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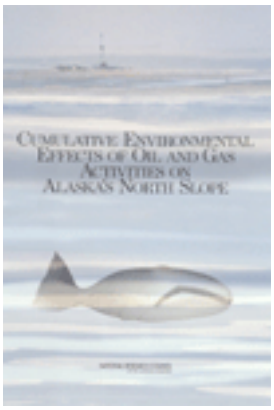

Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope

Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope, National Research Council

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This book identifies accumulated environmental, social and economic effects of oil and gas leasing, exploration, and production on Alaska's North Slope. Economic benefits to the region have been accompanied by effects of the roads, infrastructure and activies of oil and gas production on the terrain, plants, animals and peoples of the North Slope. While attempts by the oil industry and regulatory agencies have reduced many of the environmental effects, they have not been eliminated. The book makes recommendations for further environmental research related to environmental effects.

Summary

Oil fields on land and off the coast of Alaska's North Slope, including the Prudhoe Bay field, have produced about 14 billion barrels (bbl) of crude oil through the end of 2002 (one barrel equals 42 U.S. gal or 159 L). North Slope oil has averaged about 20% of U.S. domestic production since 1977, and it currently provides about 15% of the annual domestic production of approximately 3.3 billion bbl and 7% of the annual domestic consumption of approximately 7 billion bbl. If production of the large reserves of natural gas in the region were to become economically feasible, the strategic and economic importance of the North Slope's hydrocarbon energy resources would be even greater.

Oil and gas production on the North Slope has brought positive and negative consequences—economic, social, and environmental. Environmental consequences of concern include the effects of oil-related structures and activities on the migration of fish and marine and terrestrial mammals, especially bowhead whales and caribou. Concerns have also been raised about the risk of toxic contamination of plants and animals used for food by Alaska Natives, effects of oil and gas exploration and development on tundra and marine ecosystems, and effects of oil spills on marine and coastal ecosystems. Also of concern are the effects of oil activities and structures on endangered or threatened species, migratory birds, polar bears and other mammals, and on wildland (wilderness) values. Some of the socioeconomic changes resulting from oil and gas development, including those involving employment, lifestyles, health, and other aspects of people's lives, also have been of concern.

Considerable research has been done on various actual and potential effects of oil and gas activity on the North Slope's physical, biotic, and human environments. Reviews of this research have appeared in environmental impact statements (EISs), in reports funded by the Department of the Interior and other federal and state agencies, in oil industry publications, in journals, and in National Research Council reports, among others. However, there has been little assessment of the *cumulative* effects of those activities, the elucidation of which is critical to support informed, long-term decision-making about resource management. To address this lack of information and understanding, Congress requested that the National Academies review and assess what is known about the cumulative environmental effects of oil and gas activities on Alaska's North Slope.

THE PRESENT STUDY

In response to the request from Congress, the National Academies established the Committee on Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope, which prepared this report. The committee was directed to review information about oil and gas activities (including cleanup efforts) on the North Slope and, based on its review, to assess the known and probable cumulative impacts of such activities on the physical, biotic, and human environments of the region and its adjacent marine environment. The committee also was directed to assess likely future cumulative effects, based on its judgment of probable changes in technology and the environment, under a variety of scenarios for oil and gas production, and in combination with other probable human activities, including tourism, fishing, and mining. Although the cumulative effects of North Slope oil and gas activities—especially production—extend beyond the region, the committee's focus was confined to Alaska's North Slope and as far into the Arctic Ocean as there is evidence of environmental effects.

The committee met eight times over the course of its two-year study. In Alaska, it met in Anchorage, Fairbanks, Barrow, Nuiqsut, Arctic Village, and Kaktovik. It heard from federal and state agencies, representatives of the oil and gas industry, environmental organizations, and officials and community members of the North Slope Borough and the municipalities it visited. It toured the oil facilities at Prudhoe Bay, Endicott, and Alpine, and flew over the Arctic National

Wildlife Refuge, the National Petroleum Reserve-Alaska, Kuparuk, and the Northstar production facility. It also held meetings in executive session to write the report. Appendix A lists those who participated in the meetings.

UNDERSTANDING AND ASSESSING CUMULATIVE ENVIRONMENTAL EFFECTS

The basic issue of cumulative-effects assessment is that when numerous small decisions about related environmental matters are made independently, the combined consequences of those decisions are often not considered. The result is that patterns of the environmental perturbations or their effects over large areas and long periods are not analyzed.

The committee has followed the generally accepted approach to identifying and assessing cumulative effects that evolved after passage of the National Environmental Policy Act (NEPA) of 1969. The NEPA requires federal agencies to develop EISs for many major projects. If a project—and its EIS—is considered in isolation from similar projects or separately from diverse projects in the same area, some cumulative effects are likely to be missed. In 1978, the Council on Environmental Quality promulgated regulations to implement the NEPA that are binding on all federal agencies. A cumulative effect was defined as ". . . the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions. . . . Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time." The practice of cumulative-effects assessment arose to address such problems.

In interpreting the broad charge of assessing cumulative effects, the committee focused on whether the effects under consideration interact or accumulate over time and space, either through repetition or in combination with other effects, and under what circumstances and to what degree they might accumulate. As an example, consider a repeated environmental insult that is localized in space and occurs so infrequently that natural processes of recovery or human efforts can eliminate its effects before another insult occurs. In this case, one would conclude that the effects of the insult do not accumulate (rather than concluding that the insult is not "a cumulative effect"). This approach also directs attention to the circumstances under which effects might accumulate.

Although the assessment of cumulative effects has a history of several decades, doing it well remains challenging and complex, because a full analysis of how and when such effects accumulate requires the synthesis of multiple individual assessments. To address this problem, the committee developed a general process to identify how effects accumulate with respect to different receptors (i.e., the organisms, communities, and environments that are affected). The key elements are: (a) specify the class of actions whose effects are to be analyzed; (b) designate the time and space scales over which the relevant actions take place; (c) identify and characterize the receptors whose responses to the actions are to be assessed; and (d) determine the magnitude of the effects on the different receptors and whether they are accumulating or interacting with other effects.

At the most general level, the class of actions considered by the committee consisted of all activities associated with oil and gas development. The spatial area was the Alaska Arctic Slope and adjacent marine waters. The temporal period was 1965 to 2025, and the receptors were the physical, biological, and human systems of the region.

Effects typically accumulate as the result of repeated activities of similar or different types. However, in some cases the effects of a single action or event can accumulate. This is especially true if the effects persist for a long time and are augmented by the effects of other activities.

Beyond simply identifying the accumulation of effects, their magnitude and their biotic and socioeconomic importance must be assessed. The committee assessed biotic and socioeconomic importance separately for each receptor. The importance of effects is perceived differently by different individuals or groups. The committee is not aware of a satisfactory way of attributing some absolute degree of importance to effects, and so it attempted to describe the basis on which it assessed the importance of the effects. For example, in assessing importance, the committee considered factors such as ecological consequences, importance attributed by North Slope residents, economic consequences for North Slope residents, irreversibility, and degree of controversy.

OVERVIEW OF THE NORTH SLOPE ENVIRONMENT

Climate

The North Slope—or Arctic Slope—of Alaska is the 230,000 km^2 (89,000 mi^2) region north of the crest of the Brooks Range, an area slightly larger than Minnesota (Figure S-1). It encompasses the drainage basins that empty into the Beaufort and Chukchi Sea. The land slopes gradually from the crest of the rugged Brooks Range northward to the Arctic Ocean. Summer temperatures on the coastal plain are usually between 5 and 15 °C (40–60 °F); they can be higher for short periods, especially inland. Winter temperatures are usually below minus 18 °C (0 °F) and sometimes below minus 40 °C (minus 40 °F). From November 18 to January 24, the sun never rises above the horizon at Barrow, but there is a little midday twilight. The sun does not set from May 10 until August 2. Annual precipitation ranges from 12 to 20 cm (5–8 in.) in coastal and foothill areas and up to 100 cm (40 in.) in the highest elevations of the Brooks Range. Extensive areas are covered by thaw lakes, ice-wedge polygons, frost boils, water tracks, bogs, and other features typical of permafrost regions. Snowfall is difficult to measure accurately, but probably averages less than 50 cm (20 in.) in most coastal areas and more than 2 m (80 in.) in some mountain areas.

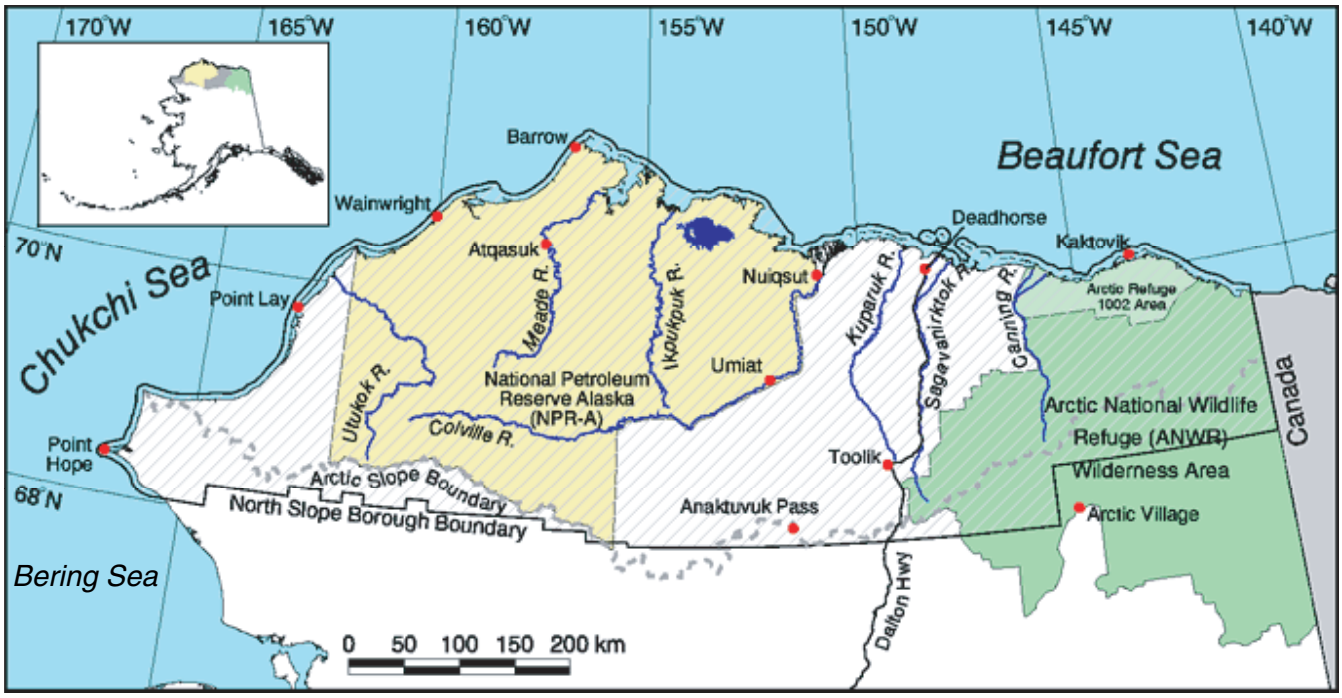


FIGURE S-1 The Alaska North Slope region. The dashed line is the southern boundary of the drainage basin. The Trans-Alaska Pipeline is close to the Dalton Highway. SOURCE: Data from Alaska Geobotany Center, University of Alaska Fairbanks, 2002.

Permafrost

Alaska's North Slope is underlain by permafrost, earth material whose temperature stays below freezing year-round. Along the Arctic coast, the permafrost extends to depths of 200–650 m (650–2,100 ft), the deepest occurring near Prudhoe Bay. Permafrost is important primarily because its groundwater generally occurs as ice, often in massive forms. If the ice melts, the ground surface can subside and become unstable. Thus permafrost poses special problems for the development of industrial infrastructure and the preservation of natural systems.

Permafrost is separated from the ground surface by an active layer that thaws each summer to depths ranging from 20 cm (8 in.) to more than 2 m. The active layer sustains tundra plants, which in turn sustain animals and control processes of surface erosion and water flow.

Changes in surface conditions, such as disruption of the insulating organic mat or impoundment of surface water, can cause the surface to settle and create thermokarst—a disruption of the tundra's surface associated with warming and thawing of permafrost. This process is difficult to reverse and has ecological effects as well as effects on structures. To maintain permafrost, activities on the tundra must be controlled carefully, and buildings, roads, and other structures must be designed to avoid thawing their own foundations. Special conditions exist offshore where development takes place on deep permafrost warmed by the sea to temperatures close to melting. Engineering designs for the infrastructure might eventually have to be reconsidered if North Slope climates warm as predicted in the twenty-first century.

Geomorphology

The North Slope is divided into three major regions: the Arctic Coastal Plain, the Arctic Foothills, and the Brooks Range. To date, all oil production has occurred on the coastal plain, but there is increasing exploration in the foothills. The only directly influenced area in the Brooks Range is the corridor for the Trans-Alaska Pipeline, which crosses those mountains at Atigun Pass.

Surface Water

The Arctic Coastal Plain is generally flat, with large lakes and extensive wetlands that are important habitat for waterfowl and shorebirds. Lakes and ponds are among its most striking landforms. Most lakes in the developed oilfield region between the Sagavanirktok and Colville rivers are shallow, typically less than 6 ft (1.8 m) deep. Lakes are deeper to the west and south, with mean maximum depths of more than 30 ft (9 m) in lakes south of Teshekpuk Lake, the largest lake on the coastal plain (816 km^2 or 315 mi^2). Lakes on the coastal plain are typically ice-covered from early to mid-October until early July. During winter, flow ceases in the region's many rivers, and ice develops to a thickness of about 1.8 m (6 ft). Spring break-up begins in the Brooks Range and foothills, which warm more rapidly than does the

coastal plain. During this time, the lower reaches of rivers are frozen, and the tundra is still snow-covered. Thus, there is substantial ice-jamming and over-bank flooding.

Terrestrial Biota

The Arctic Coastal Plain has the largest expanse of arctic fens (mineral-rich, sedge-covered wetlands) and thaw lakes in the world, and the foothills comprise the largest expanse of tussock tundra (tundra dominated by the cottongrass *Eriophorum vaginatum*) in the world.

The most important consumers of living and dead plant tissues in terrestrial arctic tundra are mammals, birds, arthropods, and nematodes. The mammals include caribou, moose, muskoxen, grizzly bears, foxes, and wolves. Most bird species that breed in Alaska north of the Brooks Range nest in tundra habitats, associated wetlands, or adjacent marine lagoons. The dominant groups, both in the number of species and in their abundance, are waterfowl—ducks, geese, and swans—and shorebirds. Loons and some other species are of concern because their populations are generally declining elsewhere in and outside Alaska.

No cold-blooded terrestrial vertebrates can survive the arctic cold; birds and mammals are the only terrestrial vertebrates. The most abundant and important terrestrial invertebrates are insects. In fresh water, most fish species spend their lives in rivers and lakes, although some migrate between fresh water and coastal marine waters.

Marine Ecology

The nearshore marine environment contains three main aquatic habitats: delta fronts (places where fresh water from river deltas meets coastal marine water), coastal lagoons, and open coast. Some areas of the coast are open and directly exposed to the wind, wave, and current action of the Arctic Ocean. Other stretches of the shore are protected by chains of barrier islands. The sea is usually covered in ice from November through June.

The Arctic Ocean supports a specialized biotic community, despite its low biological productivity. However, especially near the coast, there is relatively high primary productivity because of the ice edge and upwelling.

More than 100 phytoplankton species have been identified from the Beaufort Sea, mostly diatoms, dinoflagellates, and flagellates. The zooplankton is dominated by herbivorous copepods; amphipods, mysids, euphausiids, ostracods, decapods, and jellyfish also are present. Kelp communities and benthic invertebrates are important components of the marine ecosystem.

Twenty-nine species of fish are regularly found in freshwater and nearshore habitats of the North Slope. Most marine species inhabit deeper offshore waters and are rarely found in the North Slope coastal zone. Marine mammals include three truly arctic species (ringed seals, bearded seals, and polar bears) and four principally subarctic species (spotted seals, walrus, beluga whales, and bowhead whales) that move into the area seasonally from the Bering and Chukchi seas.

The Human Environment

Alaska's North Slope is one of the most extreme environments in which humans live and work. The social organization of Alaska Natives centers on group subsistence activities and on an extensive network that shares subsistence harvests. Cultural knowledge and practices of North Slope Alaska Natives have been refined over many generations in an environment where one bad decision can lead to individual deaths or even to starvation of an entire village.

Initial contact with Western culture came in the mid-nineteenth century, when the area was first visited by commercial whalers and Protestant missionaries. Steady-wage jobs were first introduced with the U.S. Navy's petroleum exploration on the North Slope in the 1940s; construction of distant early warning radar sites in the 1950s also provided some employment. But even with these sources of income, wage-earning jobs on the North Slope were scarce throughout the 1950s and 1960s, and subsistence activities were the main source of food for most families.

North Slope Human Cultures in the Oil Era

The announcement in 1968 of the discovery of oil at Prudhoe Bay—the largest oil field in North America—catalyzed changes that affected the human environment of the North Slope and increasingly moved North Slope residents into the mainstream economy. The enactment of the Alaska Native Claims Settlement Act in 1971 established the Arctic Slope Regional Corporation and the village corporations. The North Slope Borough was established in 1972. The extremely rural nature of the North Slope Borough and the isolation of its small communities influence the nature and extent of the effects of oil and gas activities.

Environmental Limitations on Human Activities

The physical environment of the North Slope shapes and limits the ways that human communities operate. Agriculture and forestry are impossible; wood for construction is locally available only as driftwood in coastal areas. Most travel between communities on the North Slope, or between those communities and subsistence-hunting areas, occurs by air, by snow machine in the winter when the tundra is frozen, or by water in the summer. Transportation beyond the region is almost entirely by air.

The costs of transportation and of goods that must be transported to the North Slope are considerably higher than in the rest of Alaska or the continental United States. Because North Slope residents do not have greater incomes per capita than do some of their counterparts in Alaska, and those

in the United States in general, they must either have a lower standard of living or rely to a greater extent on subsistence harvest, or both.

FINDINGS

The committee's unanimous findings and recommendations are presented in two sections. This one is an evaluation of major effects and how they accumulate. The next section provides recommendations for filling knowledge gaps.

Growth of Industrial Activity

Industrial activity on the North Slope has grown from a single operational oil field at Prudhoe Bay to an industrial complex of developed oil fields and their interconnecting roads, pipelines, and power lines that stretches from the Alpine field in the west to Badami in the east (Figure S-2). A highway and pipeline cross the state from near the Arctic coast to Valdez. This network has grown incrementally as new fields have been explored and brought into production. For many reasons, nearly all of the roads, pads, pipelines, and other infrastructure are still in place and are likely to remain so for some time. The environmental effects of such structures are manifest not only at the "footprint" itself (the area physically covered by the structure), but also at distances that vary depending on the environmental component affected. Effects on hydrologic processes, vegetation, and animal populations occur at distances of up to a few miles (several kilometers) from the physical footprint of a structure. Effects on wildland values—especially visual ones—extend much farther, as can the effects on marine mammals of sound caused by some offshore activities. All visual effects due to the structures and associated activities will persist as long as the structures remain, even if industrial activity ceases. They will accumulate with expanded activity.

Regulatory oversight can be critical in reducing the accumulation of undesirable effects. The committee's predictions of future effects and their accumulation assume that regulatory oversight will continue at least to the extent of the recent past.

Interactions of Climate Change and Oil Development

Global and regional climates have changed throughout the Earth's history, but climate warming during the past several decades on the North Slope has been unusually rapid. Animals and plants evolve and change their ranges in response to environmental changes. Humans have migrated in and out of the area, and their cultures—including social, economic, and legal elements of those cultures—have changed as well. Those changes complicate and confound the assessment and isolation of the effects of oil and gas activities on the North Slope. If recent warming trends continue, as many projections indicate they will, their effects will accumulate over the next century to alter the extent and timing of sea ice, affect the distribution and abundance of marine and terrestrial plants and animals, and affect permafrost. Such changes would eventually affect existing oil-field infrastructure and would continue to affect the usefulness of many oil-field technologies and how they affect the environment. Climate change also would affect arctic ecosystems and Native Alaskan cultures as well as the way they are affected by oil and gas activities. In some cases, it is relatively easy to apportion the causes of observed changes between climate or oil and gas activities; in others, it is impossible.

Damage to Tundra from Off-Road Travel

The tundra of the North Slope has been altered by extensive off-road travel. Networks of seismic-exploration trails cover extensive areas. The currently favored 3-D surveys (three-dimensional surveys that obtain geophysical data) require a higher spatial density of trails than earlier methods. Some effects of seismic exploration accumulate because areas have been resurveyed before the tundra recovered from the effects of previous surveys. Seismic exploration has adversely affected vegetation and caused erosion, especially along stream banks. In addition, because seismic trails are readily visible from the air, they have degraded visual experiences on the North Slope over a large area. How long damages caused by seismic surveys and other off-road travel will persist is not known, but some effects are known to have persisted for several decades.

There have been substantial improvements in technologies, especially of exploration, and the operators have been taking increased care. The technology used for obtaining seismic data continues to improve, but there is still potential damage to the tundra because of the large camps, the number of vehicles used, and the higher spatial density of 3-D trails. The new technology has reduced but not totally eliminated damage to the tundra.

Roads

Roads have had effects as far-reaching and complex as any physical component of the North Slope oil fields. In addition to their direct effects on the tundra, indirect effects are caused by dust, roadside flooding, thermokarst, and roadside snow accumulation. Roads also alter animal habitat and behavior and can increase access of hunters, tourists, and others to much of the region. Roads can enhance communication among communities, and in the future could increase contacts between North Slope communities and those outside the area.

Effects on Animal Populations

Animals have been affected by industrial activities on the North Slope. Bowhead whales have been displaced in

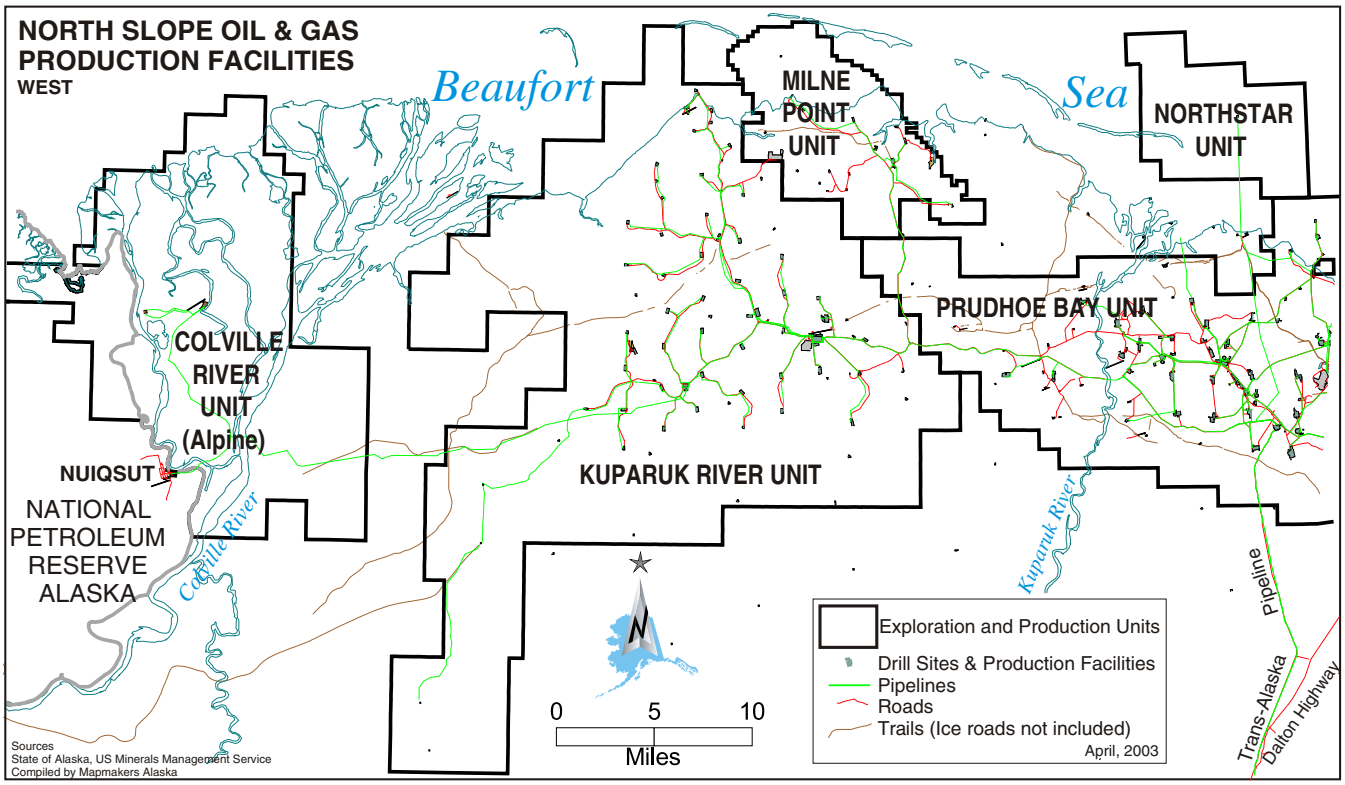


FIGURE S-2 North Slope Production Facilities, Colville to Canning Rivers. Funded by the National Academies. Drawing by Mapmakers Alaska, 2003.

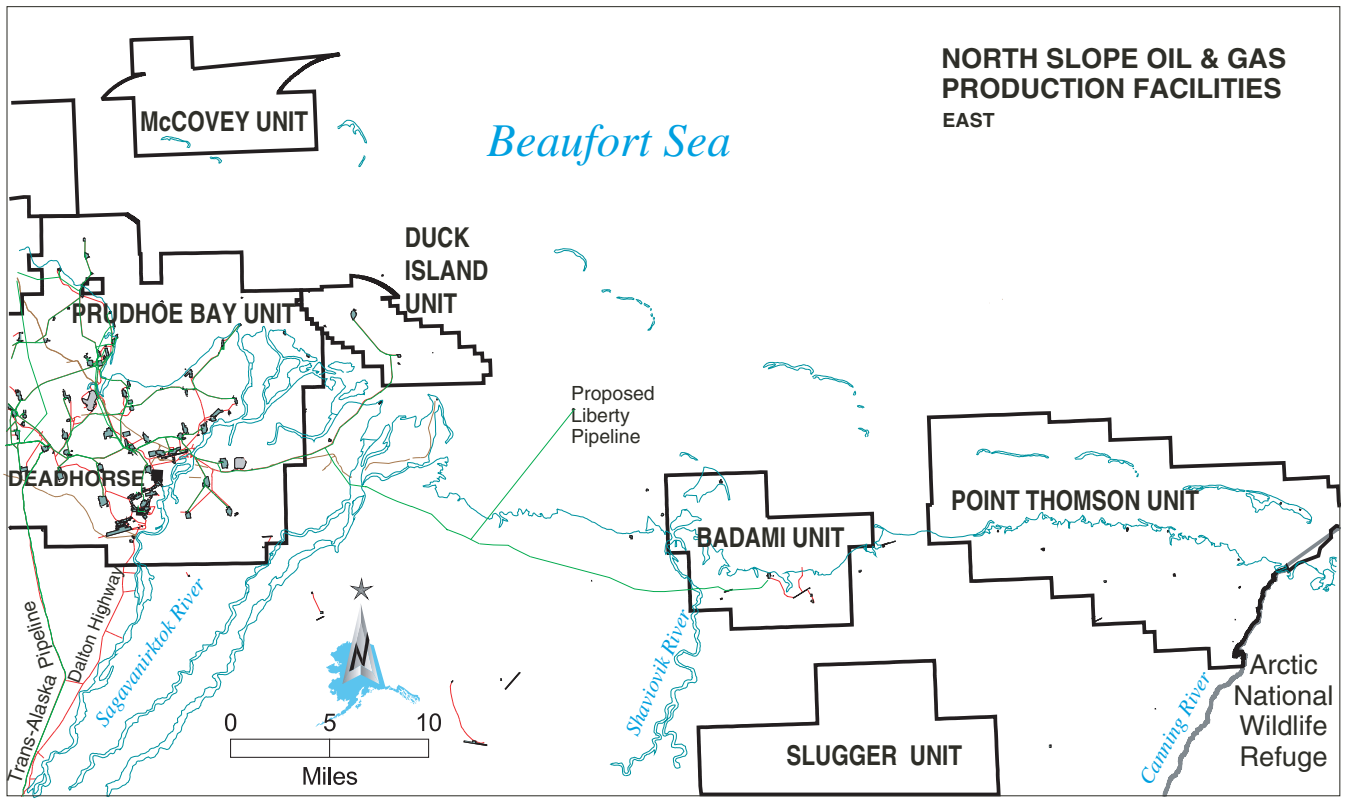
their fall migration by the noise of seismic exploration. The full extent of that displacement is not yet known. Some denning polar bears have been disturbed. The ready availability of new sources of food from people in the oil fields has resulted in increases in predator densities. Because brown bears, arctic foxes, ravens, and glaucous gulls prey on eggs, nestlings, and fledglings of many bird species, the reproductive success of some of those species in the developed parts of the oil fields has been reduced. Efforts to reduce the amount of supplemental food available to predators have been only partly successful, because some predators have become expert at defeating anti-predator devices, and it is difficult to persuade people to stop feeding them.

The high predation rates have reduced the reproductive success of some bird species in industrial areas to the extent that, at least in some years, reproduction is insufficient to balance mortality. Those populations—called *sink* populations—might persist in oil fields only because of immigration. Sink populations have not been unambiguously detected because census data (counts) alone do not reveal them. However, several species of birds apparently have been affected in this way.

As a result of conflicts with industrial activity during calving and an interaction of disturbance with the stress of summer insect harassment, reproductive success of Central Arctic Herd female caribou in contact with oil development from 1988 through 2001 was lower than for undisturbed females, contributing to an overall reduction in herd productivity. The decrease in herd size between 1992 and 1995 may reflect the additive effects of surface development and relatively high insect activity, in contrast to an increase in the herd's size from 1995 to 2000, when insect activity was generally low. Although the accumulated effects of industrial development to date have not resulted in large or long-term declines in the overall size of the Central Arctic Herd, the spread of industrial activity into other areas that caribou use during calving and in summer, especially to the east where the coastal plain is narrower than elsewhere, would likely result in reductions in reproductive success, unless the degree to which it disturbs caribou could be reduced. Without specific information on the exact nature of future activity and its precise distribution, it is not possible to predict to what degree the distribution and productivity of caribou herds would be affected.

Oil Spills

Major oil spills have not occurred on the North Slope or adjacent oceans through operation of the oil fields. There have been three major spills from the North Slope segment



of the Trans-Alaska Pipeline. Many small spills have occurred in the oil fields, but they have not been frequent or large enough for their effects to have accumulated. The effects of a large oil spill at sea, especially in broken ice, would likely be substantial and accumulate. No current cleanup methods remove more than a small fraction of oil spilled in marine waters, especially in the presence of broken ice.

Expansion of Activities into New Areas

Seismic exploration is expanding westward into the National Petroleum Reserve-Alaska and southward into the foothills of the Brooks Range. Current technology and regulations governing seismic-exploration permits and other off-road travel have reduced but not eliminated damage to the tundra. The nature and condition of permafrost in the foothills is poorly characterized, and the hilly topography increases the likelihood that vehicles will damage vegetation, especially on knolls and riverbanks, causing increased erosion, exposing bare soil, and creating thermokarst. In addition, future exploration will be carried out in a climate that is likely to continue to warm, with milder winter temperatures and shorter periods of freezing. It is hard to predict the consequences of vehicular traffic in winter on tundra under these altered conditions.

Legacy of Abandoned Infrastructure and Unrestored Landscapes

The oil industry and regulatory agencies have made dramatic progress in reducing the effects of new gravel fill by reducing the size of the gravel footprint required for many types of facilities and by substituting ice for gravel in some roads and pads. Much less attention has been directed to restoring already disturbed sites. To date, only about 40 ha (100 acres), or about 1% of the habitat on the North Slope affected by gravel fill, has been restored. With the exception of well-plugging and abandonment procedures, state, federal, and local agencies have largely deferred decisions about the nature and extent of restoration that will be required. The lack of clear state or federal performance criteria, standards, and monitoring methods governing the extent and timing of restoration has hampered progress in restoring disturbed sites. In addition, if a site has potential for future use, restoration could make that future use more expensive or perhaps impossible, thus influencing decisions to defer restoration. Potential liability for contaminated sites also constitutes a barrier to re-use of gravel.

Because the obligation to restore abandoned sites is unclear, and restoration is likely to be expensive, the commit-

tee judges it unlikely that most disturbed habitat on the North Slope will be restored unless current constraints change dramatically. Because natural recovery in the Arctic is slow, the effects caused by abandoned and unrestored structures are likely to persist for centuries. They could accumulate further as new structures are added in the region.

Socioeconomic Changes in North Slope Communities

The North Slope Borough, the Alaska Native Claims Settlement Act, and hence the Arctic Slope Regional Corporation were created as a result of the discovery and development of North Slope oil. Without it, they would not exist or, if they did, would bear little resemblance to their current form. Modern western culture, including oil development and the revenue stream it created, has resulted in major, important, and probably irreversible changes to the way of life in North Slope communities. The changes include improvements in schools, health care, housing, and other community services as well as increased rates of alcoholism, diabetes, and circulatory disease. There have been large changes in culture, diet, and the economic system. Many North Slope residents view many of these changes as positive. However, social and cultural shifts of this magnitude inevitably bear costs in social and individual pathology. These effects accumulate because they arise from several causes, and they interact. As adaptation occurs, the communities and the people who make them up interact in new and different ways with the causes of social change. The largest changes have occurred since the discovery of oil at Prudhoe Bay in 1968.

Interference with Subsistence Activities

Offshore exploration and development and the announcement of offshore sales have resulted in perceived risks to Inupiaq culture that are widespread and intense and are accumulating effects. The Inupiat of the North Slope have a centuries-old nutritional and cultural relationship with the bowhead whale. Most view offshore industrial activity—both its observed effects and the possibility of a major oil spill—as a threat to the bowheads and, thereby, to their cultural survival. Fall-migrating bowhead whales avoid areas where the noise from exploratory drilling and marine seismic exploration exceeds 117–135 dB. The distances over which the migratory pathways of the whales are altered are not yet known, but the deflections have forced subsistence hunters to travel farther from home to hunt whales. This increases their risk of exposure to adverse weather and the likelihood that whale tissue will deteriorate before a carcass can be landed and processed. Recent agreements to limit or move some exploration activities in the fall, which are renegotiated annually, have reduced the effects on hunters. The Inupiat view the possibility of a major oil spill as a potential catastrophe, even though no such spill has occurred there. Those threats accumulate because they interact and they are repeated with each new lease sale.

Proposals to explore and develop oil resources in the Arctic National Wildlife Refuge have resulted in widespread, intense perceived risks to Gwich'in culture that themselves are accumulating effects. The Gwich'in Indians of northeast Alaska and northwest Canada have a centuries-old nutritional and cultural relationship with the Porcupine Caribou Herd. Most Gwich'in oppose any oil development that would threaten the herd, especially on its calving ground, and, thereby, threaten their cultural survival. This threat accumulates, because repeated attempts to develop areas used by the herd have occurred and probably will continue to occur.

Aesthetic, Cultural, and Spiritual Consequences

Many activities associated with oil development have changed the North Slope landscape in ways that have had accumulating aesthetic, cultural, and spiritual consequences. They have reduced opportunities for solitude and have compromised wildland (wilderness) and scenic values over large areas. They also violate what some Alaska Natives call the "spirit of the land," which they describe as central to their relationship with the land. Those consequences have increased in proportion to the area affected by development, and they will persist as long as the landscape remains altered. They will accumulate further if the area affected by development increases.

Response of North Slope Cultures to Declining Revenues

The current, altered way of life of North Slope communities will be impossible to maintain unless enough money continues to come into those communities from outside sources after oil and gas activities cease. But likely continuing sources of funds appear to be modest. Painful adjustments to reduced financial resources can and probably will be postponed for as long as oil and gas are being extracted, but eventual adjustment is unavoidable. The nature and extent of adjustment will be determined by the adaptations North Slope societies have made to the cash economy made possible by oil and gas and other activities.

FILLING KNOWLEDGE GAPS

A great deal of time and effort has been invested in studying North Slope environments and assessing the effects of oil and gas activities there. Some of the research recommendations that follow are for new investigations, but many of them represent a sharpening of the focus and the emphasis of current research efforts.

To the degree possible, information on the effects of industrial development on the North Slope (including information on the physical, biotic, and human environments) should be gathered concurrent with oil and gas activities to

take advantage of opportunities for learning and to promote better management (i.e., adaptive management).

Need for Comprehensive Planning

Decisions about where, when, and under what conditions industrial activities are permitted on the North Slope are made by many federal, state, municipal, and other agencies. Communication among them has usually been weak and sporadic. Decisions generally have been made on a case-by-case basis, without a comprehensive plan and regulatory strategy that identifies the scope, intensity, direction, and consequences of industrial activities judged appropriate and desirable. The anticipated high costs to dismantle and remove infrastructure and to rehabilitate and restore the North Slope environment raise concerns about the availability of funds for restoration when production ends. For these and other reasons, comprehensive planning is needed. All comprehensive plans are necessarily provisional and will need to be revised as new information becomes available. Nonetheless, a comprehensive framework and plan should be developed for the North Slope so that decisions can be evaluated with respect to their compatibility with overall goals, the likely effects of individual activities on all receptors that might be affected by them, and the likelihood that the activities will result in undesirable effects that are long-lasting or difficult to reverse. The plan should include all phases of oil and gas activity, from lease sales, to dismantlement and removal of infrastructure, to environmental rehabilitation and restoration. The plan also should identify areas for research.

Ecosystem Research

Most ecological studies in the Prudhoe Bay region have been local; ecosystem-level research has largely been lacking. Although ecological communities within an oil field are likely to differ from similar unaffected communities elsewhere, the extent and nature of the differences are largely unknown. To assess those differences, researchers should be given access to protected areas inside and outside the industrial complex. Particular research attention should focus on the ecological processes most likely to be altered by industrial activities.

Offshore Oil Spills

Although no large oil spills have occurred in marine waters off the North Slope, their potential is such a major concern that the committee recommends research into mitigating their effects. Such research would help refine assessments of the accumulation of effects of a major spill in that environment. This committee did not attempt to reach consensus on whether, when, and how experimental oil spills might be used in a research program. Other research seems to be warranted, however, including on possible ways of deflecting bowhead whales and perhaps other marine mammals from spill-affected areas, and on the effectiveness and environmental liabilities and advantages of nonmechanical methods of cleaning up oil spilled in the sea (dispersants, in-situ burning), especially in broken ice.

Zones of Influence

The effects of industrial activities are not limited to the footprint of a structure or to its immediate vicinity; a variety of influences can extend some distance from the actual footprint. They range from the effects of gravel roads and pads on animals, which can extend for several miles from the footprint, to the influence of industrial structures on wilderness values, which can extend much farther. The full accumulation of effects of oil and gas activities to date, as well as future accumulation, cannot be assessed without better quantitative information about the ways in which various kinds of effects extend for various distances.

Human Communities

The communities of the North Slope have not been adequately involved in most research in the region. As a result, some important information concerning accumulated effects is missing or sparse. To improve the assessment of effects and their accumulation, research on the North Slope should be a cooperative endeavor with local communities. Traditional and local knowledge includes rich and detailed information about many aspects of the environment. Balancing economic benefits of oil and gas activities against loss of traditional culture often is a dilemma for North Slope residents. Research should be conducted to better characterize the specific benefits and threats that North Slope residents perceive are posed to their way of life and health by oil and gas activities. The studies should attempt to separate the effects of oil and gas activities from other causes of socioeconomic change. Research should seek to establish how oil and gas activities have affected the behavior of individuals and communities. Research should be done to identify the direct and indirect monetary rewards and costs—including non-use values such as existence and bequest values—associated with petroleum development on the North Slope.

Human-Health Effects

Human-health effects of oil and gas activities have not been well documented. Although some problems on the North Slope—increased use of alcohol and drugs, increased obesity, and other societal ills—are evident, it is not possible to say with the limited data available to what degree they are the direct result of oil and gas activities. Other concerns are widespread among Native residents of the North Slope. The degree to which increased financial resources related to oil have balanced adverse effects by improving the quality and

accessibility of local medical care is unknown. These questions are in great need of additional reliable information.

Air Contamination and its Effects

Air pollution is a concern to many North Slope residents. Little research has been done to quantify the effects of air pollution on the North Slope or to determine how local and regional air masses interact. Air-pollution monitoring has been limited to priority pollutants from 1986 through 2002 at a few sites. Not enough information is available to provide a quantitative baseline of spatial and temporal trends in air quality over long periods across the North Slope. Given local concerns about air quality and the perception that poor air quality is affecting the public health, research and monitoring should be implemented to distinguish between locally derived emissions and long-range transport of air contaminants to determine how they interact, and to monitor potential human exposure to them.

Off-Road Traffic and the Tundra

Networks of seismic trails and trails of other off-road vehicles, ice roads, and ice pads cover large areas of the tundra. They cause concern because of the damage they do to vegetation and because of their visibility from the air. Continuing advances in the technology of seismic-data acquisition might reduce its effects by reducing the weight, tracks, or number of vehicles used, but the degree to which this will happen is not known because the effects of the new technologies have not yet been extensively studied.

Studies are needed to assess the long-term visibility of seismic trails from the air. Research also is needed to determine the amount of snow cover and the frost penetration required to adequately protect the tundra from the effects of seismic exploration and the use of Rolligons (low ground-pressure vehicles) and other off-road vehicles. New areas where oil and gas exploration are likely to occur differ substantially from current areas. Characterization of those environments should include descriptions of topography; permafrost conditions; sand, gravel, and water availability; hydrological conditions; and biotic communities.

Caribou and Bowhead Whales

A better understanding is needed of the seasonal habitat requirements of caribou, the natural environmental constraints that affect their reproductive physiology and movements, their vulnerability to natural disturbance, and how anthropogenic disturbance affects them at various times of the year in the Arctic.

Studies are needed to determine the qualitative relationship between the noise generated by offshore operations and the migratory and acoustic behavior of bowhead whales. The studies should include analysis of the effects of multiple noise sources. Better information is also needed about the degree to which bowheads feed in the Alaskan portion of the Beaufort Sea.

Consequences of Water Withdrawals

Water for ice roads and pads and for other purposes is taken from lakes on the North Slope. Water depth has a great influence on the distribution of fish in coastal-plain lakes because lakes shallower than 1.8 m (6 ft) freeze to the bottom in winter. Because most lakes in the existing development area, between the Colville and Sagavanirktok rivers, are shallower than 1.8 m, few fish are present and effects have been minimal. As development spreads into regions with deeper lakes, such as the Colville delta and the eastern portion of the National Petroleum Reserve-Alaska, there is a greater chance that fish populations will be affected.

The current regulatory criterion, which allows 15% of the minimum winter water volume to be removed from fish-bearing lakes, should be studied to determine its ability to prevent loss of fish and invertebrates. A study of the effects of withdrawing water from lakes that do not contain fish should also be conducted to assess the degree to which current water use affects the biota associated with those bodies of water.

Dealing with Uncertainty

Actions undertaken to identify and reduce the undesirable effects of interactions among perturbations and receptors should greatly improve the quality and quantity of data for future decision-making. However, for several reasons it is unreasonable to expect that sufficient data will ever be available to meet all needs for information. Some animal species, such as marine mammals and fishes, are intrinsically difficult to study. Detecting even fairly large changes in their population densities and other demographic characteristics could be impossible no matter how much money is allocated for research. Also, adequate experimental controls could be impossible to establish.

Whenever a statistical test is performed to assess an environmental effect, the magnitude of the effect that could have gone undetected should be explicitly stated. Those uncertainties should be communicated clearly to decision makers.

THE ESSENTIAL TRADE-OFF

The effects of North Slope industrial development on the physical and biotic environments and on the human societies that live there have accumulated, despite considerable efforts by the petroleum industry and regulatory agencies to minimize them. To the best of its ability, and given the time, data, and resources available, the committee has identified those effects. It has also attempted to assess how effects are likely to accumulate with future expansion of industrial ac-

tivities into new areas. Continued expansion is certain to exacerbate some existing effects and to generate new ones—possibly calling for regulatory revisions. Whether the benefits derived from oil and gas activities justify acceptance of the inevitable accumulated undesirable effects that have accompanied and will accompany them is an issue for society as a whole to debate and judge. However, if wise decisions are to be made, the nature and extent of undesirable effects likely to accompany future activities must be fully acknowledged and incorporated into regulatory strategies and decision-making. We hope this report will assist in the process.

Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope

Committee on Cumulative Environmental Effects of
Oil and Gas Activities on Alaska's North Slope

Board on Environmental Studies and Toxicology

Polar Research Board

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Cover design by Van Nguyen, National Research Council. The bowhead whale was carved by the late Alaska Native artist Harry Koozaata, Sr., probably in the 1970s. The drilling rig is in the Kuparak oil field.

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Preface

Since production began on Alaska's North Slope in the early 1970s, about 14 billion barrels of oil have been extracted from underground deposits and sent to markets elsewhere. As much as 20 billion additional barrels of oil might be extracted from the area. In addition, the region has huge reserves of natural gas and coal. Therefore, if market conditions remain favorable, exploration and extraction are likely to continue on the North Slope and to expand into areas that have until now been uninfluenced by industrial activity.

The residents of Alaska and throughout the United States have benefited from oil and gas production on the North Slope, but, as with all industrial developments, these activities have brought with them social and environmental costs. Although research has been carried out on the North Slope during the past several decades to understand the effects of oil and gas exploration, development, and production, an integrated, comprehensive assessment of those effects has not been attempted. Understanding the nature, extent, and causes of both the benefits and costs is an essential component of effective, long-term decision-making about resource management on the North Slope.

To rectify this gap in knowledge, the United States Congress asked the National Research Council to review information about oil and gas activities on Alaska's North Slope and to assess their known and probable future cumulative effects on the physical, biological, and human environment. The NRC established a committee whose 18 members had expertise in a wide range of disciplines, including geology, hydrology, physics of permafrost, biology, sociology, anthropology, and economics. In making its assessments, the committee relied on its collective expertise, extensive literature review, information gathered during public meetings held in various places in Alaska, and written materials supplied by many individuals and organizations.

The task undertaken by the committee was difficult. The area of concern—from the crest of the Brooks Range to the Arctic Ocean and from the Canadian border on the east to the Chukchi Sea on the west—is about the size of Minnesota. It includes the continental shelf and coastal waters, flat coastal tundra, undulating foothills, rivers, lakes, and mountain slopes. Industrial activity has affected primarily the area between the Canning River and the eastern part of the National Petroleum Reserve-Alaska, but more of the North Slope could be influenced by future developments. During the several decades over which industrial activities expanded on the North Slope, technological advances dramatically changed how the industry operated and how it influenced the North Slope environment. There is every reason to believe that technical innovations will continue in the future, adding to the difficulty of making projections of future cumulative effects. In addition, the climate of the North Slope has warmed considerably during the past several decades, and the rate of warming is likely to accelerate in the future. Climate change is likely to influence nearly all aspects of industrial activity in the area and the effect of those activities on the environment.

Because of the complexity of its task, the committee met eight times. Members visited the North Slope during both winter and summer conditions. Its sessions sometimes lasted as long as a week, during which there were extensive in-depth discussions of the available data and their interpretation. Considerable work was carried out between meetings by both committee members and NRC staff. Despite the highly varied professional backgrounds, knowledge, and perceptions of the committee members, candor, mutual respect, and collegiality dominated the committee's proceedings. This spirit of cooperation made this consensus report possible.

The committee was ably assisted by staff of the Board on Environmental Studies and Toxicology (BEST) and the Polar Research Board (PRB), the two NRC boards under whose auspices the study was carried out. The efforts and experience of David Policansky (BEST) and Chris Elfring (PRB) assisted the committee in numerous ways and helped

keep us on track. James Reisa (BEST) provided his usual thoughtful advice. Logistical, informational, and other invaluable support was provided by BEST staff members, especially Leah Probst, Jessica Brock, Dominic Brose, Margaret Walsh, and Suzanne van Drunick. Walter Gove provided much useful information to the committee, as did the many people who made presentations to the committee and helped us on our visits (please see Appendix B for list of participants in our meetings).

Many people made our task possible by providing information, hospitality, and logistic support. We thank the governments and people of Arctic Village, Barrow, Kaktovik, and Nuiqsut for their kindness, as well as members of the North Slope Borough. We thank representatives of the oil industry for sharing information and logistic support, in particular Joseph Hegna of Phillips Petroleum, and Steve Taylor of BP. Theodore (Ted) Rockwell, Lisa Morales, and Tracie-Lynn Nadeau of EPA provided advice, encouragement, and information to the committee while serving as the sponsoring agency's technical representatives. We also thank the other state and federal agencies and members of the public who provided us with information, guidance, and assistance.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Garry D. Brewer, Yale University
Ingrid C. Burke, Colorado State University
Brian Davies, BP Exploration-Alaska (retired)
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John J. Stegeman, Woods Hole Oceanographic Institution
Arlon R. Tussing, Institute of the North
Gunter Weller, University of Alaska Fairbanks
William J. Wilson, LGL Alaska Research Associates, Inc.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by John Bailar, University of Chicago (emeritus) (review monitor) and Wilford Gardner, University of California, Berkeley (emeritus) (review coordinator). Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Important though it is to identify and assess the nature of cumulative effects and their causes, the committee recognizes that this knowledge, by itself, cannot specify public policy. Nonetheless, without such analyses, decision-makers lack a background against which to evaluate the assertions of different groups that have specific benefits to gain from policies or who are likely to bear the brunt of costs. The committee has identified the most important cumulative effects of oil and gas development on the North Slope and has attempted to show why they have happened. The committee has also concluded that some effects have been much less important than they are widely believed to be. Therefore, this report should help focus future discussions on the major cumulative effects of industrial development on the North Slope. It should also direct attention to the inevitable tradeoffs that must be balanced when choosing future management options and the rules and regulations under which they will be carried out. If this report serves that purpose, we will all consider ourselves suitably rewarded for our efforts.

Gordon H. Orians
Chair, Committee on Cumulative
Environmental Effects of Oil and Gas
Activities on Alaska's North Slope

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Whalers return from successful hunt. Barrow, September 1992. Photograph by David Policansky.