by the FWS in close consultation with the Department of State. Upon approval by the Department of State, a U.S. delegation will be selected and a negotiation meeting with Russia scheduled.

It is anticipated that, whenever a formal negotiation meeting is scheduled for the polar bear bilateral agreement, continued working-level talks also will be scheduled for walrus. The FWS is concerned that current economic and political issues in Russia have resulted in the loss of key Russian scientific programs and personnel for walrus. It is considered important to the conservation of Pacific walrus to keep talks progressing between the two governments, as well as between indigenous people on both sides. Preparation of an EA for the Pacific walrus bilateral agreement is being planned.

The role of Native people in Russia and Alaska is critical to the development and implementation of these proposed bilateral agreements. As subsistence users of polar bears and walrus, their "stake holder" role in the conservation of these species is essential for the future of the Native lifestyle and heritage. Also, their role in development and implementation is a key to the effectiveness of the proposed bilateral agreements for the conservation of polar bears and Pacific walrus into the future.

# Assessing Caribou Habitat Selection at a Landscape Level

*This article was prepared by Tom McCabe and Brad Griffith of the USGS/ Biological Resources Division and Janet Jorgenson of the Arctic National Wildlife Refuge.*

The research we have been engaged in over the past decade has involved the Porcupine caribou herd and the Arctic National Wildlife Refuge (NWR) in northeast Alaska. Within the boundaries of the Arctic NWR are 607,000 ha of coastal plain (known as the 1002 Area) that is considered, based on geology, the next best prospect for discovering recoverable amounts of oil in North America (Clough et al. 1987). The Porcupine caribou herd—the second largest of the caribou herds found in Alaska, estimated at 163,000 animals—has come to symbolize the struggle for and against opening the Arctic NWR to oil development. The Porcupine herd has a 291,000-km<sup>2</sup> range between Canada and the United States. The cogent point relative to the caribou and the potential oil development is that the Porcupine caribou use the coastal plain of the Arctic NWR as their primary calving grounds. For us to assess potential impacts of development on caribou over such a large landscape necessitated using a plethora of remote sensing and field techniques.

Initially, to determine if the coastal plain of the Arctic NWR is important to the caribou, we used all of the known calving sites derived from radio-collared females (Fancy and Whitten 1991) for the period 1983–1993 to define the calving area, employing an adaptive kernel procedure (Worton 1989, Kie et al. 1996). We found the maximum extent of the calving grounds to be 2.3 million ha, with the annual calving grounds utilizing between 20 and 75% of the area. We also found that more than 50% of the annual calving occurred within the Arctic NWR in all but two years. Having demonstrated that the coastal plain is important to the calving caribou, we then wanted to determine what characteristics were influencing the selection of the coastal plain for calving habitat.

To evaluate the important aspects of the habitat across this landscape for the Porcupine herd, it was necessary to have an accurate map of the vegetation on the 18,000-km<sup>2</sup> coastal plain within Alaska. At first blush, mapping this landscape would seem to be a fairly easy assignment, albeit large. Coastal tundra appears as a treeless plain, seemingly covered uniformly by small sedges and shrubs, but such is not the case. The coastal plain, in fact, consists of five distinct terrain types—flat thaw-lake plains, hilly coastal plains, foothills, alpine tundra and river floodplains—each with its own unique floral composition and structure.

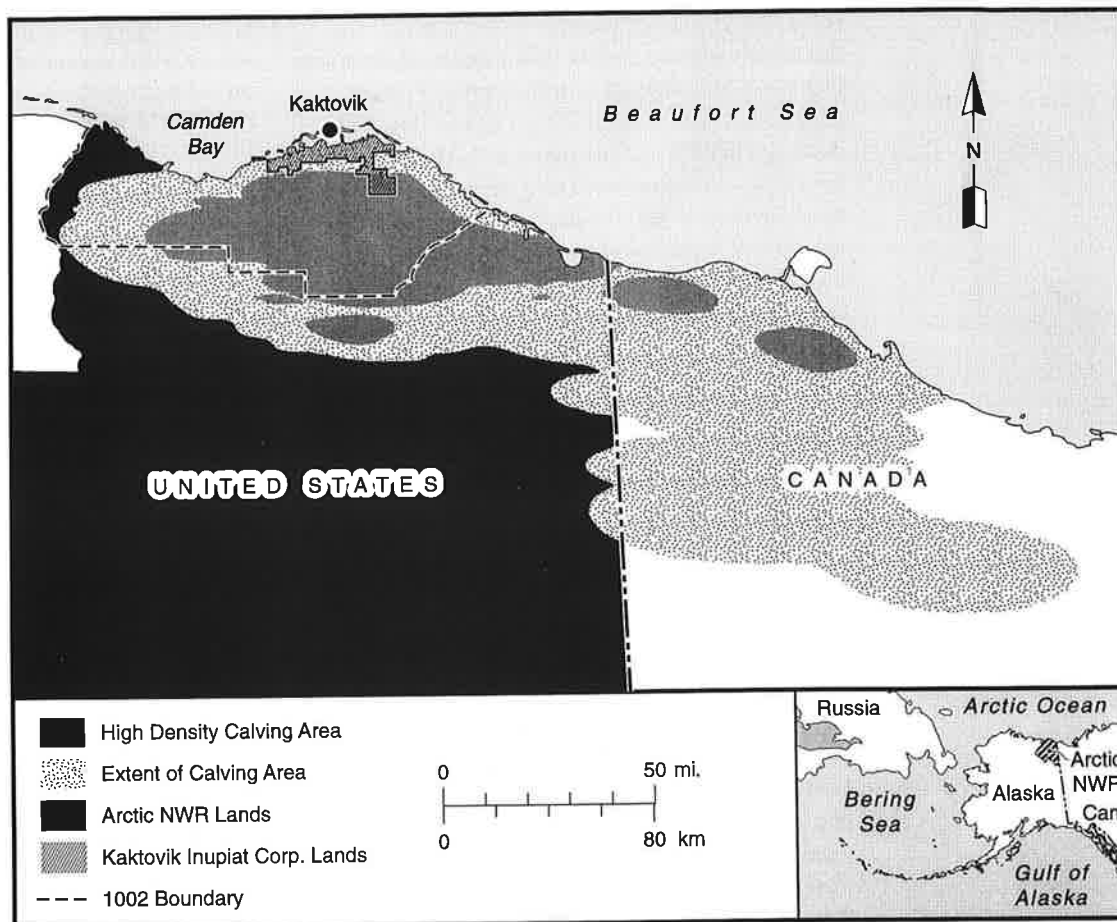
In the early 1980s, two attempts had been made to map the 1002 Area and the entire refuge using Landsat multi-spectral scanner (MSS) satellite images (Walker et al. 1982, Markon 1986). Subsequent checking of the accuracy of these maps showed that they provided a 37% accuracy when compared to on-site inspection (Felix and Binney 1989). By the end of the 1980s, Landsat thematic mapper (TM) imagery was available. This provided finer spatial resolution and additional wavelength bands, which would help in identifying unique vegetation signatures (Jacques 1989).

In developing a digital vegetation map, the primary goal is to accurately portray the juxtaposition of the various vegetation types on the landscape to the level of 30- × 30-m pixels. The ideal map would consist of the largest number of unique vegetation types that could be physically discerned.

Initially we developed a unified vegetation classification scheme using several hierarchical classifications that had been previously employed in describing coastal tundra (Walker 1983, Viereck et al. 1992). Ground-truthing vegetation data were acquired at 896 plots in 50 intensive study areas within the Arctic NWR coastal plain. A systematic vegetation sampling study incorporating 63 study sites also was conducted to provide estimates of habitat distribution across the coastal plain, as well as an independent data set to assess the accuracy of the Landsat-TM map (Jorgenson et al. 1994).

The Landsat-TM scene was first classified into 110 distinct spectral reflectance classes, then subsequently refined to 16 spectral classes (Joria and Jorgenson 1996). The intensive vegetation study plots for the coastal plain were then geo-referenced within our geographic information system (GIS) and overlaid with the Landsat-TM data, and the spectral classes corresponding to the vegetation plots were assigned to one of 13 vegetation classifications. The accuracy of the Landsat-TM map was determined by comparing the mapped classes with the systematic vegetation plot data. Accuracy assessment for the map based on spectral data alone showed 45% agreement with the intensive vegetation study plots and 42% agreement with the independent, systematic study plots. Because the tundra vegetation community consists of overlapping gradients of moisture, soils and elevational differences, we found that obvious dis-

*Porcupine caribou herd calving areas on the coastal plain within the Arctic National Wildlife Refuge, Alaska, and the northwest portion of the Yukon Territory, Canada, 1983–1994.*



continuities between closely related vegetation types were not identifiable using spectral reflectances alone. Therefore, both analytic and subjective determinants were used to develop the map incorporating these additional data layers. Post-modeling agreement improved to 50% with the independent data set for the 13 vegetated and 3 water types (Jorgenson et al. 1994).

A 16-class map was statistically too cumbersome for analyzing habitat use by wildlife, so a 6-class map was made by combining closely related vegetation types. By eliminating error associated with closely related types, we found that the accuracy of the map, when compared to the independent data set, improved to 74% (Jorgenson et al. 1994).

With the vegetation map available, it was now possible for us to test hypotheses regarding the use of the coastal plain habitat by calving caribou. To assess the value of the habitats to the caribou, we wanted to test the null hypothesis that calving caribou use the coastal plain habitats in relation to their availability. To adequately test this hypothesis, it was necessary to get accurate locations of caribou over a long period of time and an extensive land area. Obtaining the necessary data involved a three-step process :

- Collecting a sample of known locations where caribou were observed;
- Determining the exact coordinates of those locations on the coastal plain for projecting on the vegetation map; and
- Deriving the habitat type used by the caribou from our GIS database.

Also, we wanted an independent data set each year, so we could not use our long-term data for radio-collared adults. The solution was to capture newborn calves and fit them with a break-away radio collar. In this instance the calf became a surrogate for the cow, since the calf would always be in close proximity to its mother. We captured approximately 75 calves each year from 1992 to 1994. By monitoring the location of the calves, we were able to get a location of the cow-calf pair. Locations were obtained using aircraft equipped with radio relocation antennae and a global positioning system (GPS), which was attached to a laptop computer. A location was identified by flying to the telemetry fix, flying low over the calf and entering the GPS location as the plane passed over the animal. Between 1500 and 1700 locations were obtained in this manner each year.

The second part of the experiment was to determine the accuracy of the GPS-derived locations



relative to the actual location of the caribou. We did this by placing collars on the tundra at locations that we could pinpoint to within a meter using a differential GPS program and a monitoring base station. Then we had the pilots and observers find the collars and simulate fixing the point as was done for the calves. The data string from the GPS was downloaded instantaneously at the touch of the computer key, but four factors were potentially influencing the accuracy of the location:

- The plane was traveling at 20–30 m/s;
- The GPS updates every 1–1.5 s;
- It was difficult to tell if the plane was directly over the calf; and
- Selective availability imposed an unknown error.

Analysis of the data indicates that there was no difference between pilots, observers, planes or interactions of these variables, indicating that their collective abilities were basically the same. The overall mean distance for the error was 101.8 m.

Since the average error lies between 92 and 111 m, we decided to look at two possible levels for assessing what habitat would be assigned to the caribou, conservatively a 100-m radius and liberally a 200-m radius. We compared the actual GPS pixel classification with the dominant classifications within the two error circles. We found that the agreement was best with the 100-m radius at 84%, compared to 79% for the 200-m area. We therefore used the vegetation classification for the 100-m radius for determining the habitat used by the caribou.

The relative frequency of selection among habitat variables across years was used to assess the relative importance of habitats to caribou. The more frequently selected habitat classes were considered the most important. From the vegetation map we were able to determine the percentage availability for the six vegetation classes and compare them, using a chi-square goodness-of-fit procedure, to a random sampling of the cow-calf location sites that had been verified by ground inspection. Finding that there was a significant difference between the use and availability of the different habitats, we conducted a Bonferoni multiple comparison test to see which habitats were influencing the chi-square statistic. These results showed that the caribou selected moist sedge tundra, tussock tundra and riparian shrub habitat in greater proportion than expected and avoided dry alpine tundra and the "other" category, which comprised water, ice, bare ground and areas of disturbance. From this analysis we can postulate that caribou are selective and that the habitats they select are limited in distribution, since they occupy only 32% of the total area. Additional analyses should illuminate the specific

**Habitat selection by Porcupine caribou on the Arctic NWR coastal plain, 1992–1994, based on the estimated amount of time caribou occupied a habitat (use) versus the percentage of the vegetation type on the coastal plain (availability).**

<i>Vegetation classification</i>	<i>Percent available</i>	<i>Percent used</i>
Wet sedge tundra	8.34	7.02
Moist sedge tundra	18.46	33.47
Tussock tundra	12.04	32.23
Shrub tussock tundra	7.40	9.92
Alpine tundra	15.69	0.83
Riparian shrub	2.20	16.53
Other	35.86	0.0

advantages of the various vegetation types to the calving caribou.

The biological implications of our results are not inconsistent with our observations of forage selection. Tussock cottongrass is the primary forage when the caribou arrive on the calving grounds. It produces a succulent, nutritious and highly digestible flower stalk as the snow melts. Tussock cottongrass is, not surprisingly, associated primarily with tussock tundra. As the cottongrass progresses through its phenological stages, it becomes less palatable, and the caribou shift to the succulent buds of dwarf willow, which are just starting to appear. The willow is a dominant species in moist sedge habitats.

Our research is providing a clearer picture of caribou habitat usage. By integrating remote sensing data with aerial and ground data, we were able to ascertain the extent and juxtaposition of the habitats selected by caribou using a landscape-scaled vegetation map. This capability is particularly significant in relation to the Arctic NWR, where development of petroleum resources could impact a large geographic area and thereby influence the accessibility of habitats to the calving caribou. If development on the Arctic coastal plain were to occur, then this technique provides a basis for mitigating potential impacts based on a landscape view of the distribution and availability of habitats.

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# Traditional and Ecological Knowledge of Seabirds on St. Lawrence Island

*This report was prepared by Caleb Pungowiyi, Principal Investigator, Inuit Circumpolar Conference, 401 East Northern Lights Blvd., Anchorage, Alaska 99503.*

St. Lawrence Island, located in the northern part of the Bering Sea, is home to millions of seabirds and other migratory birds during the spring and summer. These birds are an important food and cultural resource to the people on the island. Approximately 1000 Siberian Yupik live on St. Lawrence Island and are one of the few indigenous people who have retained their language and culture. Native people on the island harvest seabirds as a traditional food, and they depend on the birds for cultural activities such as cooperative hunting, sharing of harvest, handicrafts and food preparation. In some areas of the Bering Sea, certain species of seabirds have been or are declining. No studies had been done to document the knowledge of the local people concerning the natural history of seabirds and their traditional management practices.

## *Purpose and Goals of the Project*

The overall goal of this project is to survey and relate the human and other environmental dimensions of seabird distribution and utilization on St. Lawrence Island and selected areas in Chukotka, Russia. Other related objectives are the following:

- Document parameters of subsistence harvest, including use areas, methods, timing of take, sharing and species harvested;
- Comprehensively update the data on the location, size and count of the population of seabird colonies; and
- Document the traditional knowledge of the natural history of seabirds, including management strategies employed by the residents.

*Shawn Stevenson videotaping flocks of crested and least auklets.*



Other purposes are to seek greater recognition in the scientific community of the value and importance of traditional and environmental knowledge; facilitate the integration of traditional knowledge into research; and provide opportunities for participation of Alaska Natives in science.

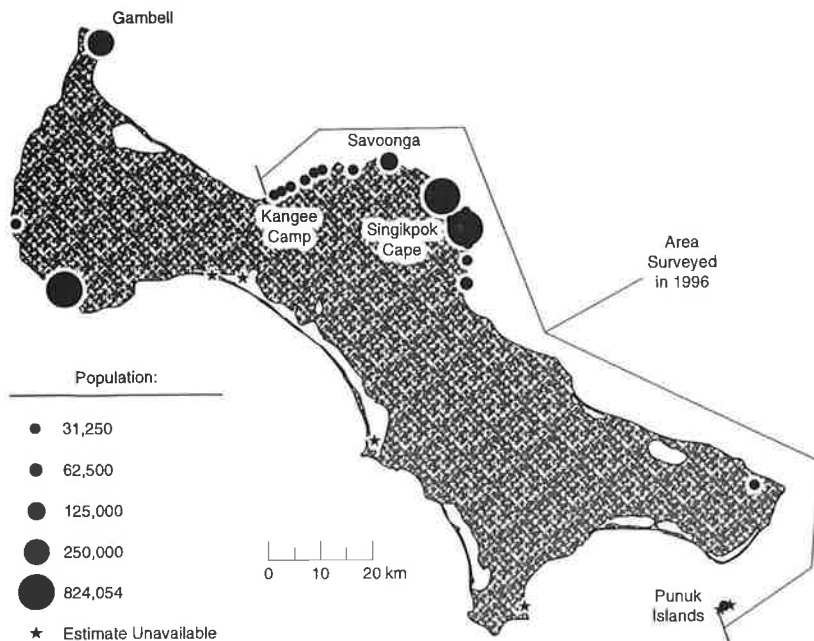
## *Methodology*

The project has two parts and three phases; the first part is to survey and census all seabird colonies with the U.S. Fish and Wildlife Service (USF&WS), and the second is to collect the traditional knowledge with the National Park Service. The first phase, covered in this report, was conducted in and near the village of Savoonga. The second phase will be conducted in Gambell in conjunction with the companion cooperative agreement with the USF&WS. The third phase is to survey seabird colonies on selected areas of the Chukotka peninsula and gather traditional knowledge of the Russian indigenous people. The USF&WS, assisted by a project crew, provided expertise in censusing, recording biological data, producing maps and reporting on the survey.

The author and Ida Murdock, an employee of the National Park Service, interviewed 40 residents of Savoonga who were identified by other residents as knowledgeable or high users of seabirds. The questionnaire was used to identify use areas, seasons of harvesting, species targeted for gathering, observations of change, sharing patterns, effects of the weather on birds, and local management methods.

## *Results*

A total of 16 sites were censused and cataloged during the 1996 season. Another site, the Punuk Islands, were accessed, but due to fog and inclement weather no counts were made during the project. A total of 1,610,287 seabirds were counted. Censusing was conducted from a 17-ft inflatable boat or an 18-ft aluminum boat 20–75 m offshore. Crested and least auklets were censused from land by counting birds on land and in the air every 15 minutes for a one- to two-hour period. The censuses were conducted in accordance to USF&WS Standard Operating Procedures for inventories of seabirds.



Population estimates of seabird colonies on St. Lawrence Island.

Interviews on local knowledge and observations indicated that common and thick-billed murres have been increasing the past ten years, expanding their colonies into new nesting areas. This expansion is forcing pelagic cormorants to move to the south side of the island. Kittiwakes have not been laying eggs for a number of years, even though the numbers have remained stable. Some of the respondents said that their eggshells are thin and break easily. Many respondents felt that the number of gulls have increased and that their predation on the eggs and young of other seabirds is becoming a greater problem. They have observed that other predators, such as foxes, gulls, ravens and voles, are increasing on the island.

#### Quotes

"Too many gulls now. They take many eggs from murres and eider ducks. They have taken over nesting sites from eider ducks."

—Ivan Pungowiyi

"Kittiwakes haven't had young ones for several years now. Their egg shells are thin and break easy. They still fix their nests and act like they are going to lay eggs."

—Mary Seppilu

"Murres lay eggs at least five times. Each time the egg is a different shape and color. The fifth egg is narrow and about the size of a pigeon guillemot egg. We leave these smaller eggs alone to perpetuate the murre population. When these eggs hatch, they have normal chicks."

—Floyd Kingeekuk

#### Estimates of seabirds near Savoonga on St. Lawrence Island by species.

Pelagic cormorant	298
Herring gull	115
Glaucous gull	71
Black-legged kittiwake	21,942
Dovekie	2
Common murre	53,145
Thick-billed murre	52,714
Pigeon guillemot	2,248
Least auklet	1,021,158
Crested auklet	454,666
Parakeet auklet	1,594
Tufted puffin	869
Horned puffin	1,465

"We gather mostly murre eggs because they are harder to break and are delicious to eat. When they start getting embryos, we stop gathering eggs."

—Alexander Akeya

"When birds start laying eggs, we stop hunting birds. It's a rule that has been passed down from generation to generation. It is same today as it was in the old days."

—Joe Noongwook

"Murrelets lay eggs in the mountains. They are quite rare, hard to see. We call them Tagheettoiig 'fog bird.' They have green eggs with black markings and are laid right on the gravel."

—Clarence Wahiyi

"I hurt for not being able to hunt eider ducks when I am hungry. We obey the law even when we are hungry. They tell us there are less birds or no more. They should come here and see for themselves and count the eider ducks that fly by our island. They are government birds. I want to tell them I don't travel to their lands to tell them not to do certain things. They have their own plants. If it is a bad year for their farmers, the government helps them. Our sea is like our garden. If something should happen to it, we would really suffer but the government will not help us."

—Alexander Akeya

"I save the crest and cheek buttons from crested auklets for use in making dolls. Recently I told Fish and Game I received an order for a murre skin parka from a museum. They told me I could not make and sell a bird skin parka. Our ancestors always used to make and wear bird skin parkas. I can't understand why I can't sell something I make."

—Kathy Noongwook



Hunters returning from  
spring bird hunting near  
Savoonga.

"They used to make parkas out of bird skins. It would take 25 cormorant skins to make one adult parka."

—Chester Noongwook

"Our ancestors took great care to keep our land clean. Land animal bones were buried or left on the land, never thrown in the water. Marine mammal bones were always returned to the sea. We could tell time and weather by looking at the stars. The earth is fast now. More wind, more storms. There is a lot of erosion around the island."

—Mabel Toolie

"My stepsister was born premature. Her skin was opaque and you could see her internal organs. Pinaaya made an eider duck skin bag and put her in the bag. They hung the bag over the seal oil lamp to keep her warm. They would feed her with a strip of seal blubber dipped in cooking broth. They constantly took care of her. After two months, Pinaaya told Pyaagnah to make a new bag, for the baby was outgrowing the first bag. She was just a little bigger than your hand when she was born. With constant care, she grew up to be a normal child. This was the Eskimo way of raising a premature baby."

—Mabel Toolie

"Small islands in Koozaata lagoon have disappeared from high water, so eider ducks don't lay eggs around there anymore."

—Elsie Kava

"The tall spires we used to call Soolongnat were destroyed by big waves about 4 years ago. They were about 12 miles east of Savoonga and cormorants and gulls used to nest there."

—Floyd Kingeekuk, Jr.

### *Harvesting and Sharing*

Bird hunting would start in May when the birds returned to the island and end in mid- to late June when the birds started laying eggs. Some birds stayed year-round in the open waters offshore. Most of the spring bird hunting was done by boat. All of the catch was shared equally among the crew. All of the families surveyed shared their harvest with relatives or neighbors. Some would send a portion of their catch to relatives outside of the village, usually Nome. Murres and crested auklets were the ones most harvested in spring. Bird hunting would resume in the fall after the young birds left their nest. Ducks, cormorants, geese, loons and young guillemots were the targeted species in the fall bird hunts.

Egg gathering and sharing has an important social and cultural significance to the people of Savoonga. People took great pride in sharing their harvest of eggs with neighbors and friends. Subsistence harvest surveys (Wentworth 1994, 1995, 1996) showed that the people of Savoonga gathered around 10,000 eggs annually. Murre eggs are gathered by climbing by rope or simply by hand. No protective gear or climbing equipment is used. Accidents do happen. This past spring one young man was seriously injured and another died from a fall during egg gathering.

According to the respondents, 1996 was an unusual year, with extremely early spring breakup and very little snow; the sea ice broke up and disappeared by early June. They said that weather plays an important role in successful laying of eggs and raising of the young. Deep snow and late springs affect the laying of the eggs. Wet, windy summers kill many of the young birds, especially least auklets.

### *Further Research*

Similar work will be done during the summer of 1997 at the village of Gambell and the colonies on the southwest side of St. Lawrence Island. Pending funding and permit approval, surveys and colony counts will be carried out in 1998 on selected sites of the Chukotka Peninsula.

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# Fall Migration of Shorebirds and Waterfowl at Carter Spit, Alaska

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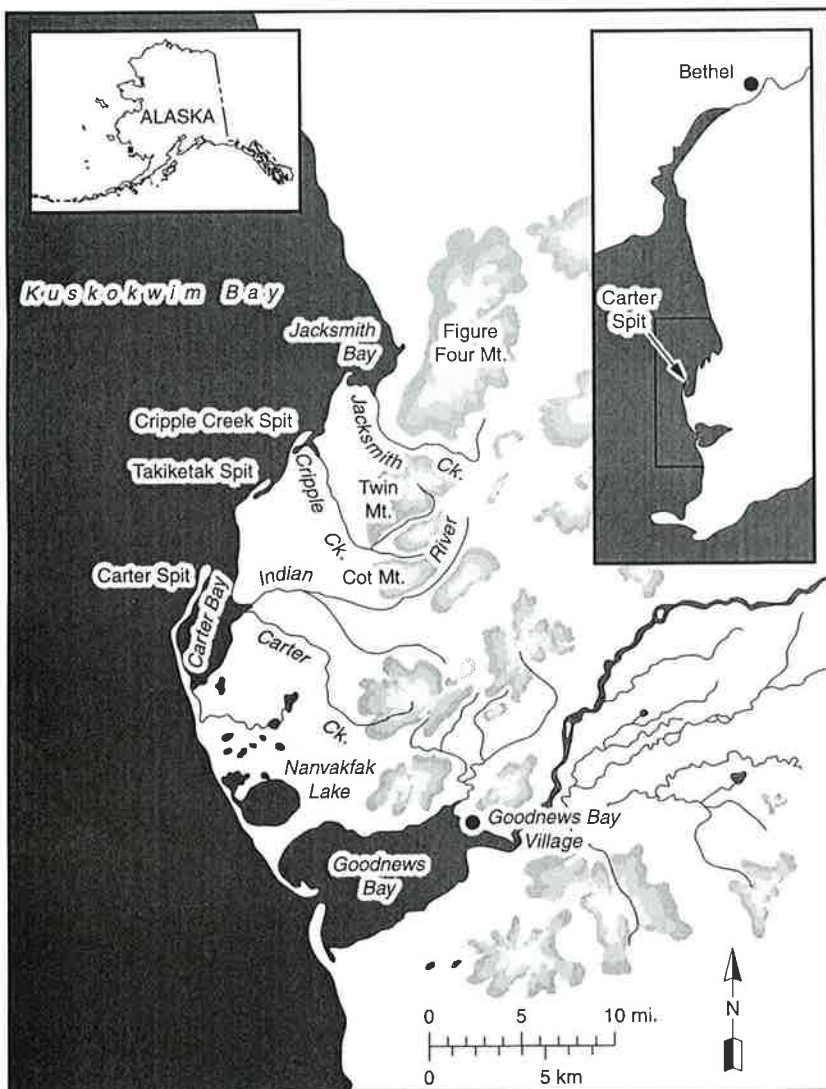
In Alaska the eastern Bering Sea region contains vast expanses of intertidal and inland vegetated intertidal areas. Many species of shorebirds depend on these littoral and supralittoral habitats for breeding and migration. Coastal areas are especially important after breeding, when many populations depend on littoral habitats while undergoing molt and premigratory fat deposition (Gill and Handel 1981). The millions of birds of many species that stage and migrate in these coastal areas are vulnerable to littoral zone disturbances, particularly oil spills.

Within the eastern Bering Sea region the Yukon-Kuskokwim Delta (Y-K Delta), with littoral areas rich in benthic organisms and adjacent inland nesting areas, is used by more species in



*Flock of shorebirds at Carter Spit.*

*Location of the Carter Spit  
study area.*



greater numbers and in higher densities than any other littoral area in the region (Gill and Handel 1981). An estimated 1–2 million shorebirds use the central delta for nesting and post-breeding staging, with densities in fall migration as high as 1800 shorebirds/km<sup>2</sup> (Gill and Handel 1990). The delta supports large portions of the Pacific Rim or world populations of at least six shorebird species (Gill and Handel 1990). Species using the delta winter in Asia, Australasia and Oceania, as well as the contiguous United States, Central America and South America (Gill et al. 1994).

South of the central Y-K Delta, a complex of spits and tidal mudflats exists at Carter Spit, an area on the southern end of Kuskokwim Bay. Although the central delta and the greater Y-K Delta are far greater in area and overall numbers of birds, Carter Spit is a significant migratory staging area for shorebirds and waterfowl, particularly in fall migration, and it represents the southernmost extension of tidal mudflats associated with the Y-K Delta.

The area also includes a substantial number of inland tundra ponds that provide nesting and brood-rearing habitat for waterfowl, and many species use the seacoast to molt, including the Stellar's eider. This species is of particular management interest because of steady population declines over the past several decades and their subsequent listing as Category 1 candidate designation under the Endangered Species Act. The area also represents a significant post-fledging staging spot for waterfowl.

Land in the Carter Spit area is a mosaic in terms of land ownership and management, with Federal, Native and State agencies and interests involved. The Bureau of Land Management (BLM) is one of





*King eiders in a tundra pond.*

the Federal agencies with management responsibilities in the region and has an interest in the area's importance to wildlife, especially migratory birds. In 1994 and 1995 the BLM conducted a study to gain a better understanding of the importance of the area to birds. Particular attention was focused on the significance of the area for waterfowl staging prior to migration and for resting and feeding by shorebirds during migration.

### *Description of the Study Area*

Carter Spit lies 135 km south of Bethel. The study area encompassed about 400 km<sup>2</sup> and was within a line bounded by the north spit of Goodnews Bay, Jacksmith Bay, the coastal Ahklun Mountains and the Kuskokwim Bay coastline. The nearest villages are Goodnews Bay, 25 km to the southeast, and Platinum on the south spit of Goodnews Bay, 25 km to the south. Four drainages flow from origins in the mountains to the coast: Carter Creek, Indian River, Cripple Creek and Jacksmith Creek. The deltas of these rivers have formed four coastal spits along 40 km of coastline, which in combination with large expanses of tidal mudflats create exceptional habitat for migrating shorebirds and waterfowl. The area includes an inland portion with numerous shallow tundra wetlands.

### *Methods*

Working from a field camp with four persons, we were present on the study area from 2 July to 12 August 1994 and from 11 July to 25 August 1995. The project's primary objectives were to inventory coastal areas for shorebirds and waterfowl in fall migration and to evaluate the significance of coastal spits, bays and tidal mudflats to staging and migrating birds, particularly shorebirds and waterfowl, using aerial and ground counts. Inland and alpine areas were also surveyed for

birds. Using ground counts, riparian zones along the four rivers, the mountain slopes, ridges and valleys and open tundra areas were surveyed to estimate the numbers and species of birds. Aerial waterfowl brood surveys were also conducted on most of the area's inland tundra ponds for waterfowl production estimates.

### *Results and Discussion*

In 1994 we saw only 13 duck, 7 swan and 3 loon broods of nine species during aerial brood surveys. In 1995 we saw 28 duck, 9 swan, 10 loon and 2 grebe broods of nine species. Dabbler broods were represented by mallard, green-winged teal and pintail, and diver and sea duck broods by red-breasted merganser, greater scaup and black scoter. Brood densities were quite low compared to other known duck-producing areas of the state (Y-K Delta, Bristol Bay, Yukon Flats), but direct comparisons may not be appropriate. The same species were most abundant in 1992 and 1993 waterfowl production surveys of nearby Bristol Bay (Hodges and Conant 1992, 1993). In the Carter Spit area, for this study, dabblers made up 49% of the duck broods seen, divers 34% and sea ducks (black scoters) 17%.

Of the 127 species of birds seen on the study area, 68 are known to breed there, and an additional 21 species are suspected of breeding but could not be confirmed. Inland ponds provided breeding habitat for the greatest number of species (30), and alpine, the least. Twenty-one landbird species were found breeding in the willow thickets of the four rivers and in alder patches in the draws on the hills and slopes of the mountains. Many were neotropical migrants. Intertidal habitats hosted 21 species of breeding birds, mainly shorebirds, gulls and waterbirds that used the mudflats as a source of food while raising a clutch of eggs or nestlings. Coastal tundra provided breeding habitat for sandhill cranes, northern harriers, willow ptarmigan, black-bellied and golden plovers, red-necked phalaropes, common snipe, sandpipers, jaegers, ravens, gulls, terns and some passerines, among others. Raptors and other landbirds were noted breeding in alpine areas.

There were at least 75 species that used the Carter Spit area for migration and staging. Many species listed as breeding here also passed through from breeding areas outside the study area. The intertidal zones, both vegetated and unvegetated, were by far the most important habitat for migrating and staging birds, mostly shorebirds and waterfowl, and also for the local movement of gulls, terns, cormorants and some seabirds. Coastal tun-

dra was used by some migrating raptors and shorebirds, and inland ponds by migrating loons, grebes and waterfowl, but the largest numbers and the most sudden influx of migrants were seen on intertidal zones.

Overall bird use in each of the species' predominantly used habitats was highest for the intertidal zone, with 55 species, about 43% of the total number of species seen in the study. Twenty-six species (20%) used inland ponds, with the remaining use distributed among coastal tundra, riparian and alpine habitats. The intertidal flats were used by 75% of the species migrating through Carter Spit, suggesting the importance of intertidal zones to migrating birds relative to other habitats.

Only 7 of the 31 shorebird species recorded in the study were confirmed breeders, but the mud-

flats that characterize this part of the coast were equally important to local breeders and migrants. The use of the mudflats by local breeders was most apparent from our observations of western sandpipers. Adult birds made up the majority of the flocks when we first arrived but were gradually replaced by ever-increasing numbers of juvenile birds. By late July in both seasons, very few adult western sandpipers could be found. Apparently adult birds migrate first, leaving hatch-year birds behind to feed in the intertidal zones to mature and gain migration reserves. From our observations of fledgling western sandpipers on the margins of inland ponds and on the coastal tundra, it seems likely that many of the juvenile birds using the mudflats in late July and early August are locally produced. The replacement of the adults by juveniles did give us some indication of turnover rates for the species for early July.

#### Migrant Waterfowl

The mudflats along Carter Bay and the spits to the north were a significant fall staging site for waterfowl, beginning in early August. Most of our observations were of large mixed flocks of northern pintail and green-winged teal, with smaller groups of northern shoveler, usually viewed at great distance with spotting scopes on the exposed mud.

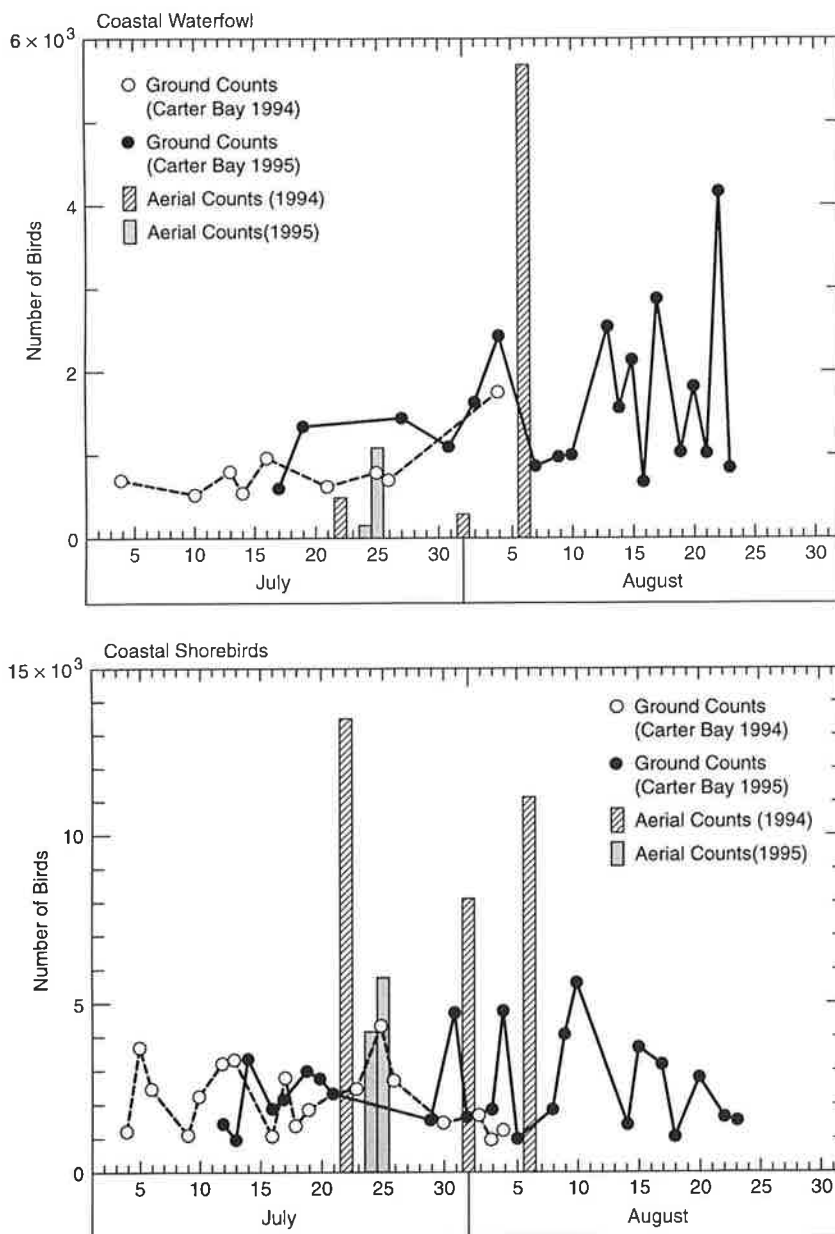
In overall tallied counts that included 26 species of waterfowl, about 18,000 birds were recorded in 1994 and 41,000 in 1995. The increase in 1995 undoubtedly resulted from counts being two weeks later in the season, when the bulk of the waterfowl migration occurs. Northern pintail were by far the most abundant migrant duck, with over 16,000 birds in 1995, most in mid-August in flocks of about 2,000 in Carter Bay. Green-winged teal were also abundant on the mudflats and tidal sloughs. Other noteworthy records include about 100 Stellar's eiders each season (mostly molting males), about 6,000 king eiders in 1995 (these numbers probably increased in September, as they are later migrants), and 1,600 black scoters in 1995 (this was a common duck in both seasons).

#### Migrant Shorebirds

Numbers of shorebirds in Carter Bay varied from 1,000 to 4,000 birds and consisted mostly of western sandpipers. The peak ground count in 1994 was 4,287 birds on 25 July. A peak aerial count of 13,423 "peeps" from Carter Bay to Jacksmith Bay occurred on 22 July. In fixed-wing surveys on 1 and 6 August 1994, we counted about 8,000 and 11,000 peeps, respectively.

About 5,000 and 6,000 birds were recorded in the only two aerial counts of the coastline in 1995

Aerial and ground counts of waterfowl and shorebirds in coastal areas of Carter Spit, 1994 and 1995.





from the helicopter. Ground counts in 1995 varied between 1,000 birds in July to 5,000 in August. The peak ground count in 1995 was 5,800 birds.

Overall we recorded 31 species of shorebirds, with tallied daily counts for all species combined of 80,000 birds each year. Western sandpipers were by far the most abundant shorebird, with total counts of 60,000 in 1994 and 53,000 in 1995. Dunlin were probably the second most abundant shorebird on a daily basis, but dowitchers were also very common. Over 11,000 dowitchers were recorded in 1995, usually in small flocks in the vegetated intertidal or on shallow inland ponds. Of those that could be identified to species, 60% were short-bills and 40% were long-bills; these were separated mainly by call. About 4,000 hudsonian godwits, a wader uncommon in large concentrations, were seen in flocks as large as 400 birds.

#### *Estimated Magnitude of Migration*

From our counts of peeps on Carter Bay, we estimated the numbers of birds moving through the coastal area from 15 July to 15 September. The average daily count of peeps for both years in Carter Bay was about 2,500 birds. We did not determine turnover rates of migrating shorebirds at Carter Spit. Butler et al. (1987) researched western sandpiper migration in the Fraser River Delta in British Columbia in fall and estimated that adult birds stayed in the area for 1–3 days. Fifteen-day turnover rates were reported for semipalmated sandpipers in the Bay of Fundy in fall by Hicklin (1987). Juvenile western sandpipers are the major shorebird migrant at Carter Spit, and from our observations during this study, it is probable that juvenile birds have a longer length of stay than adults to mature and gain migration reserves.

**Estimated magnitude of shorebird migration from 15 July to 15 September using hypothetical turnover rates. The table assumes an average daily use in Carter Bay of 2,500 birds and an even distribution of feeding and roosting birds on the exposed mud flats.**

<i>Days to turnover</i>	<i>Carter Bay</i>	<i>All spits and bays*</i>
2	78,750	236,250
3	52,500	157,500
4	39,375	111,125
5	31,500	94,500
6	26,000	78,000
7	22,500	67,500
10	15,750	47,250
15	10,500	31,500

\* Carter Bay is  $\frac{1}{3}$  the total intertidal area of all spits and bays, so values are calculated as three times that of Carter Bay.

To estimate the number of birds using the area during migration, we used eight hypothetical turnover rates and estimates of the number of birds in Carter Bay, then extrapolated the total number of birds over the entire study area coastline. Using an average of 2,500 birds in Carter Bay and multiplying that number by three for all spits and bays, we calculated the potential number of staging birds for the various turnover rates over a 63-day period. If the length of stay is only 2 days, over 230,000 shorebirds move through the area in that time. If the turnover rate is as long as 15 days, about 31,000 birds move through. This assumes that the numbers of shorebirds in the area remain constant from 15 July to 15 September and that birds are evenly distributed across coastal areas. If these estimates are accurate, it is likely that at least 30,000 shorebirds, mainly western sandpipers and least sandpipers, stage on the coastal areas of the study area each fall. Carter Spit has been recognized as an Important Bird Area by the American Bird Conservancy because of the species and total numbers of birds that use the area in fall migration.

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# Yellow-Cheeked Voles and Fire along the Upper Kobuk River Valley, Alaska

*This report was prepared by Shelli A. Swanson, Gates of the Arctic National Park and Preserve, National Park Service.*

Since 1991 the National Park Service (NPS) has been collecting natural resource information from the Kobuk Preserve Unit of Gates of the Arctic National Park and Preserve. This information will enable NPS staff to make knowledgeable decisions regarding potential road development across the Kobuk Preserve Unit to the Ambler Mining District (as authorized under the park's establishing legislation).

Voles, shrews and lemmings are small but integral components of the taiga ecosystem in the upper Kobuk River Valley. Wildfire is another integral component of this ecosystem, and the abundance and distribution of several small mammal species appears to be affected by it. In 1992, NPS initiated a three-year study to look at the relationship between small mammal abundance and distribution in different-aged, post-fire black spruce stands (S. Swanson 1996). Species captured during the study included red-backed voles, yellow-cheeked voles, masked shrews, dusky shrews, pygmy shrews, northern bog lemmings and brown lemmings. Findings from this study pertaining to yellow-cheeked voles, their habitat and wildfire are presented in this article.

*Location of the Kobuk Preserve Unit within Gates of the Arctic National Park and Preserve, Brooks Range, Alaska.*



## Kobuk Country

The study was conducted in the Kobuk Preserve Unit of Gates of the Arctic National Park and Preserve, Alaska. The Kobuk River, a designated Wild and Scenic River, is located in Pleistocene glacial deposits along the southern foothills of the Brooks Range. The topography ranges from undulating plain in the valley bottom to high hills and low mountains forming the valley sides. The Kobuk Valley area has a subarctic continental climate: summers are short and warm with frequent light rain, and winters are long and cold. Rain appears to be a constant companion in the Kobuk River Valley, particularly in August. In August 1994 (the third year of the study), extensive rain precipitated a 100-year flood in the Kobuk and Koyukuk River drainages; the entire area was declared a Federal disaster area.

Black spruce forest communities dominate the valley floor; black and white spruce is interspersed with occasional birch and aspen trees on the dry hilltops. Balsam poplar stands occur in the flood-plain and along drainage areas. Study sites selected for this project were situated in mesic black spruce vegetation in two areas along the Kobuk River. One grid pair was placed in lichen woodland habitat, with one grid in a one-year-old burned area and the other in nearby unburned mature vegetation; these grids were established in 1992. The lichen woodland grids were located on old stream terraces of alluvium. The ground cover on the burned lichen woodland grid was composed of burned reindeer lichen, downed wood and bare soil interspersed with unburned sphagnum moss hummocks. Black spruce trees on the mature lichen woodland grid were 6–8 m tall, with smaller seedlings growing underneath. The ground cover on this grid was composed of dense lichen mat.

The second grid pair (studied in 1993 and 1994) was set up in moss/shrub forest habitat, with one grid in a 16-year-old burn and its complement in nearby mature forest. The shrub layer was the most highly developed vegetation component on the burned moss/shrub forest site and consisted of blueberry, lingonberry, Labrador tea and dwarf birch. Standing dead trees, 3–4 m in height, were interspersed throughout the area. The vegetation on the mature moss/shrub forest was classified as open black spruce forest, a common climax vegetation



*View of the Kobuk Valley from the burned moss/shrub forest grid, Gates of the Arctic National Park and Preserve.*

stage on cold, poorly drained sites (Viereck et al. 1992). The ground cover was predominantly moss/lichen mat with a shrub layer of blueberry, dwarf birch and Labrador tea. Multi-strata black spruce made up the remainder of the overstory.

### *How to Build a Better Mouse Trapping Grid*

Field work was conducted in August each year to sample peak annual small-mammal populations. Trap stations, consisting of two museum special snap traps (baited with peanut butter and oats) and a pitfall trap, were placed 10 m apart on 100- × 100-m trapping grids. The four grids were operated for 900 trap-nights per grid per year during the study; trap-nights were defined as one trap set for a 24-hour period. Grids were accessed by river travel, helicopter and foot; several trap lines on the hike-in grids were unexpectedly accessible by boat during the 1994 flood.

Captured animals were identified to species, weighed and aged as juvenile, subadult or adult based on molt patterns and weight. Study skins and skeletons were prepared in the field and are now housed at the University of Alaska Fairbanks (UAF) Museum. Small-mammal kidney, heart and liver tissues were collected for the UAF Museum's frozen tissue collection for future research on genetics and environmental pollutants; tissues were quick-frozen and transported in nitrogen tanks. Percent cover was estimated for all plants in a randomly selected 10- × 10-m plot within each trapping grid. Soil classification and stratigraphic information was collected from two soil pits at each grid site. Weather data were evaluated hourly by cold, wet trapping crews, particularly during the 1994 flood, when field camps had to be moved to higher ground on several occasions.

## *Where the Voles Roam*

### *Life is Good in the Burned Moss/Shrub Forest*

Of the four habitat types studied, small-mammal abundance was highest on the burned moss/shrub forest. Yellow-cheeked voles accounted for 30–31% of the small mammals captured, and more yellow-cheeked voles were captured from this area than from the other areas studied. This relatively high density of yellow-cheeked voles appears to be related to the burrowing conditions and food availability in this habitat type.

Yellow-cheeked vole populations are associated with good burrowing conditions and recently burned sites (West 1979, Wolff and Lidicker 1980). The 1978 fire appears to have changed soil conditions in the area of the burned moss/shrub forest grid, resulting in conditions apparently well suited to yellow-cheeked voles. Following a wildfire the charred, dark soil surface (which has lost its overstory vegetation and insulating mosses) is subject to greater soil heat absorption, and soil temperatures become warmer (Viereck and Schandelmeier 1980). These higher soil temperatures facilitate deeper seasonal thaw levels, and soils become drier in some cases (D. Swanson 1996). This process of soil warming probably occurred on the burned moss/shrub forest grid, since permafrost was not encountered within 1.25 m of the mineral soil. In contrast, permafrost was encountered on the mature moss/shrub forest grid at 55 cm in one soil pit and 100 cm in the other. Also, soils on the burned moss/shrub forest grid did not show evidence of reduction (indicating wet soils) until 30 cm in depth in one soil core and 60 cm in the other, but soils on the mature moss/shrub forest were saturated with water below 12 cm.

The warmer and drier soils in the burned moss/shrub forest grid (and on burned sites in general) may serve as optimal substrates for runway and colony construction and therefore support a relatively high population of burrowing small mammals (when sufficient food is available). Rhodes and Richmond (1985) found that burrowing medium was a critical component of pine vole habitat, and the voles preferred loam/peat moss burrowing substrate where tunnel integrity, reduced resistance to burrowing, and soil moisture factors were highest. The abundance of moss and the moderately deep organic layer on the burned moss/shrub forest grid probably had similar burrowing and digging properties as the loam/peat moss substrate. Organic mat depth also correlates to small-mammal density (Morris 1979, D. Swanson 1996), and the organic layer on this grid was 9 cm, second only to the mature moss/shrub forest grid (20 cm).

Plant composition was probably an important

factor in establishing and maintaining yellow-cheeked vole populations on the burned moss/shrub forest. Plant productivity on recently burned black spruce sites is high in response to high nutrient availability; common post-fire plant species such as fireweed, bluejoint and horsetail particularly benefit from this high nutrient availability (Viereck and Schandelmeier 1980, Viereck 1983). These post-fire plant species are primary food sources for yellow-cheeked voles and are likely critical for colonization of recent burns by this species. Summer foods for yellow-cheeked voles consist of horsetail, graminoids, dicots (forbs) and berries (West 1979, Wolff and Lidicker 1980), plants that were common on the burned moss/shrub forest grid. More graminoids and forbs were found on the burned shrub/moss forest than on the other vegetation types studied, enabling it to support a high yellow-cheeked vole population.

Fireweed and horsetail rhizomes (thickened roots) are critical components of winter food caches for yellow-cheeked voles (Wolff and Lidicker 1980). Since horsetail, bluejoint and fireweed spread into post-fire areas primarily via rhizomes growing in mineral soil (Viereck and Schandelmeier 1980), burn sites should support a plentiful supply of rhizomes for winter food caches (unless fire intensity is high and rhizomes are destroyed). Fireweed and horsetail were relatively abundant in the burned moss/shrub forest grid, and horsetail is a common and relatively abundant forb on most burns less than 50 years old (except on dry sites) in the Kobuk Preserve Unit (D. Swanson 1996).

Post-burn sites retain a well-developed herbaceous layer until the canopy closes late in the tall shrub/sapling stage (sometime within 50 years post-fire) (Foote 1983). Since trees in the burned moss/shrub forest site (16 years post-fire) were still seedling/small shrub height and the canopy was not yet closed, the herbaceous layer was still well developed during the study and capable of sustaining a high population of yellow-cheeked voles.

#### *Life is Hit or Miss in the Mature Moss/Shrub Forest*

Habitat conditions on the mature moss/shrub forest site were apparently marginal for yellow-cheeked voles. Yellow-cheeked voles accounted for only 12% of the animals captured on this site in 1993 and were not captured at all in 1994. Yellow-cheeked voles are found in burn sites (West 1979, Wolff and Lidicker 1980, Johnson and Paragi 1992) and along taiga waterways and lakes where flood and ice disturbance maintains a dense growth of graminoids and light-seeded, quickly developing plants (West 1979). These small areas of consistent habitat may be easily overpopulated, causing excess animals to disperse in search of other suitable disturbed sites. West (1979) speculated that a few voles might be sustained where toppled trees allowed light to reach the forest floor and enhance herbaceous growth. The northeast corner of the mature moss/shrub forest grid, where canopy cover was less than 10% (in contrast to 25–50% closure elsewhere on the grid) and sedge was abundant, may have served as a small pocket of suitable yellow-cheeked vole habitat.

**Habitat characteristics and corresponding yellow-cheeked vole numbers for four different-aged, post-fire black spruce stands in Gates of the Arctic National Park and Preserve, Alaska, 1992–1994. Soils were characterized at two soil pits on each grid, and measurements reflect the depths at which each feature was first encountered.**

<i>Habitat characteristics</i>	<i>Burned moss/shrub forest</i>	<i>Mature moss/shrub forest</i>	<i>Burned lichen woodland</i>	<i>Mature lichen woodland</i>
Depth of organic layer (cm)	9	20	7	4–5
Depth to reduced and/or saturated soils (cm)	reduced: 30 and 60 saturated: >125	reduced: 12 and 45 saturated: 12 and >125*	reduced: 0 and 6 saturated: 72 and 75	reduced: 65 and 70 saturated: >125
Depth to permafrost (cm)	>125 *	55 and 100	>125 * cryoturbation: 6–20	88 and 122
Tree canopy closure (%)	1	45	10	35
Density of rhizome-producing plants (%)	25	10	5	3
Mean number of yellow-cheeked voles captured	23	6	5	0

\*Soil pits were 125 cm deep; >125 cm indicates that the feature was not encountered in the soil pit.

*Funding for this project was provided by the Minerals Management Division, National Park Service, Anchorage Field Area Office. This project is part of a cooperative effort by the Koyukuk/Nowitna National Wildlife Refuge, the Kanuti National Wildlife Refuge, and the Gates of the Arctic National Park and Preserve to study small mammals in post-fire seral stages.*

low-cheeked vole habitat; all yellow-cheeked voles captured on the grid were from this corner. Burrowing conditions were good in the 20-cm organic layer, but soils were wet or frozen below this layer. Graminoid and forb abundances may have been insufficient to sustain a larger yellow-cheeked vole population.

#### *Life is Lonely in Burned Lichen Woodland*

Of the small mammals captured on the grid, yellow-cheeked voles comprised 21% in 1992 and 56% in 1993; however, they were the only small-mammal species captured on the grid in 1994, when small-mammal populations were low on all the grids. All yellow-cheeked voles captured on the burned lichen woodland grid came from a colony situated in the southeast corner. Whether the colony existed prior to the 1991 fire is unknown, but the tremendous increase in excavations in and around the colony between the first and second years of the study indicated that it was expanding. The yellow-cheeked vole colony was situated on an unburned sphagnum moss area; the 1991 fire left burned lichens and bare mineral soil over much of the area, but unburned sphagnum moss hummocks and willow swales were interspersed throughout the burn. Digging conditions in the moss at the colony site appeared to be adequate, and downed trees and sphagnum moss hummocks provided sufficient escape cover.

The yellow-cheeked vole forb/rhizome diet may enable them to establish year-round residency in burned areas before other small-mammal species. Forb and graminoid availability was low during the first year of the study but increased slightly during the second and third years. Rhizomes and early successional forbs and grasses are often available for yellow-cheeked voles well before berry-producing plants are available for other small mammals (such as the red-backed vole); this may enable yellow-cheeked voles to overwinter on a recent burn when other species would have to move to more productive areas with greater berry availability in early to mid-winter.

Food sharing and communal nesting by yellow-cheeked voles in winter may also speed residency establishment on burns. Food caches established during the summer provide 90% of winter foods, which means less time and energy would be spent in foraging activity (Wolff and Lidicker 1980). Communal nesting would also decrease the amount of energy expended per individual to maintain body temperatures. A communal nesting and food sharing system may have enabled yellow-cheeked voles to persist on the burned lichen woodland grid in 1994 when other small-mammal species on the grid either died off or dispersed from the site.

#### *Life Can Be Grim in Mature Lichen Woodland*

The mature lichen woodland grid had the lowest abundance of small mammals and the lowest species diversity of all four black spruce types examined. Lack of escape cover, food and good digging conditions on the mature lichen woodland grid apparently precluded habitation by yellow-cheeked voles. Yellow-cheeked voles have been positively correlated with areas of greater micro-relief where herbaceous escape cover was abundant; herbaceous escape cover was particularly important in forests with moss- or lichen-dominated understory (such as that on the mature lichen woodland site) (Douglass 1977). Very little vertical herbaceous escape cover was available on this grid, and food sources associated with yellow-cheeked voles on the other grids in the study were either absent or present only in small quantities. Fireweed seldom persists into the mature black spruce stage, and horsetail cover is generally low on mature black spruce forest on permafrost (Foote 1983, D. Swanson 1996). Sedges can be relatively abundant in mature black spruce forest on permafrost (D. Swanson 1996), but they were sparse on this site.

Burrowing conditions for yellow-cheeked voles on this grid were marginal at best. The organic layer was the thinnest of the four grids studied, and moss only accounted for 1–5% of the ground cover. In addition, the soils were cold and wet in this habitat type. Permafrost was encountered at 88 and 122 cm below the organic layer in the two soil pits, and pitfall traps were often partially filled with water.

## *Conclusions*

The impacts of fire on small mammal populations, particularly the long-term effects, are hard to predict. In the short term, wildfire behavior and intensity can determine the soil conditions, the vegetation and consequently the habitat conditions in boreal vegetation communities. Wildfire appears to be an important factor for maintaining populations of yellow-cheeked voles by creating new habitat with good burrowing/digging conditions and abundant food supplies. Wildfire can indirectly alter the typically cold, moderately wet soils present in black spruce communities, making them warmer and drier within a few years post-fire. Yellow-cheeked voles, which create underground colonies and runway systems, seem to find these soil conditions highly compatible with their lifestyle.

Fire also promotes the growth and availability of plant species serving as the voles' main food supplies. Common post-fire plant species such as horsetail, fireweed, sedges and grasses are the pri-





The author with a 120-g yellow-cheeked vole, Gates of the Arctic National Park and Preserve.

mary food sources for yellow-cheeked voles; these plants often survive fires since they are rooted in mineral soil or have light seeds that are easily transported to the newly exposed soil. In addition to consuming the green vegetation from these plants in the summer, the rhizomes they produce are cached by yellow-cheeked voles for winter consumption. As the overstory canopy closes and vegetation composition changes over time, burned areas will likely become less habitable for yellow-cheeked voles. Perhaps they will then be sniffing the winds for the smell of smoke and the new habitat it may promise.

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# The Arctic Alaska Dinosaur Program

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Little did Robert Liscomb, a Shell Oil Company exploration geologist looking for oil prospects, suspect that a small collection of dark brown bones and bone fragments that he was making in 1961 along the Colville River would turn out to be one of the most significant discoveries in dinosaur science. In fact, it took over two decades before the true nature of these bones was clearly determined. Apparently the age of the entombing strata was questionable, and the general lack of extensive petrification and alteration did not allow Dr. Liscomb to appreciate the antiquity and dinosaurian origins of his find. The overlying Gubik Formation of Quaternary age can contain abundant vertebrate remains. Some 31 years later it is clear that Liscomb's field collection is part of a very Late Cretaceous (68–72 million years ago) fauna that occupied Arctic North America permanently or as seasonal migrants and that dinosaurs called the Arctic home over a period stretching from 100 to 68 million years ago.

The Arctic Alaska Dinosaur Program began in 1985 when a field team comprising personnel from the U.S. Geological Survey, the University of California at Berkeley's Museum of Paleontology and the University of Alaska Museum and Department of Geology and Geophysics confirmed and collected Dr. Liscomb's original field locality. Subsequently U.C.M.P. and the U.A. Museum carried on a joint research program from 1987 to 1990 supported by two National Science Foundation grants. In 1990 the bulk of the research program was assumed by the U.A. Museum's Department of Earth Sciences. Support for the program since 1990 has been a combination of State of Alaska funds,

Dwight D. Eisenhower Math and Science Education Act teacher training grants and private funds made available through The Dinosaur Society, Dinamation International Society and individual volunteers.

Although field work has been typically confined to a two-week period from late July to the middle of August over much of the last 12 years, efforts during this period have resulted in an extraordinary accumulation of dinosaur remains and associated contextual data. Most remains were collected from a single unit informally designated as the Liscomb bone bed. Over 6000 individual skeletal elements, ranging from teeth to leg bones, have been collected and cataloged. Most skeletal elements require little conservation or preparation to make them available for study, a most unusual occurrence. The fine-scale mapping and collection from the Liscomb bed have resulted in an unmatched data set. The 1996 field season, which was the longest ever attempted, added 783 specimens to the collections. Approximately 90% of the fossils were collected from the Liscomb bed.

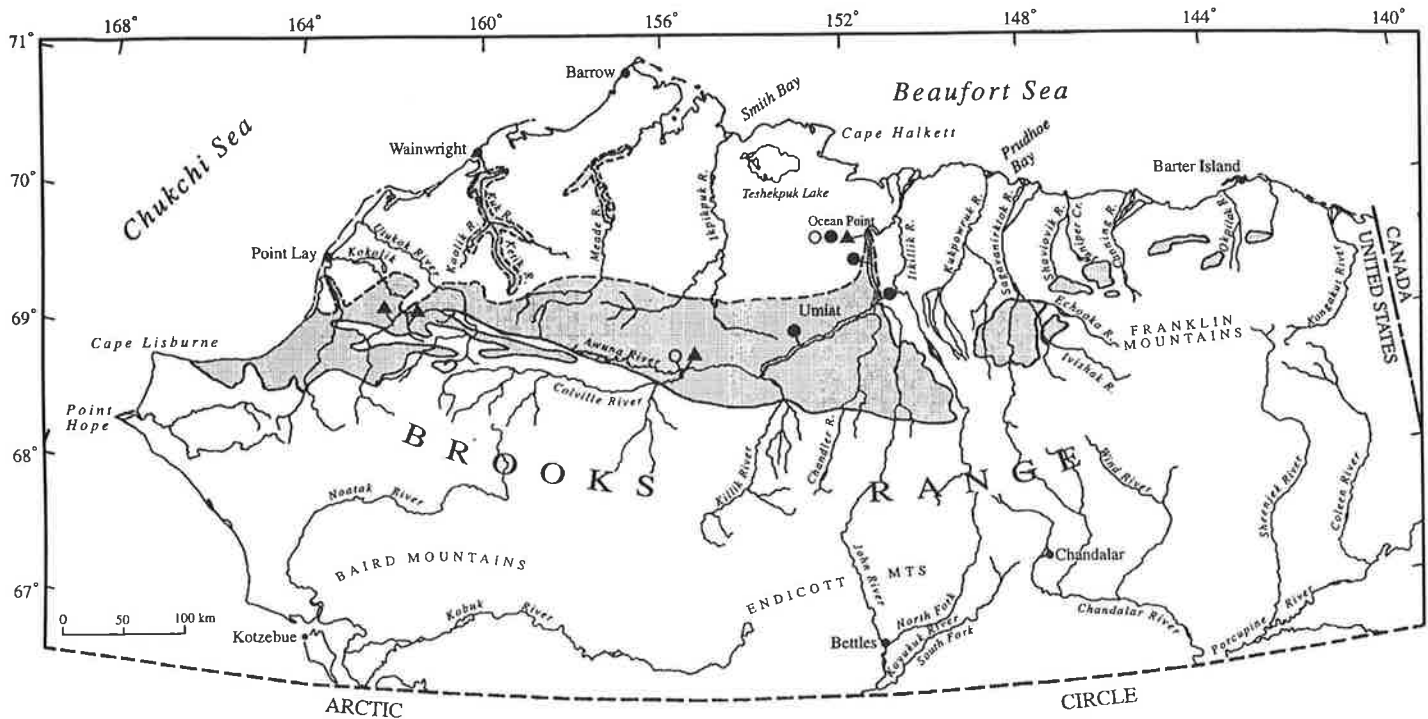
The data set from the Liscomb bed alone exceeds the grand total from all the published localities at the same or higher latitudes in both hemispheres. Thirteen locations yielding over 30 sites (Rich and Gangloff, in press) have been documented at paleolatitudes near or above the Arctic and Antarctic Circles during the Mesozoic. Twelve sites have been documented along a 60-mile stretch of the lower Colville River alone, with another four being found between Umiat and the upper reaches of the Kokolik River (Gangloff 1994). As one of my colleagues recently put it, "You may have the Arctic equivalent of the Red Deer River Valley of southern Alberta." This region of Canada has proven to contain the most diverse and abundant record of Cretaceous dinosaurs in North America.

The main components of the Arctic Alaska Dinosaur Program are:

- Excavation and collection of Cretaceous dinosaurs and associated vertebrates from a series of highly fossiliferous bone beds and lag deposits found along a nine-mile stretch just south of Ocean Point on the west side of the Colville River, including high-resolution, three-dimensional mapping of dinosaur remains combined with large-scale geochronologic, stratigraphic and sedimentological studies;
- Prospecting for new dinosaur and fossil

*Colville River bluffs, with the Liscomb bed just above the waterline. Note the layered Cretaceous rocks just above and the poorly consolidated Quaternary sands in the upper third of the photo.*





■ Nanushuk and Colville Group rocks (110–66 millions years old)

● Dinosaur teeth and bones

▲ Dinosaur tracks and skin impressions

○ Vertebrate fossils other than dinosaurs

*Geographic distribution of Cretaceous rocks that contain evidence of dinosaurs or offer the best possibilities for future finds, northern Alaska. (Modified from Huffman 1985.)*

vertebrate localities between previously documented sites, which entails exploring and prospecting along the Colville River for nearly 300 linear miles as well as several main tributaries such as the Awuna, requiring coverage of an area with the right age and types of deposits that enclose approximately 4000 square miles;

- Preparation, restoration and cataloging of thousands of skeletal elements, as well as systematizing the derived and contextual data with entry into a relational database;
- Study and analysis of the data obtained to arrive at an understanding of the age structure of dinosaur assemblages, conditions of death, burial and fossilization, and the establishment of the earliest appearance of Eurasian-derived dinosaur lineages in North America in order to test physiological, migrational, extinction and behavioral hypotheses related to Late Cretaceous dinosaurian records in North America; and
- Involvement of teachers, students and volunteers from 9th grade through university graduate levels in all aspects of the research, as well as involvement of colleagues from several disciplines, including paleobiology, geology, geophysics, molecular and field biology, engineering and statistics.

## *The Arctic Alaska Dinosaur Fauna*

All of the unequivocally Arctic dinosaurs thus far documented in Alaska are Cretaceous in age. The vast majority are very Late Cretaceous (74–68 million years ago) coming from a ten-mile stretch of the northern third of the Colville River. This area contains the most extensive record of body fossils found in bone beds such as the Liscomb bed, as well as the greatest variety of dinosaurs thus far identified. At least ten dinosaur taxa are known. The dinosaur fauna of Alaska is dominated by several types of hadrosaurs or duckbills. The most abundant fossils document the presence of a non-crested or flat-headed variety. Ceratopsian (horned) dinosaurs are primarily represented by cranial and postcranial fragments. However, a nearly complete upper cranium of the distinctive and rare taxon *Pachyrhinosaurus* was excavated in 1988. Theropods (bipedal carnivores) are represented by three to four families and a variety of teeth and bones.

## *Importance of Arctic Alaska Dinosaurs*

The Arctic Alaska dinosaurs are dominated by suborders and families that are Central Asian in their origins (Russell 1993) and show their closest affinities with faunas described from the Late Cretaceous of central to northern Alberta at the generic and species levels. This Cretaceous Asiatic

The last 12 years of work has been supported by grants from the National Science Foundation, the Dwight D. Eisenhower Mathematics and Science Education Act, the Dinosaur Society, the Geist Fund, the University of Alaska Museum and the generosity of volunteers from Alaska and other parts of the United States. The field portion of the program has been a cooperative effort joining personnel and resources from the Bureau of Land Management, the U.S. Geological Survey, the State of Alaska, the University of Alaska and U.A. Museum, Ilisagvik College of Barrow, Alaska, as well as the University of California at Berkeley's Museum of Paleontology.

## Arctic Alaska dinosaur fauna and associated vertebrates and plants.

### I. DINOSAURS

#### A. HADROSAURS

- Edmontosaurus* sp., most common duckbill, noncrested, juveniles and young adults dominate
- Kritosaurus* sp., noncrested duckbill, teeth only
- Lambeosaurid*, crested duckbill, teeth and upper jaw

#### B. CERATOPSIANS

- Pachyrhinosaurus* sp., nearly complete upper cranium, rare form found only in Alaska and Alberta, Canada
- Anchiceratops*-like form, part of the rear end of the skull

#### C. HYSILOPHODONTID

- Thescelosaurus* sp., small bipedal herbivore, teeth and toe bone

#### D. THEROPODS

1. Tyrannosaurid
  - Albertosaurus* sp., moderate to large, bipedal carnivore, teeth and bones
2. Troodontid
  - Troodon* sp., small, lightly built, large-brained, bipedal carnivore, teeth and skull fragments
3. Dromaeosaurids
  - Dromaeosaurus* sp., small, lightly built, large-brained, bipedal carnivore, teeth only
  - Saurornitholestes* sp., very similar to *Dromaeosaurus*, teeth and vertebra

### II. OTHER VERTEBRATES

#### A. Fish

- Acipenser* sp., an early sturgeon, vertebrae and dorsal spines
- Chandlerichthys strickeri*, a primitive teleost, preserved as thin carbon film

#### B. Turtle

- Possible dermatemydid pond turtle with Asian affinities. This is the earliest turtle from above the Arctic Circle, partial internal mold of carapace.

#### C. Plesiosaur

- A single tail vertebra tentatively assigned to this marine reptilian group

#### D. Crocodilians and amphibians conspicuously absent

### III. PLANTS

Forests consisted of coniferous trees with low-diversity angiosperm understory and ground cover. Ground cover of horsetails, ferns and some aquatic plants. Closest living analog is the coastal high-latitude, mixed coniferous forests of North America.

#### A. Wood

- Xenoxylem latiporosum* and six other taxa of conifers

#### B. Deciduous conifer

- Parataxodium wigginsii*, needles and fronds

#### C. Rushes

- Equisetites* sp., impressions and casts of stems, rhizomes and tubers

#### D. Angiosperms

- Hollickia quercifolia*, leaf and fruit(?) impressions
- Quereuxia angulata*, leaf impressions

character of the North American dinosaur fauna has been appreciated for some time. However, the prior lack of a high-latitude record in Alaska or the extreme northeastern part of Asia cast doubt on a postulated major land connection between eastern Eurasia and North America. The discoveries of Nessov (1992), combined with the abundant and diverse Arctic Alaska dinosaur fauna described here, strongly support such a Beringian-like connection between these continental areas in-

dependent of geomagnetic and paleotectonic data. The earliest evidence of such a connection is now of great interest to paleobiogeographers, as is the possibility of an eastern North American-western Eurasian migrational route. Presently the bulk of evidence points to the latter part of the Early Cretaceous as the time for the beginning of this great faunal interchange (Dore 1991, Vereschagin and Ronov 1968). Dinosaur research being carried on by James Kirkland in the Early Cretaceous of east-

central Utah promises to emphasize even more the critical biogeographic position of Alaska during the Cretaceous.

In addition to being central to questions concerning the intercontinental migration of dinosaurs, the Arctic Alaska dinosaur record is an integral part of the debate and theories concerning dinosaurian physiology, energetics and possible long-distance seasonal migration (Paul 1988, Currie 1989). The Alaskan record of dinosaurs is abundant and diverse for over 15 million years. This record, combined with discoveries of very high paleolatitude dinosaurs in Australia (Rich and Gangloff, in press) in Lower Cretaceous rocks (110 million years old), certainly strengthens the argument for the presence of endothermy or "warm-bloodedness" in some lineages of dinosaurs. Alternatives such as hibernation and long-distance seasonal migration must be considered if endothermy is not accepted.

One of the most intriguing and vexing questions concerning dinosaurs is the question of their extinction at the end of the Cretaceous. Much of the impetus and support for the work done from 1987 to 1990 on Arctic Alaska dinosaurs was directly aimed at addressing this fascinating question. The conclusions of Clemens and Nelms (1993) and Clemens (1994) challenge any impact scenario that calls for subsequent short-term catastrophic climatic effects as an explanation of dinosaur extinction (Alvarez 1986). Clemens and Nelms, in their research, never established the uppermost range of Arctic dinosaurs in Alaska. This aspect of their record still remains to be documented and is directly cogent to the testing of general extinction theories (Kauffman and Erwin 1995) that predict that high latitudes should be the last to experience mass extinction events like the one at the end of the Cretaceous.

### *Future Research Directions*

Although an unequaled collection or data set of fossil skeletal elements has been accrued thus far, continued collection from the Liscomb bed combined with comparable efforts in several other known bone beds is needed to test several hypotheses that have been put forward to explain the dinosaur age structure and seeming lack of critical ectothermic ("cold-blooded") reptiles and amphibians. This will require several new approaches to excavation and mapping of the deposits. One new and innovative methodology is centered on the use of a tunneling machine to dig permafrost-supported galleries above the bone beds and then quarry down from the galleries. This approach would result in the recovery of better data and, in



*Three elementary-school teachers from Fairbanks, Alaska, mapping and collecting dinosaur bones from the Liscomb bone bed.*

some cases, allow excavation of fossiliferous beds that are presently out of reach due to their positions high on the Colville bluffs. In addition, data collected in this manner would allow us to further test hypotheses explaining the age structure and conditions of accumulation and fossilization as well as the statistical validity of our present collections. The feasibility of such an approach was determined in 1994 thanks to the financial support of The Dinosaur Society. The project awaits finances to dig a prototype tunnel.

Exploration and prospecting expeditions are needed to search for new dinosaur-bearing sites and to properly document previously reported ones farther up the Colville River drainage and farther back into earlier Cretaceous time. It is critical to document the dinosaur and associated vertebrate assemblages throughout the Cretaceous in order to test and enhance the present paleoclimatic models based primarily on plant remains (Parrish et al. 1987). The first of several such expeditions is planned for the summer of 1997.

The first phase of research conducted by the author, students and volunteers has delimited several promising lines of investigation using the collections made to date. These include using gross anatomical and detailed histological studies of teeth and bones of the abundant hadrosaur to establish the age range and possible growth cycles and series of this most common form. Microbiological and biomolecular studies have begun in cooperation with researchers in France and Montana. Several preliminary studies of the variety of teeth representing non-hadrosaurs are in progress. This line of research promises to establish even greater diversity among the theropods than was previously appreciated. The theropods, or carnivorous dinosaurs, are also critical to establishing greater resolution regarding the ancient ecology of these animals at high latitudes. Preliminary data indicate that the theropods may be consistently smaller than their southern relatives and therefore reflect adaptations to colder climes.



*Dr. Gangloff with prepared duckbill dinosaur leg bones from the base of the Liscomb bone bed.*



Dave Norton pointing to volcanic ash bed lying above the Liscomb bone bed that allows for potassium-argon dating of the sequence.

## Conclusions

The Colville River from Umiat to Ocean Point, Alaska, has been documented, over the last 12 years, as the most productive dinosaur-bearing area in the polar region of either hemisphere. The last 12 years of effort only adds up to a little over three months of field work, the bulk of which has been concentrated at a single site and on only one rock unit—the Liscomb bed. However, much has already been determined. Dinosaurs were abundant and diverse during the Late Cretaceous of Arctic Alaska. Hadrosaurines or non-crested duckbills were dominant. These herbivores were accompanied by a variety of horned or ceratopsian species, as well as a variety of small to medium-sized carnivorous and scavenging forms called theropods. The Alaskan assemblage most closely resembles that found in contemporary deposits from central to northern Alberta, Canada. The presence of the rare ceratopsian *Pachyrhinosaurus* is especially definitive. The preponderance of evidence suggests that during the time the Liscomb bed was being deposited, Arctic Alaska dinosaurs were at a latitude of at least 70°N and were most probably residents or short-distance seasonal migrants.

At least one major route for terrestrial faunal interchange was well established by the Late Cretaceous. This route joined northeastern Eurasia and northwestern North America, as documented by dinosaur assemblages found in both regions. Determining the exact timing of this connection and its detailed history will depend on the further elucidation of the record of dinosaurs, associated vertebrates and fossil floral remains from Alaska and Chukotka.

A very small part of the massive mapping and exploration effort that has been expended in northern Alaska and the circum-Arctic since World War II has been directed towards discovery and study of dinosaurs and associated fossil vertebrates. Certainly much remains to be discovered, mapped and analyzed in this vast region.

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# The Mesa Project

## Interactions Between Early Prehistoric Humans and Environmental Change in Arctic Alaska

*This report was prepared by Michael L. Kunz, Bureau of Land Management, Northern District Office, Fairbanks, Alaska, and Daniel H. Mann, Institute of Arctic Biology and Department of Geology, University of Alaska Fairbanks.*

At the height of the last Ice Age, Alaska lay at the eastern end of the Bering Land Bridge, the dry land connection between Asia and North America. Alaska comprised most of the eastern portion of a large subcontinent called Beringia, which was made up of eastern Siberia, the Land Bridge, Alaska and part of the Yukon Territory. Until some time between 10,000 and 9,000 years before present (BP), humans and animals could walk across the Bering Strait on land that today is covered by 50 m of ocean water. Since humans evolved in the Old World and migrated to the New World, a perennial subject of archaeological debate has been, when did humans first cross the Land Bridge?

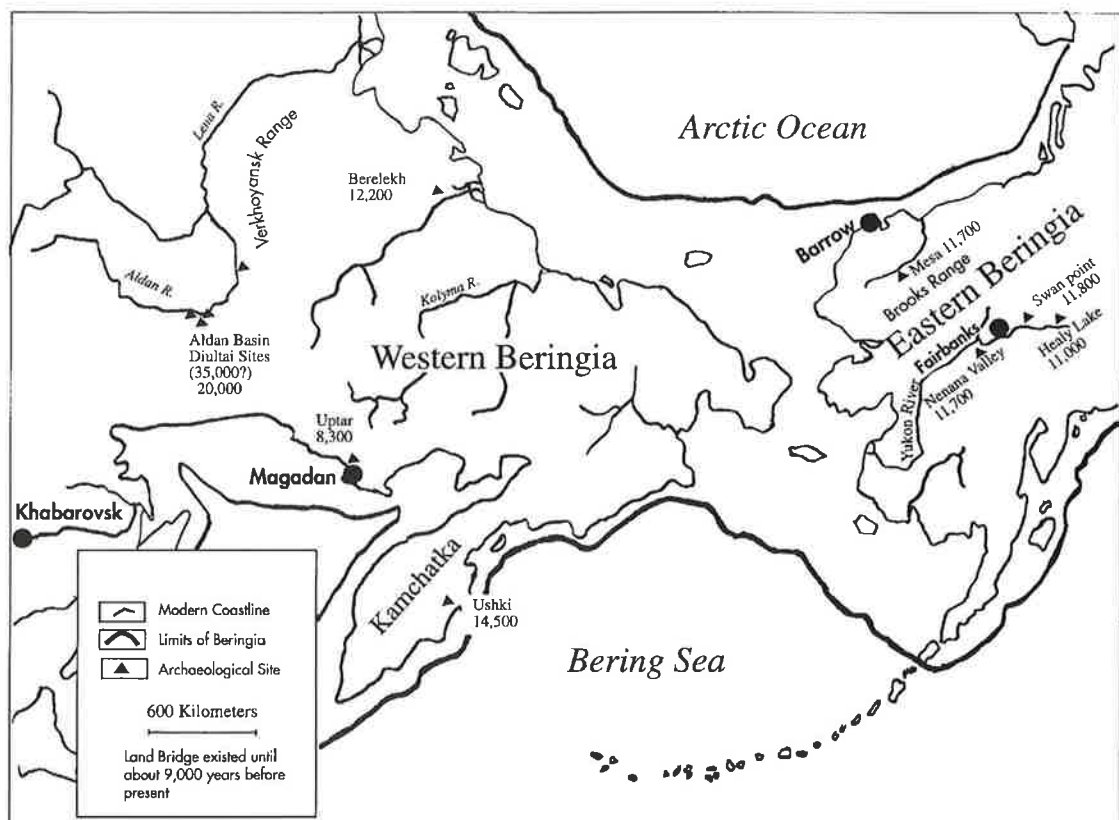
Although the debate is ongoing, the archaeological record of Alaska indicates that humans did not cross the Land Bridge and enter North America much before 12,000 years BP. However, what happened after these earliest immigrants reached eastern Beringia (Alaska) is the subject of even

greater debate. Did they enter the Western Hemisphere through Alaska, moving southeastward into the interior? Perhaps they took more exotic routes by sea along Alaska's southern coast or possibly across the open Pacific Ocean even farther south?

Answers to such questions about the earliest Americans and their travel routes probably await chance discoveries in the future. In the meantime there are several other intriguing pieces to the puzzle surrounding early humans in Alaska that are being addressed through an interdisciplinary project led by the Bureau of Land Management (BLM) in collaboration with researchers at the University of Alaska Fairbanks, Columbia University and NASA. The research is being conducted in northern Alaska, primarily within the National Petroleum Reserve-Alaska (NPR), and involves archaeology, geology, paleoecology, paleobotany and paleoclimatology.

The earliest, securely dated locales of human activity in Alaska come from the interval between

*Beringia, the Land Bridge, and archaeological site locations (ages in years before present).*



12,000 and 10,000 years BP, the final two millennia of the Pleistocene. These earliest Alaskans are represented by a number of archaeological sites in the Tanana and Nenana valleys and at several sites along the north flank of the Brooks Range. The surprising thing is that these ancient people are represented by three distinctly different stone-tool assemblages (lithic industries). In the archaeological record, technological diversity that occurs contemporaneously within a region is usually believed to mirror cultural diversity, and these three lithic industries—Denali, Nenana and Mesa—may represent two or possibly three culturally distinct groups. This is surprising because these first Americans would all be expected to be part of the same migration, be of the same culture, and therefore utilize the same lithic technology. It is interesting that the archaeological record of eastern Siberia does not indicate that the technological and cultural diversity of late-Pleistocene eastern Beringia was present there (Kunz and Reanier 1994). Since the techno-cultural diversity of eastern Beringia does not appear to stem from western Beringia (eastern Siberia), it may have evolved in place, possibly in response to more localized stimuli such as climate and environment.

The climate at the end of the last Ice Age was more changeable than at any time in the following 10,000 years. A variety of evidence indicates that between 12,000 and 9,000 years BP intervals of mild climate were followed by the sudden return

of full glacial conditions in the space of only a few years (Mann and Hamilton 1995). Such repeated radical swings in climate could have disrupted whole ecosystems. Therefore, the technological and cultural diversity among the human inhabitants of eastern Beringia during this time may be the result of humans trying to cope with unstable environmental conditions.

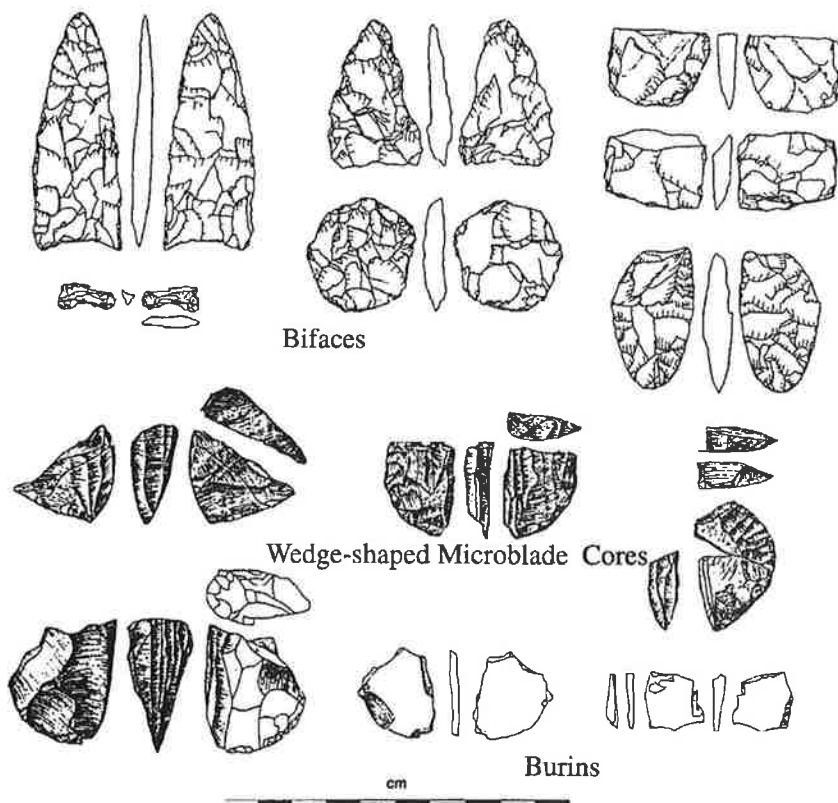
## The Mesa Site

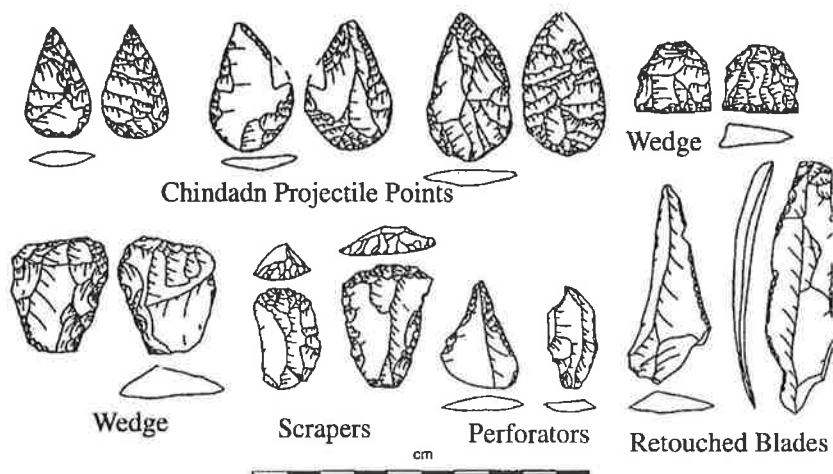
The Mesa is a sliver of igneous rock that was emplaced in the softer sedimentary country rock during the mountain-building event that created the Brooks Range about 125 million years ago. As part of the oil and gas exploration activities in the NPR-A, the Mesa was examined for the presence of archaeological remains when it was considered as a source of hard rock for riprap and crushed stone to cap the runway of a nearby test-well air strip. The site was found because some stone tools and chips were visible on the surface as the result of wind erosion of the sparse Arctic vegetation. The type and style of these surface artifacts suggested they might be Paleoindian and that the Mesa Site might represent an ancient cultural manifestation quite different from anything that had been previously found above the Arctic Circle in North America or Asia. The archaeological reconnaissance of the Mesa by BLM archaeologists prior to the onset of construction activities averted the destruction of what has proven to be one of the most significant North American archaeological sites to have been found in the last 50 years.

## Arctic Paleoindians

In the Arctic, stone artifacts are usually all that remain in unfrozen, shallowly buried locales of past human activity. This is especially true if the activity occurred more than a few thousand years ago. The type, style and association of the artifacts with each other provide archaeologists with a complex of traits by which a prehistoric culture or lithic industry can be identified and described. Almost without exception, pre-ceramic lithic industries are identified by their most distinctive component, usually a stone tool that is always manufactured by the same process and therefore always looks the same. Most often this diagnostic artifact is a projectile point. Culturally diagnostic projectile point forms are especially characteristic of the oldest archaeological cultures found in North America. Dating between ca. 12,000 and 8,500 years BP, this group of cultures, because of similarities in tool manufacture, subsistence patterns and geographic use areas, has been placed in

*Denali Complex tool assemblage. (After West 1995.)*



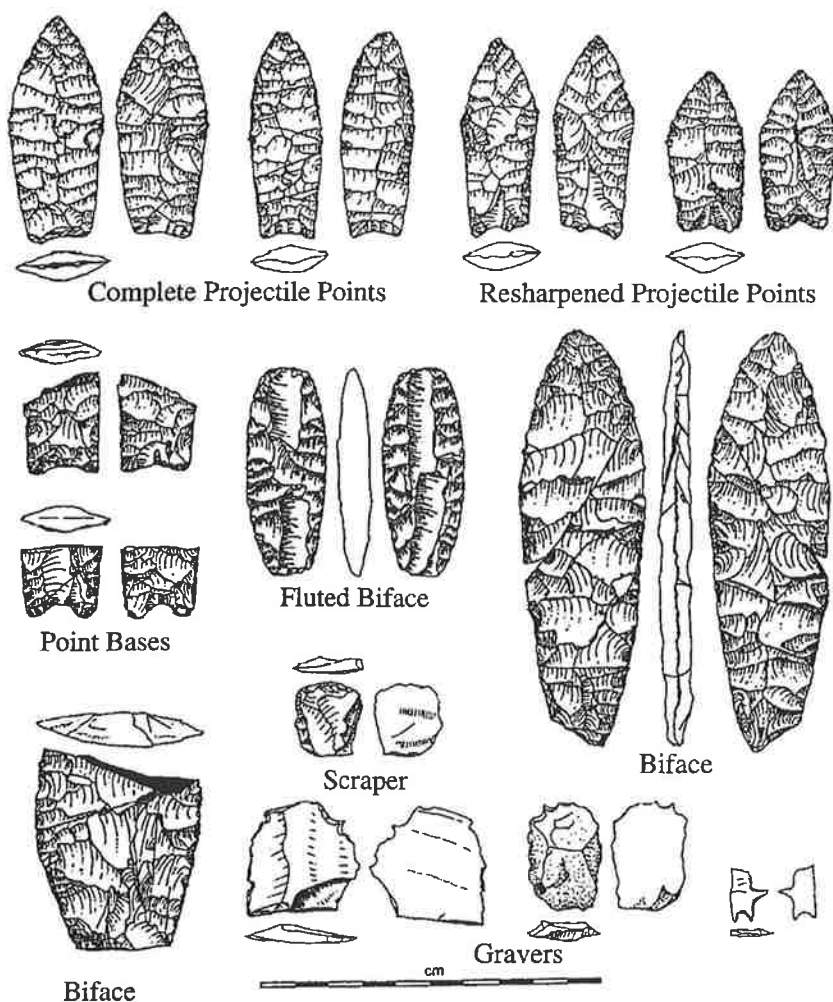


*Nenana Complex tool assemblage. (After West 1995.)*

a cultural/temporal/technological matrix referred to as the Paleoindian tradition (Irwin and Wormington 1970, Meltzer 1995).

In 1926 the first North American discovery of stone tools in direct association with the skeletal remains of extinct Ice Age animals was made near Folsom, New Mexico (Figgins 1927). This discovery indicated that the antiquity of humans in the New World was greater than previously believed.

*Mesa Complex tool assemblage. (After West 1995.)*

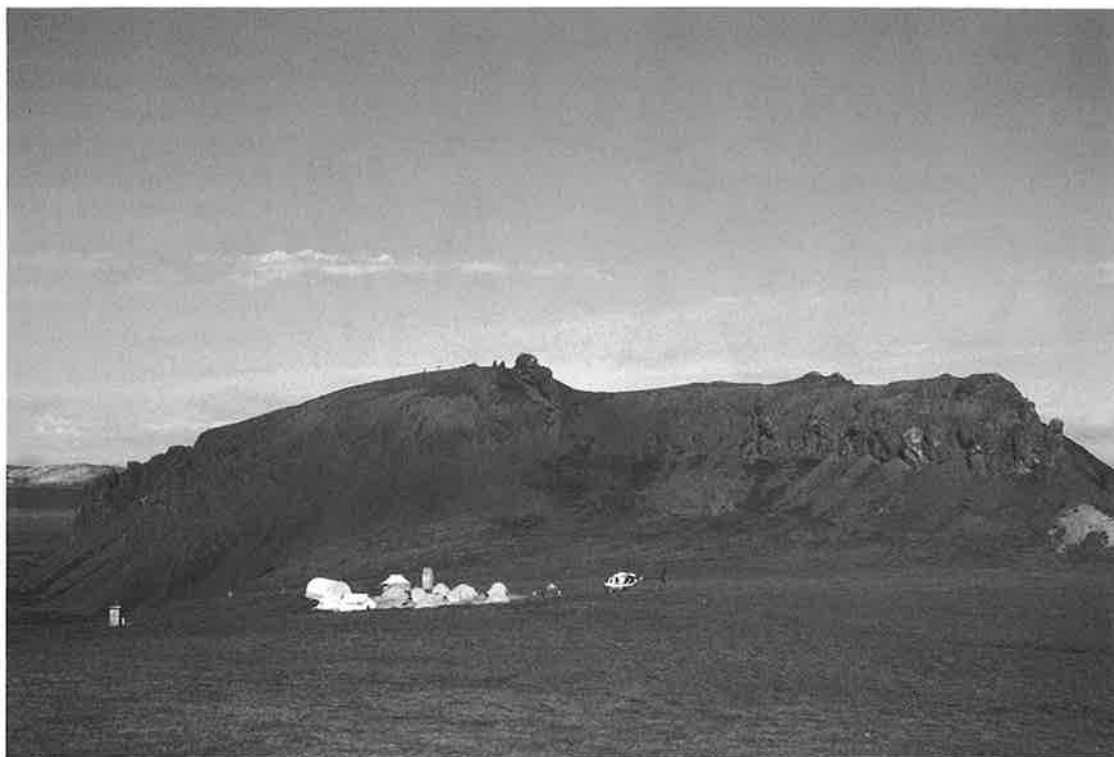


For the next 40 years archaeologists wondered why evidence of the earliest North Americans was found in the heartland of the continent, rather than near the ancient land bridge in eastern Beringia. It was not until the mid-1960s that two lithic industries of Paleoindian age—American Paleoarctic and Denali—were first reported from Alaska (Anderson 1968, 1970, West 1981) and another decade before the Nenana Complex was described (Powers and Hoffecker 1989, Holmes 1996). One of the reasons these terminal Pleistocene cultures/lithic industries in Alaska may have gone unrecognized as “American” for so long was that their stone tool assemblages were based on a core and blade technology very similar to that of their Old World Siberian contemporaries but quite different from the cobble/flake bifacial reduction technology of the mid-continent North American Paleoindians. In addition, none of the Alaskan assemblages were ever found in association with the remains of extinct Ice Age animals. Eventually refinements in the radiocarbon dating technique in the mid-1960s began to show that Alaskan lithic industries didn’t have to look like Paleoindian assemblages to be Paleoindian in age.

Given the marked differences between the Beringian core-and-blade-based technologies and the bifacial reduction technology of the Paleoindians, it seemed as though the Paleoindian cultural tradition and lithic industry just suddenly appeared in mid-continent North America. This spontaneous appearance occurs without any identifiable evolutionary connection to the roughly contemporaneous Beringian cultures, 6000 km to the north at the probable “upstream” end of the invasion corridor. This apparent paradox was explained away by the following hypothesis: sometime after the western Beringian immigrants arrived in eastern Beringia, they began to move south toward temperate North America, a journey that may have required 1000 years to complete. During this journey, these people were separated from the Old World/western Beringian techno-cultural influence. By the time 30–40 generations had lived and died on the road, these ancient immigrants reached the High Plains of North America. Over the course of their travels, their stone tool manufacturing technology had altered to the extent that their lithic industry retained few Old World/Beringian characteristics (Dumond 1980, Clark 1984), and it was these people who produced the classic Paleoindian artifact types.

### Archaeology of the Mesa Site

More than 100 complete and fragmentary projectile points have been recovered through excavation at the Mesa Site. These artifacts exhibit all the



*Research camp at the Mesa.*

technological and morphological traits that are diagnostic of projectile points of the Paleoindian tradition (Kunz and Reanier 1994). The associated artifacts and the flaking detritus are also typical of those found in Paleoindian sites of the High Plains and Desert Southwest (Kunz and Reanier 1995). The Mesa artifact assemblage is probably more securely dated than any other Paleoindian assemblage. Many of the diagnostic artifacts were recovered from the charcoal soil matrix of ancient campfires, so the association between the artifacts and the material used to date them is direct. Accelerator mass spectrometry (AMS) radiocarbon dates on charcoal recovered from the remains of more than 20 ancient campfires indicate the site was sporadically occupied between 11,700 and 9,700 years BP, the early and middle portions of the Paleoindian period in temperate North America (Kunz and Reanier 1995). Stone tool style and concordant radiocarbon dating demonstrate that the Mesa Site represents a Paleoindian presence in eastern Beringia during terminal Pleistocene times. Furthermore, the Mesa is not an isolated example of Paleoindian presence in the Arctic. At least three other northern Alaskan sites representing the Mesa lithic industry are now AMS radiocarbon dated to the same time period (Kunz and Reanier 1995, Reanier 1995, Ackerman 1996).

The presence of Paleoindians in eastern Beringia creates a theoretical dilemma regarding the cultural evolution of Paleoindians in general. Therein lies the basic importance of the Mesa discovery. Data from Mesa research have caused archaeolo-

gists to re-examine long-held theories concerning human migration to the New World and the cultural evolution of the earliest North Americans. Could the Paleoindians represent an obscure Old World culture that left few traces of its existence in northeast Asia before crossing into the North American Arctic at the end of the Pleistocene? Did the Paleoindians develop their distinctive lithic industry on land that is now covered by the waters of the Arctic Ocean, so most of the evidence for their presence in the Arctic lies below modern sea level? Certainly the fact that Paleoindians are proven to be present in eastern Beringia at the same time they are present in the heartland of the continent points out that the previously accepted model of Paleoindians evolving from an Old World Siberian culture en route to temperate North America is flawed.

### *Speculations about Subsistence and Environment*

The Mesa was used as a hunting lookout. This follows from its location as well as from the archaeological assemblage recovered there. The view from the top of the Mesa, 60 m above the valley floor, is unobstructed through 360 degrees and encompasses roughly 100 square kilometers, making it a perfect lookout for scanning the surrounding treeless countryside for game. Today, as was probably the case 12,000 years BP, the riparian zone of nearby Iteriak Creek is replete with the

resources required in daily activities, such as wood for construction and fuel, and a ready source of raw lithic material in the chert stream cobbles. The surface of the Mesa includes a considerable amount of level to near-level terrain utilized by the hunters as work areas to manufacture and repair their hunting equipment while keeping the surrounding area under surveillance. All of the artifacts found at the site, such as projectile points, gravers and large bifaces, are associated with hunting activities and the retooling of hunting kits. Most of the more than 100 points are represented either by the bases of broken points or points that were resharpened. We believe these projectile points were discarded atop the Mesa when the hunters repaired and replenished their hunting kits following a hunt. More than 300 stone tools and roughly 67,000 waste flakes, as well as the remains of more than 20 campfires, attest to the amount and intensity of the activity that occurred atop the Mesa (Kunz and Reanier 1995).

The concentrated use of the Mesa by ancient Paleoindians and the virtual absence of its use by other cultural groups from roughly 8,000 years BP to present suggests that ca. 12,000–10,000 years BP the local residents had a unique reason to make use of the site. In a treeless open landscape where views are extensive and generally unobstructed even at ground level, the intensive use of a point of elevation such as the Mesa strongly suggests a specific procurement strategy developed through a critical need to exploit a limited subsistence resource. This idea is bolstered by the settings of the three other known Mesa Complex sites—Bedwell, Hilltop and Spein Mountain. Although the easternmost and westernmost of these sites are separated by more than 800 km, like the Mesa, they are all located on promontories and were used as hunting lookouts (Kunz and Reanier 1995, Reanier 1995, Ackerman 1996). The geographical separation of the four sites suggests that the reasons for using promontory hunting lookouts existed throughout eastern Beringia during terminal Pleistocene times.

It is worth noting that caribou, because of their numbers and gregarious nature, can normally be hunted successfully without using a lookout of the Mesa's proportions. Many other archaeological sites lie in the Iteriak Creek valley and represent human occupation from at least 8000 years ago through historic times. Most of these sites lie on low creek-side bluffs, none of which offer a view equivalent to that of the Mesa. Yet caribou have been successfully hunted from these and other low-relief locales throughout the region for thousands of years. Following early Holocene times in this region of Alaska, there is little evidence for inten-

sive use of lofty hunting lookouts such as the Mesa, except for sheep hunting in the high Brooks Range. So why the intensive use of the Mesa only during this one interval of time in the past?

Paleoecological evidence suggests that the late Pleistocene vegetation in the region of the Mesa was considerably different than it is today. For instance, the late Pleistocene fossil record shows that almost all of the large herbivores, primarily ungulates, that inhabited eastern Beringia between 20,000 and 10,000 years ago were grazers (grass eaters) (Guthrie 1990, Guthrie and Stoker 1990, Hamilton and Ashley 1993). Most of these animals, such as horse, bison, antelope and mammoth, not only required a lot of grass for food, but a firm prairie-type (steppe-tundra) ground surface to achieve the mobility their survival demanded (Guthrie 1982, 1990). Since there is no modern analog for the Beringian vegetation regime (steppe-tundra), its presence may well have been due to a suite of environmental factors that have not existed in more than 10,000 years.

Pleistocene fossil evidence from the region suggests that the mega-fauna responded to a decrease in available habitat during the late Pleistocene with a continuous reduction in their numbers. An extensive suite of radiocarbon dates on late-Pleistocene fossils from northern Alaska indicates that by the time humans arrived in eastern Beringia, most of the Ice Age mega-fauna species were probably extinct and those that were not were few in number (Kunz 1996). Additionally the primary subsistence animal of the region for the last 8000 years, the caribou, appears to have been only a minor component of the late Pleistocene mega-fauna assemblage and perhaps not numerous enough to be considered a reliable subsistence resource (Guthrie 1968, 1990). Given the ecological conditions, we think that the use of the Mesa was somehow connected to the no-analog ecology of the region during terminal Pleistocene times. We are not sure what these people were hunting, but we strongly suspect it was not caribou. More likely they needed this type of lookout to locate widely dispersed solitary game animals or possibly small family groups of bison or mammoth. With subsistence resources extremely limited in a region that allows few options for survival, intensive use of a lookout locale like the Mesa, as a way of maximizing the return from hunting efforts, is understandable. It seems reasonable to speculate that the limited subsistence resources, coupled with an environment undergoing rapid changes, may have made the gateway to North America a rather inhospitable place in terminal Pleistocene times and created pressure for the rapid dispersal of humans southward.



## *The Mesa Project*

In a harsh environment like the Arctic's, where under the best of circumstances the availability of subsistence resources are often marginal, human prehistory is intrinsically connected to the history of climate. Human occupation of the Mesa Site was brief and appears to have been of a specialized nature that was not repeated during the subsequent 9,700 years. Was this brief period of occupation controlled by environmental change? How were the Mesa people making a living? How were these early Americans subsisting, and how was their spread into the New World influenced by changing climate? Our goal in the Mesa Project has been to build an interdisciplinary basis for interpreting the archaeological data by reconstructing the paleoenvironments in which the Mesa people lived.

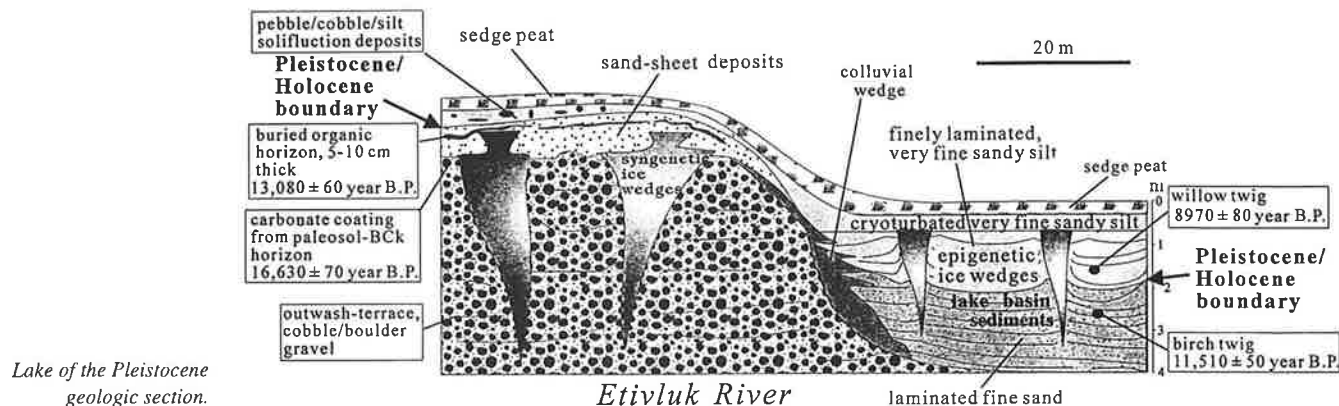
Our paleoenvironmental research has taken three main directions. Years of walking across tussock tundra has made the difficulty of foot travel north of the Brooks Range obvious to us. The formation of the modern tundra must have spelled an end to easy foot travel for humans. This idea was earlier described by Guthrie (1990) in relation to the demise of small-footed Pleistocene megafauna. We suspect that the abandonment of the Mesa Site by Paleoindians after 9,700 years BP may have coincided with the growing extent of tussock tundra in the region. We believe that before that date the substrate would have been gravel and/or sparsely vegetated silts. To test this idea we have conducted a landscape-structured drilling program, using a permafrost auger to obtain basal peat samples from representative landscape units (ridge lines, toe slopes, fluvial terraces, water tracks, etc.) in the 10 square kilometers surrounding the Mesa. The procedure is to drill down through soils and peats until we hit gravel or bedrock, then retrieve the lowermost 10 cm of sediment, sieve it for subfossil plant macrofossils, identify these macrofossils, and date them using the AMS radiocarbon technique. At present we have core samples from 15 sites around the Mesa, supplemented by eight stratigraphic sections in the banks of streams and rivers in the area. The bulk of our samples are either in the radiocarbon laboratory or are being examined for plant macrofossils. Preliminary data suggest widespread paludification (peat formation) started shortly after 10,000 years BP, although certain wet locales such as creek bottoms were colonized by tussock tundra vegetation and began accumulating peats ca. 12,000 years BP (Mann et al. 1994).

The second route we've taken towards reconstructing the paleoenvironments of the Mesa peo-

ple involves documenting changes in fluvial regime: how rivers, creeks and alluvial fans changed their flow regimes and channel forms through the time of human use at the Mesa. Fluvial landforms are crucial elements of the larger landscape because they create habitats for specialized plant communities, often highly productive for large herbivores and people, and by serving as a source for geomorphic disturbance. In the Arctic geomorphic disturbance is associated with sources of loess (wind-blown sand and silt) and with deep active layers (the depth of soil that thaws in summer). Abundant loess blowing off the wide, active floodplains of rivers and deep active layers is antithetical to the tussock tundra, with its associated accumulations of peat, cold soils, shallow active layers and resultant poor drainage. We think that the spread of tussock tundra occurred at the same time as a major change in fluvial regime from abundant barren alluvial fans and wide, braided floodplains to thickly vegetated slopes and narrow stream channels. Results to date suggest that this idea is correct. For example, a talus cone bordering the Mesa buried an 11,000-year-old floodplain of Mesa Creek, a small stream now flowing through a 1-m-wide, meandering channel between banks of peat and silt. AMS radiocarbon dates on sedge seeds deposited in pods of organics in channel beds of the buried stream provide age control. In contrast to the stream today, it was braided 11,000 years BP, flowing through multiple channels and carrying cobble gravel (Mann et al. 1994).

The third and most involved method of reconstructing paleoenvironments near the Mesa concerns a multidisciplinary reconstruction of vegetation and climate using a remarkable sedimentary archive that we found while fishing on the banks of the Etivluk River one evening. This geologic section lies 25 km west of the Mesa at a similar elevation and position relative to the northern front of the Brooks Range. It consists of an ancient lake bed (which we have named Lake of the Pleistocene, or LOP) exposed in cross section along 300 m of river bank. Depending on the level of the river, 4–5 m of lake bottom sediments are exposed in the cutbank. The LOP was drained approximately 5,000 years BP when the Etivluk River eroded through a gravel terrace and breached the lake basin. To scientists familiar with standard methods of sampling lake sediments using a coring tube several centimeters in diameter, the LOP section is a dream come true. It provides a laterally continuous section across an ancient lake roughly equivalent to 15,000 Livingstone cores taken side by side. Furthermore, the LOP sediments contain marker layers that we think record high wind events over the basin during prehistoric ice-free seasons. These "storm packets" are several

## LAKE OF THE PLEISTOCENE GEOLOGIC SECTION



centimeters thick and can be traced laterally for tens of meters. They consist of basal laminae of sand overlain by laminae of silt and finally by flattened willow leaves. We think the sand was transported into deep water during intervals of intense wave action at the shores of the ancient lake. After the sand settled to the bottom, less-dense particles settled on top. Willow leaves, blown into the lake from the surroundings, became waterlogged and settled last. In calmer weather, deposition of fine sands and silts in turn buried the storm packet. Using these storm packets as markers of continuous time horizons, we can obtain precise stratigraphic control laterally across tens of meters of section. This solves a perennial problem with the typically organic-poor sediments of Arctic lakes: obtaining enough terrestrial plant macrofossils to provide a paleoenvironmental record and yield reliable AMS radiocarbon dates. Because of contamination by old carbon, the majority of radiocarbon dates reported in the scientific literature on Arctic lakes are suspect, so paleoclimatic inferences based on sediments from these lakes are poorly constrained in time. The LOP offers the opportunity to obtain superb age control during an interval of Earth history, 12,500 to 5,000 years BP, relevant to the occupation of the Mesa Site and of great current interest for global change issues.

In 1996 we sampled a continuous vertical section from the deepest part of the LOP section. As a first step we obtained eight AMS radiocarbon dates on identified terrestrial plant macrofossils. The lowest sample is 12,500 years BP, and higher samples are progressively younger. We suspect that the LOP section continues several meters below river level and that the record may extend as far as 20,000 years BP. The LOP sediments contain abundant plant subfossils, including whole leaves, branches, twigs, seeds and, of course, pollen. Pollen, macrofossil and sediment analyses are underway at the University of Alaska Fairbanks and NASA. We also plan to measure paleomagnetic changes in inclination and declination with the idea

of establishing the first master section for magnetic stratigraphy in the region. Such a section will prove invaluable in dating the sediments of other lakes that lack the LOP's superlative AMS radiocarbon age control.

The product of our work at the Lake of the Pleistocene section will be a detailed reconstruction of vegetation through the time of human occupation of the Mesa Site. We should be able to detect the onset of tussock tundra spread in the pollen and plant macrofossil record preserved in the LOP. These results will be compared to our findings from the peat-coring portion of the research. The rate of inorganic sediment input into the LOP will provide a record of loess production. The timing of changes in loess production is relevant to the changes in fluvial regime that we are describing through field work in geomorphology and stratigraphy at other sections around the Mesa. Vegetation records from LOP will be interpreted in terms of regional climate change, contributing valuable, new, well-dated information on the rate and nature of past climatic changes in the Arctic. The storm packets in the LOP may provide a novel and valuable record of storm frequency during different time periods. In short, we hope to end up with a pretty good idea of the nature of "nature" between the end of the last Ice Age and the establishment of the modern tussock tundra.

### Summary

Our preliminary work indicates that results from interdisciplinary research in the Mesa Project will produce new and significant data regarding the human and natural history of the region that will be applicable to a wide range of past, present and future research. The Mesa Project as a whole will provide data bearing on the following topics: when humans first arrived in North America, the mystery of the sudden, near-simultaneous appearance of the Paleoindians in eastern Beringia and

midcontinent North America, and the relationship between the technologically diverse but contemporaneous cultures of eastern Beringia in the closing millennia of the Pleistocene. More specifically this research will provide us with a much better idea of what the human population of the region had to deal with on a daily and seasonal basis in terms of subsistence and survival. It follows that these data would also provide insights into the movement of cultural groups into and out of eastern Beringia, as well as the cultural and technological evolution of groups that were resident in the region. This package of information will help us interpret and map the progression of climate and environmental change in the region between the end of the Pleistocene and the establishment of modern Holocene climate and environment and see if coincidental changes occurred in technology and subsistence activities among the human residents of the region. Additionally this data may also be applicable to some aspects of today's global climate change research.

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# Past and Future in an Alaskan Desert

## Research in the Kobuk Sand Dunes

*This report was prepared by Daniel H. Mann, Institute of Arctic Biology, University of Alaska Fairbanks, and Patricia A. Heiser, Department of Geology and Geophysics, University of Alaska Fairbanks.*

Global warming is predicted to impact Arctic ecosystems first, probably within the next 50 years. The results could change the ranges of animals and plants, cause extinctions and change human subsistence patterns. However, there is still debate about these predictions: Will global warming really happen? How will natural systems respond?

The Kobuk sand dunes in northwestern Alaska are a globally unique desert ecosystem existing as an island within the boreal forest. They persist in a tension zone between desert and forest, and they may be teetering on the edge of change. The primary goal of our project is to understand how geomorphic and biological processes interact with climate to control the past, present and future extent, activity and ecological integrity of the Kobuk dunes.

### Setting

The Kobuk River drains into the Chukchi Sea near the town of Kotzebue in northwestern Alaska. Eighty kilometers upstream are the Kobuk dunes, roughly 100 km<sup>2</sup> of active, transverse and barchanoid dunes as much as 30 m high. The dune sands come from Pleistocene glacial sediments derived from the Brooks Range and transported into the area by the Kobuk River. Today the active dunes are isolated from the river by several kilometers of dense vegetation, making it a closed system with regard to sand supply. Throughout the late Pleistocene (the last 500,000 years), strong winds blowing

out of the northeast have pushed the yellowish-brown dunes westward through the middle reaches of the Kobuk valley. Today only the extreme downwind portion of what was formerly a much larger area of sand dunes is still active. Large areas upwind of the active dunes are vegetated by spruce parkland growing among the scars left by old blowouts. Around the rest of its margin, the Kobuk dunes are hemmed in by forests of spruce and birch.

The Kobuk dunes are a very unusual desert system. None of the other landforms typical of deserts in the American West or the Sahara, such as bajadas, playa lakes, hamadas or pediments, are present in the Kobuk valley. There are the dunes, an occasional boundary zone of sand sheets and then the boreal forest. The climatic setting of the Kobuk dunes is also unusual for a desert, with annual precipitation of about 420 mm, approximately a third more than the annual precipitation at Fairbanks. The striking juxtaposition of active dunes and dense boreal forest under conditions of a relatively humid climate and a limited sand supply make us suspect the Kobuk dunes exist in a sensitive balance between desertification and forestation.

### Background on Alaskan Sand Dunes

Geological mapping by David Hopkins (University of Alaska), Peter Lea (Bowdoin College) and others revealed that fossil dunes and sand sheets once covered more than 50,000 km<sup>2</sup> in interior and northern Alaska. Most were active during the last glacial maximum (23,000 to 17,000 years ago), although the stratigraphy indicates a complicated succession of eolian landscapes through time, including during the Holocene (the last 10,000 years). The nature and extent of dune fields are typically controlled by sand supply, height of the water table, windiness and vegetation cover. Climate affects all these factors and hence exerts ultimate control over the activation and stabilization of dune and sand sheet systems. For example, climate changes occurring during the transition from the last ice age to the present interglacial period in northern Alaska correlate well with changing eolian activity in the Teshekpuk dune field on Alaska's North Slope described by David Carter of the U.S. Geological Survey.

Location of the Kobuk sand dunes.



## *Global Change Research and Arctic Deserts*

Geological and biological processes in the Arctic are in general poorly understood. Consequently the responses of high-latitude ecosystems to global environmental changes are difficult to predict. However, if global climate models are correct, these poorly understood systems will be the first ones affected by greenhouse warming. The sensitivity of high latitudes to climatic changes is not unique to the present but was probably a feature of the Arctic throughout geological time. This means that the Arctic has two important roles to play in global change research. First, it is an early warning site for human-caused environmental change. Second, Arctic landscapes contain geological and biological records of the impacts of previous global changes. By interpreting these records, we can identify keystone processes, thresholds and possible effects of the climatic changes now threatening.

The use of Arctic sites to monitor global changes is not straightforward because initial greenhouse warming will be a very weak signal, difficult to distinguish from the noisy background of the climate system. In fact, although a warming trend since 1900 A.D. has been identified by some workers, others are skeptical and there is debate about the interpretation of this warming. To avoid this problem of interpretation, we need to isolate and identify the signal of anthropogenic climate changes in the Arctic environment. To do that,

we first need to understand the background signal of "natural" changes. This entails understanding the histories of cause and effect of the natural processes that have assembled the landscapes and ecosystems we see today.

### *Research at the Kobuk Dunes*

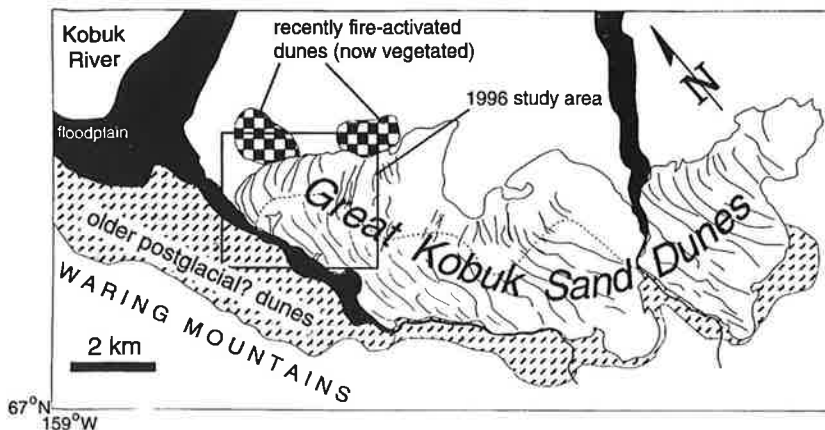
Prior to our study, geomorphic maps of the dunes had been made but little else was known. In 1996 we received a small grant from the Beringian Heritage Program of the National Park Service to start a multi-year study aimed at deciphering the processes maintaining the Kobuk sand dunes. Our goal is to test the hypothesis that the Kobuk dunes are a sensitive indicator system responding to past and future global changes. More generally we want to find out as much as we can about this unique Arctic ecosystem. Fundamental to these goals are reconstructing the history of the dunes, especially during the last 10,000 years, and deciphering the processes responsible for their activity and stabilization. Specifically we want to know:

- How big has the dunefield been in the past and how do changes in its size relate to climate change?
- What nonclimatic factors are important? Possible nonclimatic factors may be water table position and fire frequency in the surrounding vegetation. Before we can describe the dunes' responses to climate, we must try to filter out their nonclimatic responses.
- In 1997, contingent on funding, we hope to

*The Great Kobuk Sand  
Dunes.*







*The Great Kobuk Sand Dunes, which are moving westward onto the lower slopes of the Waring Mountains. Their advance displaces surface streams, possibly changing the water table in the dune field.*

expand our investigations to include a paleo-hydrological component that will reconstruct the water-level history from the sediments of lakes located near the dune margin. This work will be directed by Bruce Finney of the Institute for Marine Science at the University of Alaska Fairbanks. From lake cores we also hope to describe the history of vegetation in the area. Specifically Mary Edwards of the University of Alaska's Department of Biology wants to know when the forest first developed around the margins of the Kobuk dunes. Spruce trees may be a recent arrival to this part of Alaska, and their arrival may have started constricting the extent of the dunes by stabilizing soils around their margins.

## Work in Progress

### Dune Field History

In late summer 1996 we visited the western margin of the Great Kobuk Sand Dunes, one of two active dune areas. Tramping through the tangle of old forest fire debris west of Kavet Creek, we discovered that the ancient Kobuk dune field once extended across Kavet Creek and downstream along the south side of the Kobuk River for at least 20 km. This area is outside the region of previous geomorphic mapping and represents a large addition to the previously known extent of the ancient Kobuk sand sea.

Work in the dunes themselves revealed that a

forested area of approximately 10 km<sup>2</sup> at the northwestern corner of the Great Kobuk dunes was buried by dunes after 4000 years ago. <sup>14</sup>C dates on a thick forest soil now buried except in interdune swales tend to become younger towards the dune margin, suggesting progressive burial as the dunes expanded to the northwest. This forest was composed of spruce and birch trees. Mammal bones and human stone artifacts occur at several sites. Two stratigraphic sections exposed along Kavet Creek record the burial of former floodplains under encroaching dunes after 1400 years ago. We estimate a rate of dune spread of approximately 1 km per 1000 years. This rate is surprisingly slow but consistent with comparisons of aerial photography from 1958 and 1978 and the location of the dune margin today.

### Fire History

Wildfires are common in the Kobuk valley. We think they are potential triggers for widespread dune reactivation. In September 1996 we obtained 500 tree-ring cores from white spruce growing in fire-break areas along the dune margin. These cores are now being mounted on wooden blocks, finely sanded to reveal the tree rings, and counted. The ages of these 500 trees will describe the age structure of the forest and reveal intervals of tree establishment. In interior Alaska, white spruce forests are established mainly after fires, so their population-age structure record the timing of past fires. Our record will provide the first complete description of fire history in the area of the dunes. Tree-ring counts in the field revealed that some white spruce are very old; the oldest was 380 years. Furthermore the ring widths are highly variable, suggesting that these trees are highly sensitive to climate change and can provide a valuable record of changes in climate over the last four centuries. The same ring-marker years, distinctive sequences of rings formed under unusual climatic conditions, occur in the Kobuk dune trees as in trees near Fairbanks. This is exciting because these Fairbanks trees show sensitive responses to summer drought. A dendrochronological record of summer drought at the dunes could have direct relevance to the history of dune activity.

# *International Cooperation in the Beringia Region*

*This report was prepared by  
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Beringia has been a focal point for generations of humans, from the earliest peopling of the Americas to the present day. It is a vast territory in the Arctic, spanning two continents and three nations and centered on the Bering Strait between Alaska and the Russian Far East.

The Beringia program of the National Park Service (NPS) in Alaska developed from a recommendation in 1989 by a joint Soviet and American planning team for the creation of an international park in this remarkable region. On the American side the proposed park would be an umbrella program for existing park units, with no further restrictions on use or access. The Russian side would designate one or several newly created park units for their component of the park. While the long-term focus of the program is the establishment of an international park with Russia, the day-to-day practical application is two-fold: to promote interdisciplinary research in the region, and to work with Alaskan Native and Russian organizations on conservation and cultural issues. The guiding principles of the program are to foster a climate of mutual understanding and cooperation with people in the region in the conservation of flora and fauna, to assist in the re-establishment of cultural traditions between indigenous people in Alaska and Russia, and to meaningfully involve local communities in the Beringia program.

## *Academic Research*

The past six years of scientific research have been outstanding. The first unifying theme—studying the landscape over which early man traveled—has attracted noted scholars from across the United States and Russia. This has resulted in discoveries and sharing of information in both countries and in a wealth of scholarly publications. For instance, a layer of soil and vegetation buried under volcanic ash 17,000 years ago has yielded clues about the climate and vegetation cover that existed before humans inhabited the area. Present-day inventories and comparisons of plants and animals on both sides of the straits has produced surprises of new species in North America and one new species previously unknown to science. Coastal processes in the Arctic are becoming better understood. This information has relevance for all the coastal villages in western Alaska.

The social sciences are also well represented.

Ancient pit houses dot both coastlines and are just beginning to tell their stories. Other studies in ethnography and archeology have been undertaken—kinship, reindeer herding, science camps for village youths, and trade fairs, to mention a few. Native dancers from Russia have reintroduced dances lost from the Alaskan repertoire.

## *Partnering with Native Organizations*

The research proposals we fund directly are prioritized by a review panel, comprising three representatives of Alaska Native Corporations and two NPS management personnel. Having this panel work with us has strengthened our community ties and enhanced our working relationship with Alaska Native organizations. We now have a better balance of university academic research and local studies based on traditional knowledge. Our budget also reflects this balance. Nearly 80% of Beringia funding is passed on to researchers, with the remainder used for education and administration. In 1996, Native organizations received about 70% of these research dollars, and universities received nearly 30%.

The NPS has successfully completed its first Annual Funding Agreement (AFA) under Indian Self Governance with one of our Beringia partners. This AFA will enable the completion of an extensive oral history collection from the Bering Straits region. In addition to this agreement, we are funding a Native researcher to study the traditional use of seabird colonies on St. Lawrence Island and Native leaders in Chukotka to study subsistence use of natural resources. The seabird study received joint funding for a census of the colonies to help determine the health of the Bering Sea, one of the premiere fisheries in the world. Some of these rookeries contain over 350,000 individuals of one species. The Chukotka work received companion funding from the North Slope Borough and is a follow-up to an earlier whale migration study sponsored by the University of Alaska Anchorage.

## *Relationship with Chukotka*

Part of the international aspect of the Beringia program is to promote the exchange of research and to foster working relationships between Ameri-

can and Russian scientists. Working in Chukotka and other areas of the Russian Far East presents opportunities and challenges: opportunities to conduct comparative studies and to exchange years of data collected from parks and preserves; challenges of travel, language and permits.

In 1996 the NPS began working with the regional authorities of Chukotka to improve the exchange of scientists doing work in Alaska and Chukotka and to enhance the development of research activities. We will continue this effort in 1997. This focus reflects the decentralization of authority from the central government to regional administrations in Russia and indeed throughout the Arctic. Two areas that are receiving immediate attention are the exchange of bibliographic information covering literature in the Beringia region and the coordination of research and travel planning for visiting scientists of both countries.

### *Education*

A large element of the Beringia program is directed toward educational activities. This is in keeping with the NPS mission in education as carried out through its interpretive programs. On the local level this is accomplished in a variety of ways. Foremost is the importance of researchers, doing work in the region, to report the results of their findings to the residents in the villages. We also applaud researchers who invite local high school students to join in the field work and encourage this next generation of scientists. We have conducted science camps in the area and would like to continue to do so. Native language education is also an important part of our program. Video productions are being prepared for use in area schools for Native language and cultural education. Park service personnel fluent in Native languages have assisted with oral history collections and interview studies.

Our cooperative agreements with universities provide for partial funding of graduate students to

assist research projects. Several masters and doctoral degrees have been earned doing work on Beringia projects. As these academics begin their careers all across the nation, they carry the interest of Beringia to other universities. They, in turn, interest their students in doing research in western Alaska and Chukotka.

In Russia we provided support for the publication of the proceedings of the American Association for the Advancement of Science conference held in Anchorage and in Vladivostok. We also conducted a conservation workshop pertaining to tourism on public lands in Magadan and Anchorage. This workshop was attended by park managers from all regions of the Russian Far East and Sakha. Funding for museum displays in Provideniya of Native artifacts has been provided, and other funds have been awarded for training Native leadership in project management and natural resource issues.

### *Arctic Research*

Beringia is part of the larger pan-Arctic community. As such we have worked with the Inuit Circumpolar Conference, the Northern Forum and other similar organizations on Arctic issues. The common problems and research needs are best met by the close cooperation of the many organizations and institutions doing work in the region. We are striving to integrate work performed in our program with the larger Arctic scientific assembly.

### *Conclusion*

The Beringia program is a model program within the National Park Service. It is interdisciplinary in scope, and it bases its success on its extensive association with other institutions and individuals that have an interest in the region. In this post-Cold-War era, Beringia is a national symbolic and practical example of cooperation and discovery in the Arctic.

# *Traveling Between Continents*

## *Native Contacts Across the Bering Strait, 1898–1948*

*This report was prepared  
by Peter P. Schweitzer,  
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### *Introduction*

The area around Bering Strait served as a cross-roads of cultures until 1948, when Cold War politics terminated all official contacts across the strait. Mutual visits, trade, marriages and occasionally warfare created a closely interacting network of distinct but related Native societies. Despite an international border that cuts across the Bering Strait region, human and non-human life has been in constant interaction across the narrow body of water that separates the Eurasian and North American continents. To document and analyze the extent of cultural and social exchange that has been achieved by the Native residents of the area in countless generations, no other topic seemed more appropriate than travel, the material expression of a social process tying distant communities into a shared cultural universe.

Frequent travels across the Bering Strait by members of Alaskan and Chukotkan indigenous communities are a well-established fact. The problem starts once we want to know more about the details, structure and patterns of these contacts. Many elementary questions—like who traveled when, how and why—cannot be answered from the existing literature. In particular, the travels of the first half of the 20th century are hardly treated, since they are often thought to represent the decay of former periods. To analyze the functioning, essence and consequences of these inter-continental contacts, a four-year research project was initiated in 1993 within the Shared Beringian Heritage Program (SBHP) of the National Park Service. SBHP was initiated in 1991 and is a multidisciplinary, long-term research project directed towards a better understanding of the region's cultural and natural history.

Fieldwork during the summers of 1993–1996 was conducted in eleven communities on both sides of Bering Strait (Russia and Alaska). Linguistically and ethnically these villages consist of Inupiat, Naukan Yupiks and Chukchis. Besides the author and principal investigator, Evgeniy Golovko from St. Petersburg, Russia, was the only other researcher who took part in all phases of the project. In addition, Lawrence Kaplan has contributed to the linguistics of Bering Strait Inupiaq, Deanna Kingston has focused on the specifics of King Islanders' participation in these travels, and James Simon has looked at the role of reindeer

herding in this context. Herbert Anungazuk, originally from the Bering Strait community of Wales and currently with the National Park Service in Anchorage, contributed considerably during our work in Alaska in 1994 and 1996. Approximately 150 hours of taped interviews, countless hours of untaped interviews, in-depth genealogies for four communities, and a considerable collection of historic photographs have been assembled. In addition to already published first accounts of the project (Schweitzer and Golovko 1995, 1996, 1997), a draft monograph will be produced in the near future, synthesizing the collected data and presenting them to a wider audience.

### *Theoretical Approaches and Methods*

Our theoretical orientation was led by the conviction that a regional perspective, rather than one focusing on ethnic groups or categories, had to be applied. Eric Wolf's question of 1982—"If there are connections everywhere, why do we persist in turning dynamic, interconnected phenomena into static, disconnected things?"—has not lost its validity. Thus, our goal was to explore the dynamics of the relations between different communities as well as the range of their connectedness. Furthermore, we think that what is commonly called the "world-system approach" cannot be neglected in such a project (Wallerstein 1974).

Thus, we apply a framework for the analysis of culture contact situations in which both the expanding world-system and local systems are considered active forces (Sahlins 1994). However, we are not looking at Native travels as a mere response to the cycles of the world system but as an indigenous cultural, economic and social network adapting to outside influence. A logical result of the rejection of an approach that ultimately reduces everything to economic factors is the fact that we call the project "Traveling Between Continents" and not "Trading Between Continents." We are dealing with "networks of communication" (McNeil 1993), which encompass activities as diverse as warfare, marriage, trade, social visits and migrations. "Travel" should thus be best understood as both a metaphor and a physical expression of communication.

The concrete evidence of our inquiries consists mainly of oral testimonies provided by people who

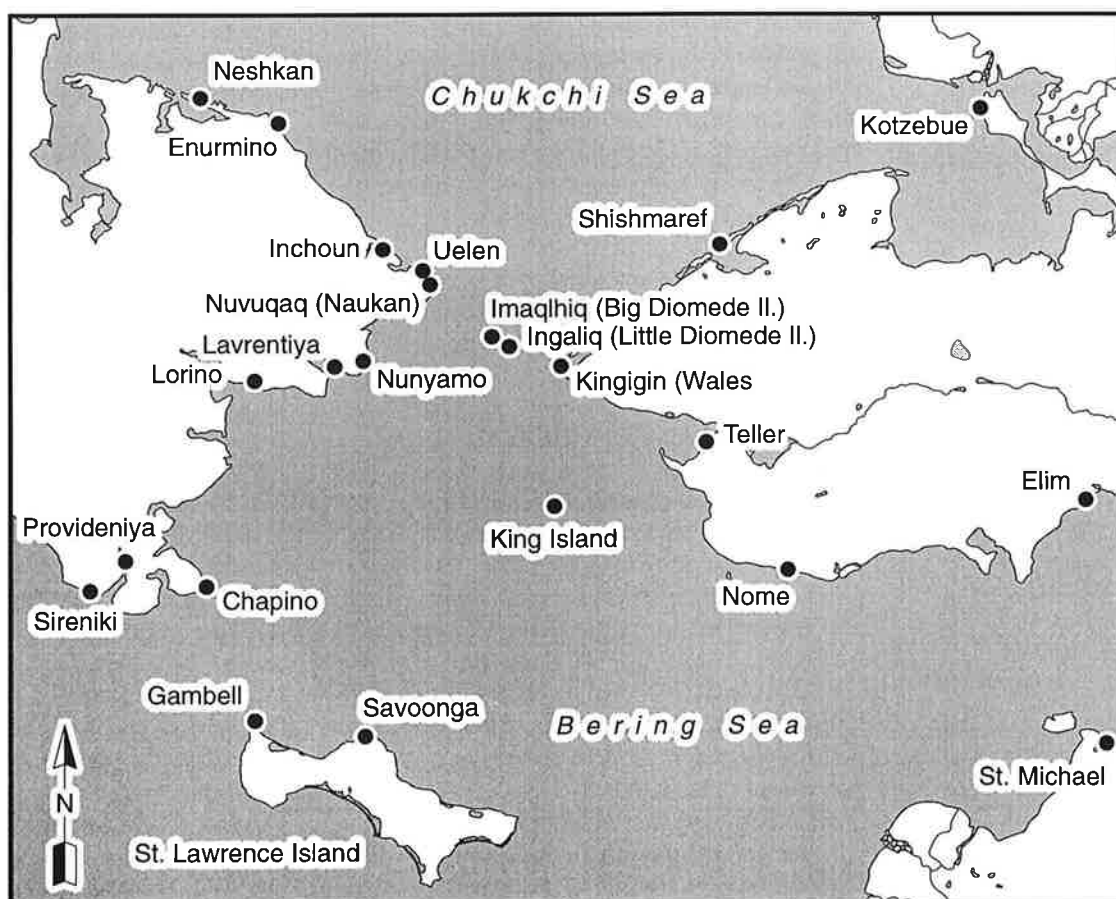
have either participated in travels or have experienced visits by guests from the other side of the strait. These memories are shaped by the personal life experiences of individuals, as well as by the collective dynamics of the social groups these individuals are members of. An important aspect of memory is forgetting, a constant side-effect of remembering, a structural necessity for ordering information. The important point is not that something is forgotten (which is inevitable) but what is forgotten.

Besides oral testimonies, we also have used written documents for the reconstruction of pre-1948 travels. Keeping in mind that written history itself is based on memory, we must critically evaluate both kinds of sources. Part of this evaluation is to keep in mind which position (or changing positions) the rememberer has occupied with regard to the event and its actors. In many cases the authors of written sources, being outsiders to the regional network under consideration, were in a superficial position to grasp the meaning of what they saw or heard. In any case, neither the oral nor the written account occupies a privileged position. Everything else being equal, writing "freezes" the memory at a particular point in time, while oral transmittance keeps the account dynamic and open to change.

Interviews were the main tool for eliciting information about the travels. Although we did not use a fixed or written interview schedule, several central questions concerning the informants' participation and/or knowledge about travels, marriage patterns, personal genealogies, etc., were asked in each interview. Since these central questions left enough room for the informants to talk about whatever seemed relevant to them in the context, our approach resembled structured interviews with open-ended questions. Participant observation, a classic and fundamental method of cultural anthropology, has little to offer for the treatment of our topics, at least on the surface, since the pre-1948 travels are obviously out of reach for present-day observation. However, the wider issue of interethnic and intercommunity relations was successfully approached by this method.

During each of the (mostly) taped interviews, we tried to collect personal genealogies from every informant. Some key informants provided additional genealogical information beyond their personal kindred in separate sessions, generally not taped. Archival sources were collected and analyzed to supplement the data on genealogies and household composition. In addition, a considerable collection of historic photographs, both

*Past and present villages in the Bering Strait area.*





from archives and from private collections, has been amassed. These images generally depict travel-related activities and/or individuals important in previous travels across the Bering Strait. The photographs are not only of historic value but have proven to be invaluable tools during interviews and talks, prompting memories of long ago to resurface.

### *Preliminary Results*

The frequency of travel during the first half of the 20th century showed no stable pattern of increase or decline. The most significant fact is that between the mid-1920s and the late 1930s there was very little travel across the Bering Strait. The decrease in travel activities in the 1920s can be partly explained by the social long-term effects of the 1918 influenza pandemic, which devastated several Alaskan Bering Strait villages, and by the increasing control Soviet authorities gained over the Asian side of the Bering Strait region. However, in 1938 an exchange of diplomatic notes between the U.S.S.R. and the U.S. formally recognized the right of Native residents of the Bering Strait area to cross the border without visas, while at the same time regulating and somehow restricting these movements (Krauss 1994). Throughout the 1940s (until the 1948 termination of all travel) the amount of travel increased significantly. While it is not entirely clear what the rationale behind these seemingly liberal policies was, it seems evident that Native Chukotkans were actively encouraged by Soviet authorities to visit Alaska during World War II, when provisions in the local stores were running low.

The question as to which communities were most active in travel across the Bering Strait can be answered by positing three categories of decreasing contact intensity:

- Communities that maintained regular (yearly) direct contacts up to 1948. In some cases (such as Uelen, Wales and King Island), these contacts were somehow loosened in the 1920s and 1930s, while Naukan and the Diomede Islands never discontinued these travels.
- Communities that had limited direct contact (mostly before 1920) but regular exposure to Native and non-Native goods from the other side. Small Chukchi villages north and south of Uelen, and the Inupiaq communities of Shishmaref, Teller and Kotzebue, are examples of this category.
- Communities that had never any direct or indirect contact with communities from the other side of the Bering Strait.

On one hand, these categories of decreasing contact correlate with the spatial distance of individual villages to the northern fringe of the Bering Strait. On the other hand, all of the communities in the first category were focused in their subsistence activities on large sea-mammal hunting on the open sea. Thus, they were technologically better equipped than others to undertake these journeys. Another important result is that intensive contacts did not exist only among Eskimo (that is, Inupiaq and Yupik) but also between Chukchi and Eskimo communities (for example, between Uelen and Little Diomede).

A particularly enigmatic aspect of the social relations across the Bering Strait are the differing and contradicting oral traditions of Chukotkans and Alaskans concerning intercontinental warfare (most of the historically documented cases occurred during the 18th and early 19th centuries). While almost nobody on the Russian side remembers any warfare activities with the American side, most people of the Seward Peninsula have kept oral traditions of Siberian attacks. The Little Diomedes report that there were war parties to both sides but that they normally did not join them. Together with the available historical evidence, this leads us to assume, first, that there were more raids from the Russian side, and second, that the oral traditions of both sides exhibit partial structural amnesia (the recollection of offensive action is eradicated in favor of successful defensive action, which seemingly took place more often on the American side). In addition, our interviews show some evidence that the generation raised on the Seward Peninsula during the Cold War is more outspoken regarding Siberian attacks.

Economic activities across the Bering Strait have a long-standing tradition. At least since the 18th century, European goods have been added to those already in circulation. Between the late 1920s and 1948, the Native part in the actual transportation of goods across the Bering Strait increased, due to the absence of Alaska-based non-Native traders who had dominated during the first two decades of the century. The difference between the two sides of the exchange was that the Chukotkans brought raw materials or goods of Native production to Alaska, while from Alaska to Chukotka went mainly goods of Euro-American production. At the same time, Naukan, and to a lesser degree Uelen, continued to play a major role as intermediaries between Chukotkan reindeer herders and Alaskan sea-mammal hunters.

Kinship links among the villages of the Bering Strait area were both the result of and precondition for travels beyond one's own community limits. Kin ties could be established through either nam-

ing, marriage, adoption or migration. Still, the boundary between kinsmen and partners was often fluid: this became visible to us when informants distinguished "relatives" (that is, partners) from "real relatives" (that is, kinsmen). To visit any community other than your home community, you needed pre-existing kinship or partnership links with somebody from the other community, or at least your social identity had to be traceable within the genealogical memory of the host community.

The frequency of kinship links between individual communities can be partially explained by geographical proximity, but social proximity is even more decisive. Between the 1920s and 1948 most newly established kinship links were between Uelen and Naukan on the one side and Little Diomed Island on the other side. Between 1898 and 1918–1922 some Alaskan communities (like King Island or Wales) were part of this kinship network, while in some cases (like Kauwerak, Kotzebue or Shishmaref) this dates back to the 19th century.

From a sociolinguistic point of view, the community of Naukan occupied an intermediary position. Naukan had close contacts with various Chukchi communities, as well as with the Eskimo communities of the two Diomed Islands and around Cape Prince of Wales. Besides their mother tongue the Naukan people had fairly good command of Chukchi, while almost no Chukchi could speak Naukanski. Between the Naukan people and the Inupiat of the Diomed Islands, there was an approximately equal level of bilingualism, which probably reflects a more balanced social relationship. An inevitable effect of interethnic contacts and bilingualism and multilingualism is a fair number of borrowings in all the languages under consideration. Chukchi and Naukanski, the Inupiaq dialects of the two Diomed Islands, Wales and King Island, show a certain mutual interaction of their vocabularies, as well as certain influence of English and Russian, in all cases depending on the length and intensity of contacts.

For a long time the notion was prevalent that there were no cases of pidginized Eskimo or Chukchi in the Chukotka area. Willem de Reuse (1994) was the first to provide linguistic and historic data showing that there might have indeed been several simplified trade languages in the area. However, during our field work we failed to obtain evidence of the existence of any jargon-like language system. At best, there are some hints that could be taken as indirect evidence for the existence of such jargons in the past: we received information that certain individuals, who have long passed away, did speak a particular kind of "English." It might be that the language referred to

was an English-based jargon to communicate with Yankee whalers.

The practice of personal naming across societal and linguistic boundaries in the area has attracted our attention (Schweitzer and Golovko, in press). While the general features of Eskimo naming systems are clearly present in the Bering Strait area, they are partly transformed through Chukchi influence. Thus, for example, the curious fact that many Naukan people bear personal names of Chukchi origin, while hardly any Chukchi person has a Naukan Yupik or Inupiaq name, could be interpreted as an indication of social dominance on the Chukchi part. However, it seems more likely that the structural differences between Eskimo and Chukchi naming systems—and the fact that they are, despite these differences, compatible—have caused this unequal distribution.

Another feature of these naming systems, which has received little attention in the anthropological literature, is that an individual may have more than one personal name. This circumstance caused initial confusion when we tried to match personal genealogies from both sides of the Bering Strait: there are instances when the same person is known under different names on the two sides of the strait. These multiple names were not necessarily from the same language. Thus, the common view that Eskimo societal boundaries coincide with a particular name universe does not seem applicable to the area under consideration.

A further consequence of our project is that we came to question the entire concept of rigid societal boundaries in the Bering Strait area. Our intention is not to redraw the boundary lines established by researchers such as Ray (1983) and Burch (1980, 1988) but to point out that their relevance was limited to certain contexts, such as the pursuit of subsistence activities. Our research indicates that intersocietal networks of communication were and are a social necessity for loosely organized groups to survive in an unpredictable environment.

## *Conclusions*

It seems evident that this intercontinental network has gone through a series of changes over the centuries. The recent reopening of the border and the resulting resumption of travels demonstrate that. Thus, the network of contacts across the Bering Strait can be viewed as an enduring, flexible and ever-changing social mechanism that is affected and influenced by regional and international developments.

While on the surface a multitude of new ele-

ments has appeared within this intercontinental network, the core seems to have remained the same: exchange. However, there are also structural changes essentially narrowing the realm of exchange. On the one hand, travels have lost their trading significance. On the other hand, especially in Chukotka, skinboat travels have ceased to be an integral part of everyday life. The overwhelming majority of hunters still do not own the boats they use and thus have little influence over where and when to travel. Even worse, it still happens that they have to wait for days to get cleared by border guards before visiting a neighboring Chukotkan village, to say nothing of travels between continents.

Nevertheless, the contemporary contacts are both continuation and innovation. The world, including Chukotka and Alaska, has changed tremendously between 1948 and 1988, and since then. There is no way of re-enacting the outward appearance of pre-1948 travels. However, after decades of focusing on the aspect of change in analyzing the 20th century, it seems necessary to pay more attention to structural continuities beneath the rapid change of material forms characterizing our age. Despite missionaries and party bosses, snowmobiles and TV sets, the cultural memory of transcultural contacts has been preserved, and it secures their future. Dealing with cultural processes in a diachronic perspective, we are sometimes forced to admit, quite unexpectedly, that the question is not one of continuity *or* change but of how the continuity *of* change shapes the development of tradition.

The work conducted within the project has made it clear that the majority of Chukotkan and Alaskan Bering Strait residents are conscious and proud of their historical connections to the other side, despite decades of negative stereotyping during the Cold War. The awareness of the pre-1948 travels is not only part of their cultural heritage but also plays an important role in contemporary contacts.

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# *The International Arctic Environmental Data Directory*

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Recent geopolitical changes have opened up new avenues for environmental protection and research cooperation in the Arctic. New initiatives such as the Arctic Environmental Protection Strategy (AEPS) and the Arctic Council have stimulated the need to locate and assess relevant environmental Arctic data and information. Identifying reliable sources of Arctic data and information is a recurring theme in these and many other international scientific, technical and political programs.

In September 1993, representatives from the IARPC met with data managers from the United Nation's Environmental Programme (UNEP) Global Resources Information Database (GRID) center in Arendal, Norway, and representatives from other Arctic-rim countries to create an international metadata directory for Arctic environmental data. A first step at this initiation workshop was the creation of an international steering committee (the Council) and a technical committee to oversee the growth and development of the directory. Titled the International Arctic Environmental Data Directory, or ADD, the directory has grown to become a significant source of information and data about the Arctic. The concept and the operation of the ADD are similar to that of the IARPC's Arctic Environmental Data Directory (AEDD), maintained by the USGS. USGS representatives are members of both the ADD Council and the ADD technical committee.

The Council is composed of members from countries with major Arctic data holdings and international circum-Arctic organizations with Arctic data directories. Institutes and other organizations having Arctic data sets may be linked to the ADD by "affiliation." The Council, composed of members from Canada, Denmark, Finland, Germany, Norway, Russia, Sweden and the U.S., defined the mission of the ADD as "to provide the international user community with an efficient and up-to-date mechanism for locating and assessing sources of Arctic environmental data and information." The Council identified the "international user community" to include "researchers in governmental agencies and academia, public interest groups, the private sector; educators at all levels; decision-makers in politics, environmental planning and management, industry and business; and the general public."

The Council developed seven objectives of the ADD process:

1. Establish the ADD as an authoritative, high-quality and user-friendly directory of environmental data sources covering the Arctic region.
2. Assess the quality and reliability of dataset descriptions by means of a set of internationally agreed-upon criteria.
3. Provide worldwide access to the ADD via the Internet. Through the Internet, directory components will be linked to a consistent, high-quality data and information source available to the global community.
4. Identify and form working relationships with institutions that hold Arctic environmental data, and inform them about and seek to reference their data in the ADD.
5. Seek advice from, and develop feedback mechanisms with, the international Arctic science and environmental planning and management community in order to establish and maintain the relevance of the ADD for addressing key environmental issues.
6. By using agreed-upon standards, develop and implement a process to identify, gather and maintain dataset descriptions that are consistent, complete, accurate and timely such that they meet the needs of the user community.
7. Promote the preservation and use of Arctic environmental data and information.

In addition to country members, usually drawn from national polar institutes, international organizations that are members of the Council or affiliated with the ADD include the Arctic Monitoring and Assessment Program (AMAP), the Conservation of Arctic Flora and Fauna (CAFF), the International Arctic Science Committee (IASC), Protection of the Arctic Marine Environment (PAME), UNEP, the Scientific Committee for Antarctic Research (SCAR) and the International Permafrost Association (IPA).

Addressing the data needs in the regions of the former Soviet Union is particularly challenging. More than half of the Arctic land area lies within the Russian Federation. Access to reliable environmental information from this area is vital to our understanding of circumpolar and global environmental processes and of the overall state of the Arctic environment. Consequently one of the primary tasks of the ADD Council has been to foster Russian participation in the ADD and to establish a Russian node for data entry. In September 1995,

*The Internet address of the  
ADD is [http://www.grida.no/  
prog/polar/add/](http://www.grida.no/prog/polar/add/)*

a workshop was held in Moscow to describe the ADD concept to nearly 100 attendees from Russian Arctic science information institutes. The workshop was jointly sponsored by the then Russian Ministry (now State Committee) of Environment Protection and Natural Resources.

As a result of the workshop the Council and technical committee have been actively working towards a large Russian node of the ADD. To accomplish this the ADD members are finalizing a standardized data interchange format (DIF) and descriptive metadata document for both English-language and Russian-language entries; producing a Russian language "starter kit" consisting of a simple step-by-step, "how-to" text in Russian, key words in Russian, DIF format in Russian, and several examples of completed Russian data set descriptions; and developing a methodology for delivery of the "starter kit" throughout Russia.

Other ongoing ADD activities include development of quality control standards for completed

database descriptions and evaluating the use of CD-ROM technology for distribution and growth of the ADD. A November 1996 workshop focused on the use of CD-ROM, global search engines and Internet connectivity for elevating the ADD to the level of the "premier gateway" to the Arctic. Additionally, English- and Russian-language descriptive brochures have been completed and distributed since the end of 1996. GRID-Arendal has also performed a pilot study for the implementation of an Arctic environmental database for Europe and Asia (AEDEA) that contains the listings of many Russian institutions. The pilot study was finished in early 1996 and is presented in a report with an implementation proposal for the establishment of a Barents Region Environmental Database. Additional next steps include the creation of an extended organizational structure by involving relevant user groups; addressing funding issues for the growth of ADD; and seeking additional participants in the ADD initiative.



# Monitoring Change in the Bering Glacier Region, Alaska, Using Landsat TM and ERS-1 Imagery

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## Background

The Bering Glacier is the longest (191 km) and largest (5174 km<sup>2</sup>) glacier in North America (Molnia and Post 1995). This glacier is one of about 200 temperate glaciers in the Alaska/Canada region that are known to surge. Surges at the Bering Glacier typically occur on a 20- to 30-year cycle. The most recent surge, which began in 1993, has advanced the terminus of the glacier approximately 9 km. An area 60 km from the terminus, flowing from the Bagley Icefield, has advanced some 13 km. Both measures indicate a far more rapid advance than any previously recorded surge.

Since August 1993, several major events have occurred:

- The extraordinarily rapid advance of the terminus;
- The rapid movement far up the glacier;
- The separation of ice from the surrounding bedrock;
- The filling of Vitus Lake by advancing glacier ice and icebergs;
- The sudden appearance, followed by a rapid disappearance, of heavy sediment yield from Seal River;
- The rapid erosion and formation of new surface water channels on the southeast margin of Vitus Lake; and
- The catastrophic flooding of the Bering River

drainage during the first week of May 1994, which dropped the surface of Berg Lake by more than 100 m.

The entire area was also subjected to catastrophic change during the 1964 Alaska earthquake, when much of the land in the Copper River Delta rose 2.4–9 m. The uplift around the Bering Glacier was approximately 2 m.

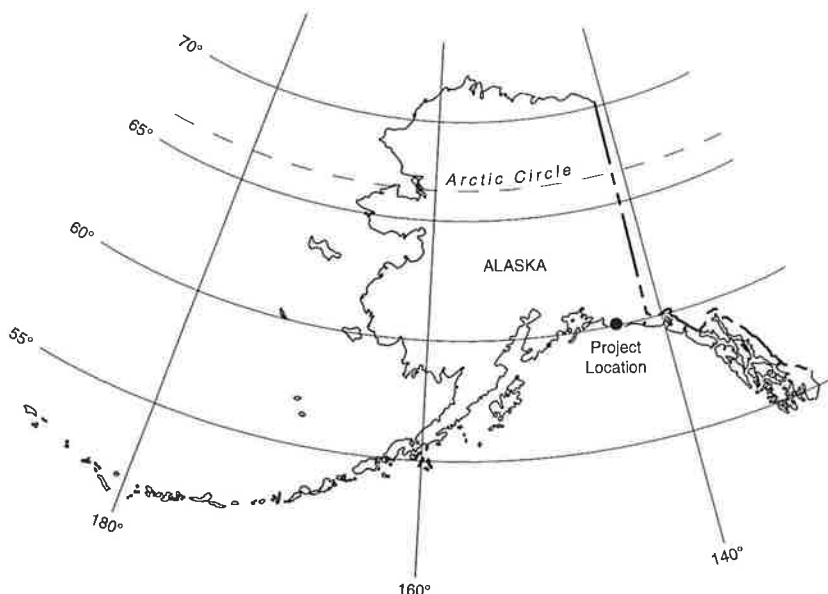
These changes have had a major impact on wildlife. The general region of the Bering Glacier, as well as the Copper River Delta to the west, provides some of the most important waterfowl staging areas in North America (Kempka et al. 1994a). In addition, two important species of waterfowl—the dusky Canada goose and the trumpeter swan—are known to nest in the region and may be impacted by the changes occurring at the Bering Glacier. The dusky Canada goose numbered some 100,000 birds prior to 1964. After the Alaska earthquake in 1964, which created new uplands and reduced available habitats for nesting and staging waterfowl, the population has steadily decreased, numbering only 8,500 birds by 1995.

Monitoring the movement of the glacier and the resulting changes in land cover is important for managing the area for wildlife and recreation. The Bureau of Land Management (BLM), in cooperation with Ducks Unlimited, the National Park Service and the U.S. Geological Survey, recently completed a project to extract information about the position of the terminus of the glacier from historic aerial photography, early 20th century ground photography, Landsat thematic mapper (TM) satellite data, and European Space Agency synthetic aperture radar (ERS-1 SAR) data and integrate it into a single digital database that would lend itself to change-detection analysis. The project had four major objectives:

- Establishing a baseline land-cover inventory;
- Monitoring glacial movement;
- Developing a digital database that could be used by resource managers for assessing impacts to wildlife and recreation; and
- Developing accurate statistics for changes to the land cover.

## Project Area

The project area covers approximately 350,000 hectares (ha) on the southeastern coast of Alaska.



The project is defined by six 1:63,360-scale U.S. Geological Service quadrangles. This region is approximately 112 km southeast of the town of Cordova, Alaska, and varies from sea level to 1500 m in elevation. The physiography is variable, including flat coastal sand beaches, glacier features such as outwash plains and moraines, and high, steep barren rock mountain peaks. The vegetation inside the circa-1900 glacier terminus is underlain by stagnant glacial ice covered by shallow organic material and sediment. Precipitation in the region is over 127 cm per year.

While most of the glacier is administrated by BLM, the upper reaches of the glacier (Bagley Icefield) are administrated by the National Park Service and the Canadian government. The forelands are under a mixture of BLM, State of Alaska and Native management.

### *Data Acquisition*

Remotely sensed data are very effective for monitoring changes in the environment (Maus et al. 1994, Green et al. 1994, Schriever and Mehrwein 1994) and for studying glaciers (Molnia and Frank-Molnia 1992). Landsat TM data, collected by the Landsat 5 satellite with its TM sensor, provide an effective tool for classifying land-cover types with a high degree of accuracy (Schriever and Congalton 1995). However, the TM sensor cannot penetrate clouds, the availability of this type of data is limited. The Landsat TM sensor collects seven bands of data, three in the visible spectrum, one in the near-infrared region, two in the mid-infrared and one in the thermal infrared. Most bands have a spatial resolution of 30 m. For this project, a cloud-free Landsat TM scene taken on 19 June 1991 was used for classifying the land cover.

A combination of ERS-1 SAR images and aerial photography was used to monitor the changes in the terminus of the Bering Glacier. ERS-1 SAR images were downloaded and terrain-corrected at the Alaska SAR Facility at the Geophysical Institute in Fairbanks, Alaska. Three SAR images were collected in the descending orbit (16 June 1992, 30 April 1993 and 22 October 1993) and three were collected in the ascending orbit (4 June 1994, 28 June 1995 and 22 September 1995). Radar data are not limited to cloud-free days.

Historic aerial and ground photographs were used to determine the location of the piedmont lobe of the Bering Glacier at various dates. These were primarily black-and-white aerial photographs that were collected by the USGS and BLM and were of varying scales. The most common scale was 1:40,000.

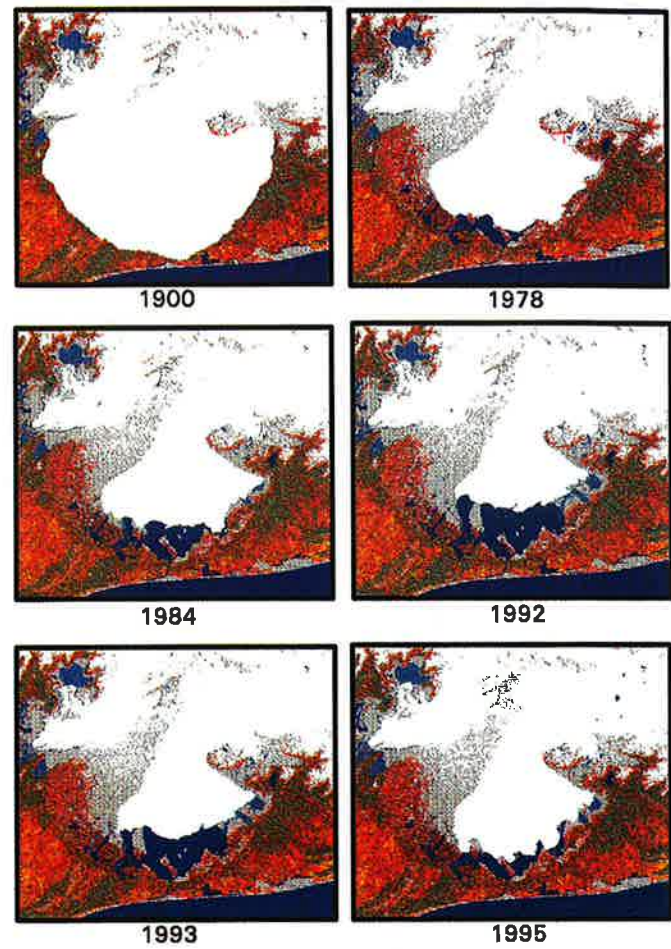
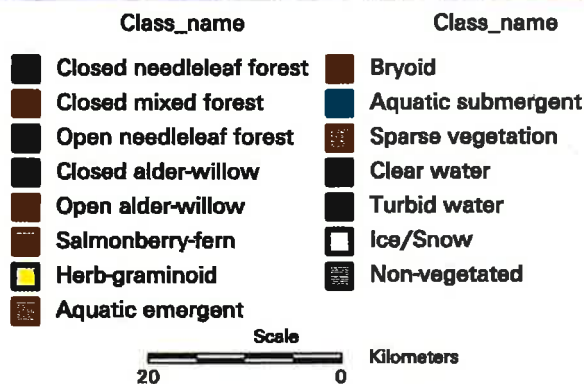
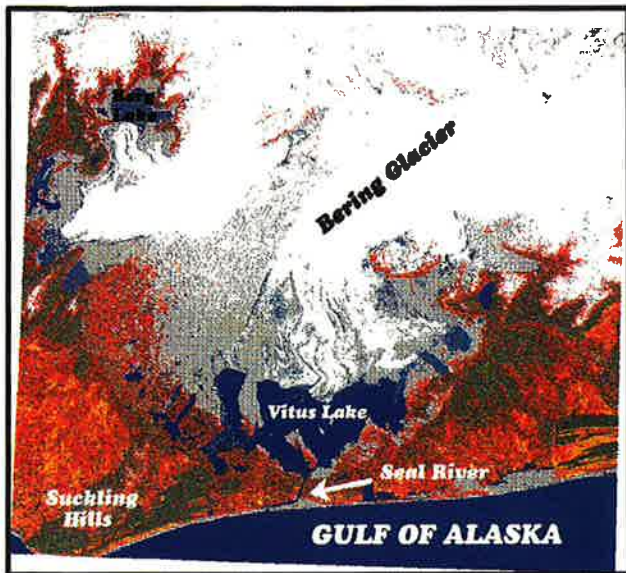
### *Methods*

Spectrally unique pixels were grouped with a minimum of five similar pixels and used as sample sites for field work. Photo analysis and a preliminary decision tree were used to develop the land-cover classification. Preselected field sites were overlain on field maps. A custom field data collection card was developed and used to record field information (Kempka et al. 1994b). Field data collection occurred during July 1994 and July 1995, with a total of 301 field sites sampled. The field sites were classified into 15 land-cover classes according to the land-cover classification decision tree.

Contact prints were used as a base for interpreting historical glacial boundaries (except circa-1900 ground photography). Stereo pairs were used to delineate the terminus of the glacier for each date of photography. Information extracted from the photographs was transposed to a 1:63,360 stable Mylar base and digitized.

The ERS-1 SAR imagery was downloaded and terrain-corrected at the Alaska SAR Facility. The terrain correction process incorporated several image processing procedures that were used to correct the radiometric and geometric distortions inherent in raw ERS-1 SAR images. The pixel brightness variations that result from range differences within the imagery are corrected with the pre-processing step of radiometric calibration. The dimensional and terrain-related distortions are corrected by geolocation of image pixels in three dimensions using a digital elevation model in the final stage of the terrain correction algorithm. When this terrain correction process is repeated with multiple images of the same area, the result is a set of co-registered images that can be studied in sequence to detect changes in a feature through time.

The terrain-corrected ERS-1 SAR images were used to determine the location of the glacier's terminus from 1992 to 1995. A vector coverage of the terminus was generated using a combination of ERDAS Imagine's region-growing tool and manual on-screen digitizing. After the coverage of the glacier's terminus was generated for each of the ERS-1 SAR images, the displacement of the terminus was visually displayed and analyzed with the Landsat TM classification as the base coverage. In addition to the vector coverages for each date of the ERS-1 SAR images, the historic aerial and ground photographs were used to produce a new classification for specific dates using the Landsat TM classification as base. For example, the 22 October 1993 coverage of the glacier's terminus was used to determine changes in the land-cover classes between the 22 October 1993 ERS-1



The Landsat TM classification and historic changes in the glacier.

SAR coverage and the 1991 Landsat TM classification.

## Results

The Landsat TM classification resulted in the project area being divided into 15 classes. The classification indicated that the dominate land-cover types are ice/snow (41.6%), clear water (14.3%), non-vegetated (12.4%) and open alder-willow (11.6%). Other land-cover classes made up the balance.

An accuracy assessment was performed on the classification with a total of 261 samples (77 field samples and 184 photo-interpreted samples). The overall accuracy was 74%. Two factors likely attributed to the low accuracy of the land-cover classification:

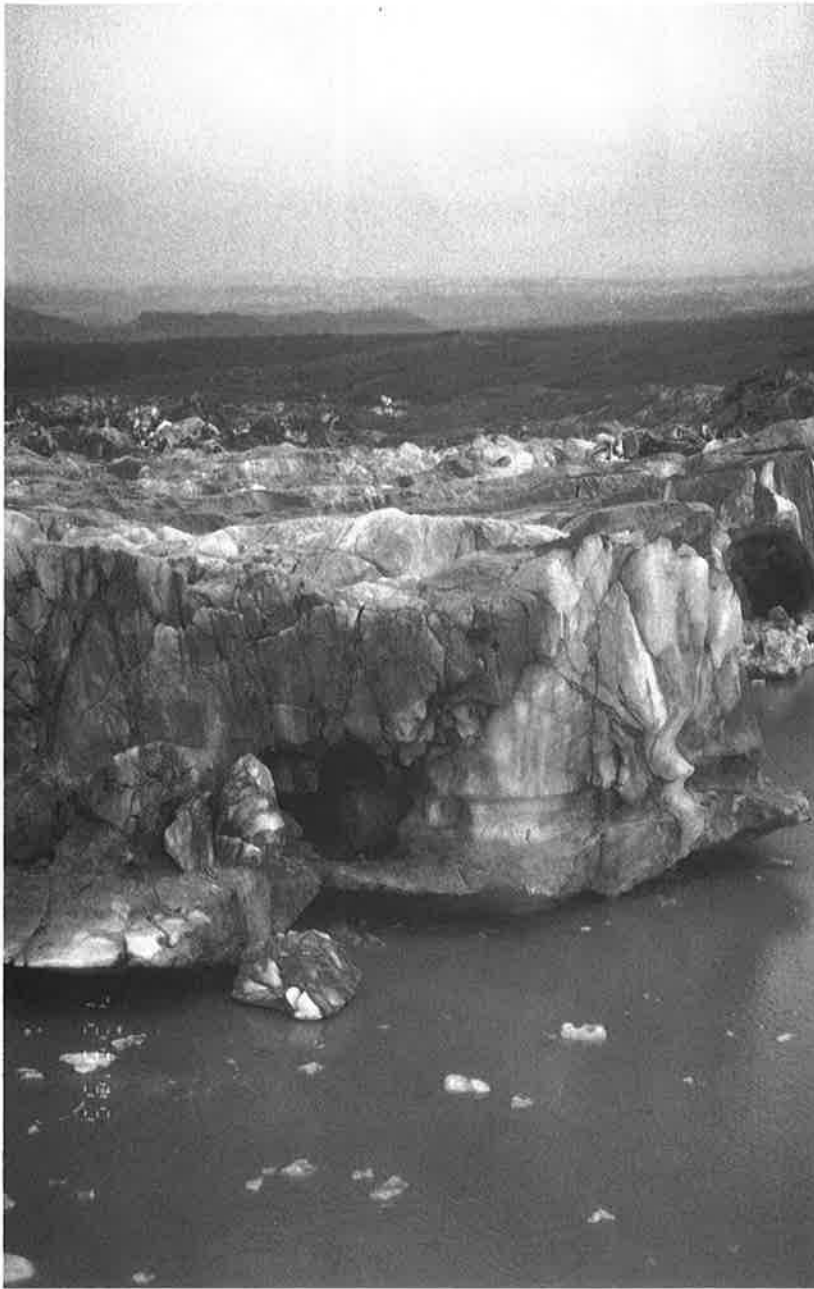
- The change in land-cover classes occurring between the six separate dates/years used as reference data and the base TM imagery used for classification; and
- The lack of a reliable ground reference network due to the movement of ice overlain by vegetation on much of the project area.

The results from 1900 to 1993 show that 33,452 ha, or 9.6% of the project area, changed from glacial ice to other land-cover classes. The class that was impacted the most from the retreating glacier was the clear water class (13,955 ha of clear water were gained). The non-vegetated and sparsely vegetated classes showed large increases due to the retreating glacier as well as the increase in early successional vegetation species such as alder-willow and salmonberry-fern types.

The results from August 1993 to 1995 show that 16,734 ha, or 4.8% of the project area, changed to glacial ice from other land-cover classes. The water class was again impacted the greatest in this time period, with a loss of 6,889 ha. As with the changes from 1900 to 1993, the sparse vegetation and non-vegetated classes also had dramatic changes.

Another major feature that was detected with the SAR radar was the difference between the ice with broken surface features, including large crevasses, and ice with a much smoother appearance. The radar imagery normally has a much lower backscatter from the smoother ice and thus appears darker. For the Bering Glacier the demarcation between the smooth ice radiating from the Bagley Icefield and





*Terminus of the Bering Glacier in 1995.*

the rough ice at the terminus of the glacier was readily apparent. Similar radar backscatter differences have been previously noted at the Malaspina Glacier (Molnia and Jones 1989).

## Conclusions

This project used Landsat TM imagery, ERS-1 SAR imagery, and aerial and ground photographs to inventory the different land-cover types, monitor the changes in the Bering Glacier from circa 1900 to 1995, and generate statistics on the amount of change in each land-cover category. The result of this combination is providing land managers with

the unique opportunity to generate complete assessments of glacial movement this century and determine land-cover changes that may impact wildlife and recreational opportunities. From circa 1900 to 1993, before the current surge, 33,452 ha changed from glacial ice to other land-cover categories. From 1993 to 1995, during the current surge event, 16,734 ha of other land-cover categories changed to glacial ice. The ERS-1 SAR imagery was very effective in determining the position of the terminus of the Bering Glacier. The clear water class was impacted the greatest during both time periods. Vitus Lake, immediately at the terminus of the glacier, showed the most change due to its size and depth. The overall accuracy was 74%, which is considered low. Variables thought to contribute to the low accuracy of the land-cover classification are two-fold: numerous sensors covering several time periods were utilized, and there is a general lack of stable ground control points due to the movement of the glacier and the overburden vegetation.

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*Highly fractured surface of  
the Bering Glacier.*

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# A Digital Shaded-Relief Map of Alaska

*This report was prepared by Jim Riehle, U.S. Geological Survey, 4200 University Drive, Anchorage, AK 99508; M.D. Fleming, U.S. Geological Survey, Everglades National Park Field Station, 40001 State Road 9336, Homestead, FL 33034-6733; Bruce Molnia, U.S. Geological Survey, 12201 Sunrise Valley Drive, 917 National Center, Reston, VA 20192; J.H. Dover, U.S. Geological Survey, 4200 University Drive, Gould Hall, Room 216, Anchorage, AK 99508; J.S. Kelley, U.S. Geological Survey, 4200 University Drive, Gould Hall, Room 210, Anchorage, AK 99508; M.L. Miller, U.S. Geological Survey, 4200 University Drive, Gould Hall, Room 101, Anchorage, AK 99508; W.J. Nogleberg, U.S. Geological Survey, 345 Middlefield Rd., MS 904, Menlo Park, CA 94025; A.B. Till, U.S. Geological Survey, 4200 University Drive, Gould Hall, Room 108, Anchorage, AK 99508; George Plafker, Retired, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025 (currently working as a USGS volunteer).*

The U.S. Geological Survey (USGS) has produced a shaded-relief image of Alaska that is remarkable for its crispness of detail and for the natural appearance of the artificial land surface. The image is at a scale of 1:2,500,000 for easy reference to the USGS Alaska series E topographic map and the state geologic map. Manually drawn images of Alaska's land surface have long been available, but the topography depicted on these early maps is mainly schematic. A major difference of the new image is its method of reproduction: a composite of half-tone images yields sharp resolution and preserves contrast during printing. Indeed, the first impression of many viewers is that the Alaskan image is a composite of satellite photographs rather than an artificial rendering of a digital-elevation model (DEM).

Even subtle physiographic features that reflect geologic structures or the type of bedrock are visible. Some of the Alaskan features have not been depicted before, so the image should provide earth scientists with a new "look" at fundamental geologic features of Alaska. The image is based on a DEM that has a grid-cell size of 300 m and that is delimited at sea level by a coastline digitized from 1:250,000 USGS quadrangles. This 300-m data set achieves a resolution suitable for the creation of a sharp, shaded-relief image at 1:2,500,000 scale. A 1,000-m grid-cell version of the DEM is currently available at a website (<http://www-eros-efo.wr.usgs.gov/agdc>). The 300-m version will be made available later.

The shaded-relief image was generated from the DEM using conventional procedures for portrayal of artificial surfaces. Because of the wide variation of topographic trends across Alaska, the image is a composite of three azimuth or illumination directions. The three azimuths are northeast (for southeastern Alaska), north (for south-central and southwestern Alaska) and northwest (for the remainder of the state). The preferred azimuths were selected by visual inspection of trial images. Inland water bodies as small as about 20 acres were added in black to the image from 1:2,000,000-scale



*Deborah Williams, Special Assistant to the Secretary of the Interior for Alaska, and USGS Director Gordon Eaton reviewing the new map as it came off the press.*

digital line graphics files of the USGS (they are not shown on the accompanying figure).

The image nicely illustrates the classic physiographic divisions of Alaska, including the rugged mountain ranges. Linear fault valleys are another type of feature that is obvious on the shaded-relief image. For example, the trace of the Fairweather fault—the transcurrent boundary between the North American and Pacific plates—is strikingly obvious in southeastern Alaska. Other linear physiographic features—lineaments—are visible on the image as well. Many of these lineaments have not been previously identified and cannot be readily attributed to specific geologic features, which points out one of the more important applications of the image: to illustrate physiographic features that, for reasons of scale, tone or directional bias, are not as apparent in other media.

## . Digital Shaded-Relief Image of Alaska

On this foldout is a small-scale photograph of the new USGS shaded-relief image of Alaska's land surface; the full-size image is at 1:2,500,000 scale. Among the many geologic features that can be seen in the image are the south-concave, curving Denali fault near Mount McKinley in south-central Alaska, and the northwest-trending trace of the Fairweather fault in the narrow portion of southeastern Alaska's panhandle.









**Sealing—The Future; International Conference and Exhibition**

**25–27 November 1997, St. John's, Newfoundland, Canada**  
Contact: NAMCO—North American Marine Mammal Commission, c/o University of Tromsø, N-8037 Tromsø, Norway  
Phone: 47 77 64 59 08  
Fax: 47 77 64 59 05  
E-mail: nammco-sec@nammco.no

**1998**

**ISOPE-98: 8th International Offshore and Polar Engineering Conference**

**24–29 May 1998, Montreal, Canada**  
Contact: Jin S. Chung, ISOPE, PB 1107, Golden, Colorado 80402-1107, USA  
Phone: 1-303-273-3673  
Fax: 1-303-420-3760

**5th International Symposium on Mining in the Arctic 14–17 June 1998, Yellowknife, N.W.T., Canada**

Contact: Symposium Secretariat, Canadian Institute of Mining, Metallurgy and Petroleum, Xerox Tower, 1210-3400 de Maisonneuve Boulevard West, Montreal, Quebec, Canada H3Z 3B8  
Phone: 1-514-939-2710  
Fax: 1-514-939-2714

**Seventh International Conference on Permafrost and IPA Council Meeting**

**23–27 June 1998, Yellowknife, N.W.T., Canada**  
Contact: J.A. Heginbottom, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8  
Phone: 1-613-992-7813  
Fax: 1-613-992-2468  
E-mail: permafrost.conference@gsc.emr.ca  
Web sites: [http://www.nrcan.gc.ca/gsc/permaf\\_e.html](http://www.nrcan.gc.ca/gsc/permaf_e.html) (English)  
[http://www.nrcan.gc.ca/gsc/permaf\\_f.html](http://www.nrcan.gc.ca/gsc/permaf_f.html) (French)

**International Society of Soil Science Congress—Cryosols 8–17 July 1998, Montpellier, France**

Contact: David Gilchinsky, Institute of Soil Science and Photosynthesis, Russian Academy of Sciences, 124292 Pushchino, Moscow Region, Russia  
Phone: 7 095 923 3558 (Moscow)  
Phone: 7 095 923 1887 (Pushchino)  
E-mail: gilchin@issp.serpukhov.su

**IASC/SCAR Symposium on Global Changes in the Polar Regions—Results and Challenges from Bipolar Science August/September 1998, Tromsø, Norway**

Contact: Executive Secretary, IASC, Secretariat, P.O. Box 5072, Majorstua, 0301 Majorstua, Oslo, Norway  
Phone: 47 22 95 96 00  
Fax: 47 22 95 96 01  
E-mail: iasc@npolar.no

**International Symposium on Glaciers and the Glaciated Landscapes**

**17–20 August 1998, Kiruna, Sweden**  
Contact: Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, United Kingdom  
Phone: 44 1223 355974  
Fax: 44 1223 336543  
E-mail: 100751-1667@compuserve.com

**17th Polar Library Colloquy Autumn 1998, Reykjavik, Iceland**

Contact: Eiríkur Einarsson, Marine Research Institute, P.O. Box 1390, 121 Reykjavik, Iceland  
Phone: 354 552 0240  
Fax: 354 562 3790  
E-mail: eirkur@hafro.is

**International Conference on Snow Hydrology: The Integration of Physical, Chemical and Biological Systems**

**6–9 October 1998, near Windsor, Vermont, USA**  
Contact: Janet Hardy, Chair, Snow Hydrology Conference, Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755, USA  
Phone: 1-603-646-4306  
Fax: 1-603-646-4397  
E-mail: jhardy@crrel.usace.army.mil

## Selected Meetings of Interest

Listed here is a compilation of recent and forthcoming meetings, workshops and conferences on Arctic or northern topics and activities. Readers are invited to submit information on upcoming meetings, as well as reports on national or international meetings attended, to Editor, Arctic Research, Arctic Research and Policy Staff, Office of Polar Programs, National Science Foundation, 4201 Wilson Boulevard, Arlington, Virginia 22203.

1997

### **International Symposium on Antarctica and Global Change**

**14–18 July 1997, University of Tasmania, Hobart, Australia**

Contact: Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, United Kingdom

Phone: 44 1223 355974

Fax: 44 1223 336543

E-mail: 100751-1667@compuserve.com

### **8th Meeting of the Canadian Quaternary Association (CANQUA)** (held jointly with the Canadian Polar Commission)

**August, 1997, Kuujuaq, Nouveau-Quebec** (with field trips in Ungava)

Contact: Michel A Bouchard, Albert Haller Department of Geology, Canadian Polar Commission, Université de Montréal, 1710-360 Albert Street, P.O. Box 6128, Station Centre Ville, Montréal, Québec K1R 7X7, Canada

Phone: 1-514-343-6821

Fax: 1-514-343-5782

E-mail: bouchami@ere.umontreal.ca

### **Naval Arctic Research Laboratory's 50th Anniversary Celebration**

**1–9 August 1997, Barrow, Alaska, USA**

Contact: Glenn W Sheehan, Executive Director, Barrow Arctic Science Consortium (BASC), P.O. Box 955, Barrow, AK 99723, USA

Phone: 1-907-852-4881

Fax: 1-907-852-8213

### **Second International Conference on Cryopedology**

**5–8 August 1997, Syktyvkar, Russia**

Contact: Prof. I.V. Zaboeva, Institute of Biology, Komi Center, Russian Academy of Sciences, 167610 Syltuykar, Komi Republic, Russia

Phone: 7-821-22-25213

Fax: 7-821-22-25231

E-mail: gilichin@issp.serpukhov.su

### **11th Northern Research Basins Symposium and Workshop** **18–22 August 1997, Prudhoe Bay to Fairbanks, Alaska, USA**

Contact: Professor Douglas L. Kane, Water Research Center, University of Alaska, Fairbanks, Alaska, 99775-5860 USA

Phone: 1-907-474-7808

Fax: 1-907-474-7979

E-mail: ffdlk@aurora.alaska.edu

### **IV International Geomorphology Conference and IPA Executive Committee Meeting** (and pre- and post-conference permafrost excursions)

**28 August–3 September 1997, Bologna, Italy**

Contact: M. Panizza, University Degli Studi di Modena, 59-41100 Modena, Italy

Phone: 059 23 0394

Fax: 059 21 8326

### **XXIV Polar Symposium—40th Anniversary of the Polish Polar Station Hornsund, Spitsbergen** **September 1997, Warsaw, Poland**

Contact: Dr. S. Maciej Salewski, Institute of Geophysics, Polish Academy of Sciences, Department of Polar and Marine Research, Ksiecia Janusza 64, 01-452 Warsaw, Poland

Phone/Fax: 48 22 37 45 05

### **Ice Physics in the Natural and Endangered Environment** **7–19 September 1997, Hotel Villa del Mare, Acquafredda di Maratea, Italy**

Contact: c/o Ice ASI, Applied Physics Laboratory, University of Washington, 1013 NE 40th Street, Seattle, WA 98105-6698, USA

E-mail: natoice@apl.washington.edu

Web site: <http://www.apl.washington.edu/natoice/natoice.html>

### **NAFO Symposium "Visioning Sustainable Harvests from the Northwest Atlantic in the Twenty-First Century"**

**10–12 September 1997, St John's, Newfoundland, Canada**

Contact: Hans Lassen, Danish Institute for Fisheries Research, Charlottenlund Slot, K-2920, Charlottenlund, Denmark

Phone: 45 33 96 33 00

Fax: 45 33 96 33 33

E-mail: hl@dfu.min.dk

or

Tissa Amaratunga, NAFO Secretariat, P.O. Box 638, Dartmouth, Nova Scotia, Canada B2Y 3Y9

Phone: 1-902-469-9105

Fax: 1-902-469-5729

### **International Symposium on Fishery Stock Assessment** **Models for the 21st Century: Combining Multiple Information Sources**

**8–11 October 1997, Anchorage, Alaska, USA**

Contact: Brenda Baxter, Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, USA

E-mail: FNBRB@aurora.alaska.edu

### **Polar Processes and Global Climate**

**3–6 November 1997, Rosario Resort, Orcas Island, Washington, USA**

Contact: Roger Colony, Director, IAPO, P.O. Box 5072, Majorstua, N-0301 Oslo, Norway

E-mail: acsys@npolar.no

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The International Arctic Science Committee has established a new service to the Arctic research community: an Arctic meetings listing available via the Internet. Called SAM (Survey of Arctic Meetings), it contains information on international Arctic meetings, as well as major national meetings with international participation. The World Wide Web address for SAM is <http://www.npolar.no/iasc/sam.htm>.

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