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ABSTRACT

The U.S. Global Change Research Program was established in 1990 to develop scientific projections of anticipated impacts of the changing biosphere on humans and social systems. As part of this program, the National Science Foundation created the Arctic System Science Program (ARCSS). This document describes the ARCSS Human Dimensions of the Arctic System (HARC) initiative to consider how humans interact with physical and biological environmental change in the Arctic. HARC cuts across traditional social, biological, and physical science disciplines; employs varied methodologies; collects data across a broad range of time and spatial scales; and involves local people and communities in research design and implementation. Five fundamental research questions address the impacts of human activity on arctic and global systems; types and sources of global change in the Arctic; effects of global changes on human societies in the Arctic; alternative approaches to current and future problems; and effects of arctic changes on people living outside the region. Ethical research issues include informed consent by individuals and communities, community involvement in research, the use and distribution of traditional indigenous knowledge, and intellectual property rights. HARC includes funding and guidelines for linking research with science education in arctic community schools. (Contains 51 references, other relevant publications, reviewers and participants in a related workshop, and photographs). (SV)

People and the Arctic

A Prospectus for Research on the Human Dimensions of the Arctic System

Front cover: Martina Phillip skins her husband Joe's seal in Alakanuk, Alaska (© James H. Barker).
Inside covers: Caribou cross Teshekpuk Lake on Alaska's North Slope (© Bill Hess, Running Dog Publications).
Back cover: A dancer from Greenland participates in festivities during the 1995 Inuit Circumpolar Conference meeting in Nome, Alaska (© Bill Hess, Running Dog Publications).

People and the Arctic

A Prospectus for Research on the Human Dimensions of the Arctic System (HARC)

for the National Science Foundation Arctic System Science Program

May 1997

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Foreword

Today, the winds of change are blowing through the Arctic. This is true in the environment itself, where we find evidence of climate change, where we see signs of ecosystem changes, where we detect contaminants carried by long-range transport from industrial areas. It is also true in our attitudes, as we increasingly recognize the role of humans in the arctic environment, as arctic peoples improve their ability to contribute to and benefit from scientific research.

For us who live in the Arctic, learning to apply science to everyday life is long overdue. There is an inseparable link between humans and the environment, and the study of one without the other can go only halfway to finding solutions to the challenges that face us. As we study the Arctic, we need to bear in mind the implications of our work.

As we develop these ideas and expand the range of our work, we will build partnerships. These include working to combine scientific and traditional knowledge, using the strengths of each to include local communities in seeking answers. These partnerships also include applying science and its findings to create solutions and develop sound policies and management practices to protect the arctic environment.

People and the Arctic: A Prospectus for Research on the Human Dimensions of the Arctic System is a big step in the right direction, providing an opportunity for exploring important topics in ways that are relevant to the lives of arctic peoples. I commend the National Science Foundation for supporting this new initiative, and I look forward to watching HARC grow, learning from both its science and its applications.

Caleb Pungowiyi
April 1997

In his keynote address at the initial HARC planning workshop, Caleb Pungowiyi reminded participants of the importance of partnerships and thanked them for their involvement in this significant effort.

Caleb Pungowiyi honored the initial HARC planning workshop by giving the keynote address and participating in the development of recommendations. His remarks provided an important foundation for the subsequent discussions and deliberations. Pungowiyi was born and raised in Savoonga on St. Lawrence Island and now lives in Nome, Alaska. He is a Yup'ik Eskimo with extensive experience as a spokesperson and advocate for Native concerns and knowledge, in regional, national, and international policy matters. As Director of the Natural Resources Program for Kawerak, Inc., Pungowiyi supervises the activities of the Fisheries, Subsistence and Eskimo Walrus Commission; serves as liaison between Kawerak, Inc. and federal, state and local governments; monitors public policies that affect the rights of tribes and their members; and works with tribes to develop conservation programs, including research projects, for subsistence resources.

Pungowiyi is a former President and CEO of the Inuit Circumpolar Conference. He currently serves on the Bering Straits Regional Commission, the Executive Council of the Inuit Circumpolar Conference, the Committee of Scientific Advisors for the Marine Mammal Commission, and the Alaska Scientific Review Group of the National Marine Fisheries Service. Pungowiyi also serves on the Boards of the Rural Alaska Resources Association, Bering Sea Impact Study (a subcommittee of the International Arctic Science Committee), and Indigenous Peoples Council for Marine Mammals. Past service has included the National Science Foundation Office of Polar Programs Advisory Committee, the Steering Committee of the Alaska Native Science Commission, the Polar Research Board Committee on Bering Sea Ecosystems, the Advisory Panel on Arctic Impacts from Soviet Nuclear Contamination, the Native erican Rights Fund, the Alaska Coastal Policy Council, and the Alaska Conservation Foundation.

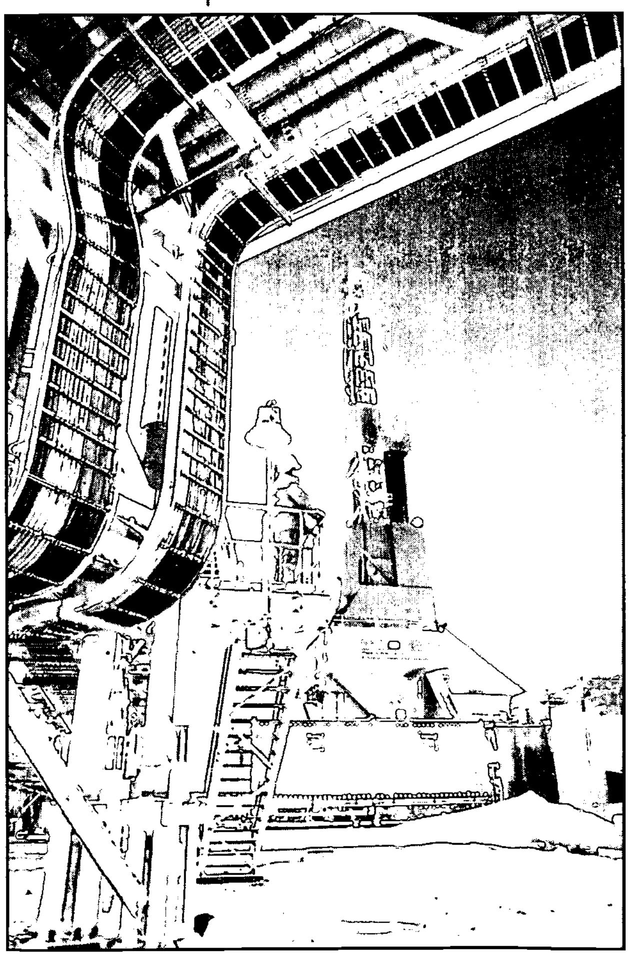
Executive Summary

Over the course of prehistoric time, the diverse and demanding environments of the Arctic fostered the development of a wide variety of human cultures throughout the circumpolar north. The North American record extends to 15,000 years before present, after the Pleistocene era of glaciation lowered sea level allowing humans (and many other species) to cross the Bering Land Bridge from Siberia for the first time. Preliminary dating of recent discoveries in what is now Siberia suggest that humans may have occupied that region much earlier.

Where researchers have studied evidence of past and contemporary cultures, it is clear that survival in the Arctic has depended upon adaptability. Changes in the Arctic have been tied historically to both local and global processes. In addition to change driven by seasonal extremes and variability, human activity within the region has caused significant environmental, economic, social, and cultural change (*e.g.*, colonization, fur trade, gold rush, urbanization), and arctic residents today have the capacity to foster or discourage some of the most extensive and precipitous changes in the region (*e.g.*, large-scale oil development, logging, alteration of fire regimes, redirection of freshwater flow to the arctic basin). Change has also come from human activity outside the Arctic (*e.g.*, high-seas fishing; transport of ozone, greenhouse gases, and nuclear waste to the region; the hunting of birds and mammals in southern portions of their migratory route). Because humans are a catalyst of change on global and regional as well as local scales, it is essential to incorporate the human dimensions in any study of the arctic system (Chapter 1).

Humans are a catalyst of change on global, regional, and local scales; it is essential to incorporate the human dimensions in any study of the arctic system.

The human capacity to adapt to change in the Arctic will be further tested, as the polar regions are expected to sustain the early and significant changes associated with contemporary global change. It is not just the Arctic that will be affected, however. Some physical changes that originate in the Arctic could propagate to lower latitudes, changing air and sea temperatures, and affecting economies. For example, major Atlantic and Pacific fisheries could depend on ocean conditions that are influenced by arctic processes affected, in turn, by changes in climate. Ten percent of U.S. oil supplies come from arctic petroleum developments that are designed to perform under current conditions. For these reasons and others, the Arctic is seen as an early warning system for emerging global changes that will ultimately affect other areas as well. The experience of arctic peoples is, thus, instructive for humans elsewhere in the world who are striving to accommodate exacerbated fluctuations and accelerating rates of change in their respective natural and social environments (Chapter 2).



An oil-drilling rig at Endicott Island, a man-made island in the Beaufort Sea north of Prudhoe Bay, Alaska (© James H. Barker).

The U.S. Global Change Research Program (USGCRP) was established through the enactment of the Global Change Research Act in 1990 to develop reliable scientific projections upon which to base sound policy options in response to the anticipated impacts of the changing biosphere on humans and social systems. Efforts to understand the Earth system are focusing special attention on sensitive areas of the world where

Growing concern about the sensitivity and importance of the polar regions led the National Science Foundation to create the Arctic System Science Program to help understand the Arctic in the context of global change.

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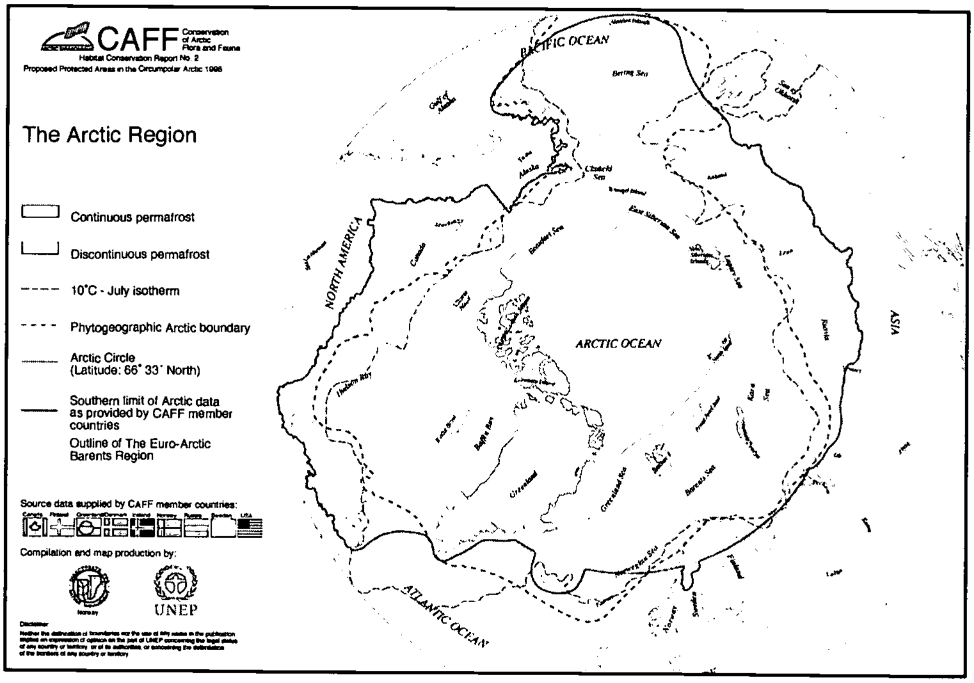
changes are anticipated to be the greatest and where changing processes are thought to have global consequences. Growing concern about the sensitivity and importance of the polar regions led the National Science Foundation (NSF) to create the Arctic System Science (ARCSS) Program, as the NSF contribution to the USGCRP, to help understand the arctic system in the context of global change. Such an understanding requires a systems approach that investigates the relationships among the physical, biological, and human features of the environment, crosses disciplinary boundaries, and connects local and global processes. Understanding the processes involved can help humans address the causes, predict future changes as they ripple through local, regional and global systems, and formulate effective policies guiding adaptations to these changes.

The ARCSS Program is presently composed of two primary components—paleo- and contemporary environmental studies—with an additional overarching programmatic emphasis on integration and synthesis. Within paleoenvironmental studies, the Greenland Ice Sheet Project (GISP2) has recovered an ice core that dates back to 250,000 years before present, and Paleoclimates from Lakes and Estuaries (PALE) looks at climate changes in the past 2,000, 20,000, and 150,000 years. Land/Atmosphere/Ice Interactions (LAII) and Ocean/Atmosphere/Ice Interactions (OAII) address modern interactions and processes. Synthesis, Integration, and Modeling Studies (SIMS) is neither a program nor a component but is a programmatic emphasis that advances integration and synthesis across all of ARCSS research, as well as with other arctic programs. The Human Dimensions of the Arctic System (HARC) initiative described in this prospectus will consider how humans interact with physical and biological environmental change in the Arctic (Chapter 3). Chapter 4 discusses existing and potential linkages between HARC and the four major ARCSS research programs included in the paleoenvironmental and contemporary studies components.



This map shows the proposed protected areas in the circumpolar Arctic as recommended in 1996 by the Arctic Environmental Protection Strategy (AEPS) working group on the Conservation of Arctic Flora and Fauna. The work begun through the AEPS will be carried on by the Arctic Council (see page 56), a circumpolar policy forum for the eight Arctic nations and three groups representing indigenous peoples in those countries (map courtesy of UNEP/GRID-Arendahl).

HARC research considers human activity, both within and outside the Arctic, as a link and vital driver among the terrestrial, marine, and climatic subsystems. Accordingly, the initiative provides a significant opportunity to integrate ecosystem and climate studies with a broad range of the social sciences. The major thrusts of the HARC initiative are to broaden our understanding of the arctic system and to assist arctic peoples to understand and respond to the effects of large-scale changes. HARC is also concerned with the effects of change in the arctic system on people who live outside the Arctic. This HARC prospectus describes a program designed to support the development of innovative research that:

- cuts across traditional social, biological, and physical science disciplines;
- employs varied scientific methodologies;
- collects data at different levels of analysis, and across a broad range of time and spatial scales; and
- involves local people and communities in research design and implementation, where possible.

The underlying objectives of HARC research and the principles by which HARC research is to be conducted are outlined in Chapter 5. The prospectus recommends strongly that HARC researchers—indeed all arctic researchers—follow the *Principles for the Conduct of Research in the Arctic*, promulgated by the Interagency Arctic Research Policy Committee, as well as guidelines established for each respective social science discipline and by the relevant governments.

Chapter 6 describes human-dimensions issues of importance to arctic residents, global change researchers, residents of the northern hemisphere mid-latitudes, and policymakers, among others. These issues are organized into five fundamental research questions:

- What are the impacts of human activity on arctic and global systems?
- What are the types and sources of global change in the Arctic?
- What are the effects of global changes on human societies in the Arctic?
- What are the alternative approaches to current and future economic, social, ideological, political and legal, health, historical, and ecological problems?
- What are the effects of changes in the arctic system on people living outside the Arctic?

Each of the primary research themes emphasized above is elaborated upon by a discussion of several evocative research questions, the relevance of each, and the maturity and tractability of each in the context of the existing body of research. Potential areas of inquiry under the five broad questions are shown in Table 1, HARC Research Questions, on pages 4-5. As a point of departure for future planning and discussions, the various research issues in Table 1 have been ranked as:

- highly appropriate for immediate research funding,
- important, requiring further planning and integration,
- important, requiring additional conceptual development and integration.

The arctic research community anticipates that the five principal questions, the research areas, and initial assessment of priorities will evolve as ARCSS research and global changes themselves unfold.

Education, training, and employment opportunities will strongly influence the strength and nature of connections between humans and the rest of the arctic system.

These are major vectors through which policy changes might alter the role of humans in the arctic system.

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Geoff Carroll, a biologist with the Alaska Department of Fish and Game, and high school student Alfred Teerik from Barrow, Alaska tag and radio-collar caribou from the Teshekpuk herd in 1995, as part of a project involving North Slope residents in science projects and wildlife management (© Bill Hess, Running Dog Publications).

Table 1: HARC Research Questions

	A What are the impacts of human activity on arctic and global systems?	B What are the types and sources of global change in the Arctic?	C What are the effects of global changes on human societies in the Arctic?
Highly appropriate for immediate funding	1. What are the cumulative impacts of large-scale development on arctic ecosystems? (Page 30) 2. How has the spread of contaminants changed the functioning of arctic ecosystems? (Page 30) 3. How has human use altered arctic food chains and resulting ecosystem processes in terrestrial, freshwater, and marine ecosystems? (Page 31) 4. How have anthropogenic changes in the surface energy balance of arctic and subarctic regions and changes in river runoff affected the water balance and regional climate of the Arctic? (Page 32) 5. How will the effects of human disturbances on the landscape and climate change interact in areas of ice-rich permafrost? (Page 33)	1. How will the worldwide economy act as a global change agent in the Arctic? (Page 35) 2. To what extent will decreases in external government support for communities act as a global change agent? (Page 36)	1. How will global changes affect the size, distribution and condition of fish and wildlife resource populations and their use by arctic residents? (Page 39) 2. How will community resilience and vulnerability respond to global changes in the environment, the economy, and society? (Page 39) 3. How will global changes affect the possibilities for economic diversification and sustainable development? Will the changed possibilities, in turn, affect the arctic system? (Page 40) 4. How will global changes affect indigenous control of local and regional institutions and the ability of arctic peoples to influence the pattern of human activities in the Arctic? (Page 40)
Important, requiring further planning and integration	6. How do economic, cultural, social, educational, and environmental factors govern the types, scale, and geographic variability of human impact within the Arctic? (Page 34)	3. What is the relative contribution of changes in mean temperature and precipitation (as opposed to their variance or the frequency of extreme weather) on resource population dynamics and other aspects of arctic life? (Page 36) 4. What is the carrying capacity of humans in the Arctic? How will the growth of human populations in the Arctic influence arctic ecosystems? (Page 37)	5. What effects will global changes have on education, training, and employment opportunities for arctic residents? (Page 41) 6. How will global changes affect health and access to health care in northern communities? (Page 41)
Important, needing further conceptual development and integration		5. What is the relative importance of the various global changes to changes in the arctic environment? (Page 37)	7. What other socioeconomic changes (e.g., emigration or immigration, family formation, birth rates, social problems, cultural continuity) are likely to accompany large-scale environmental change? Do these changes create new anthropogenic influences on the arctic system? (Page 42)

	D What are the alternatives?	E What are the effects of changes in the arctic system on people living outside the Arctic?
Highly appropriate for immediate funding	1. Economic: What economic alternatives are available to arctic communities, and what are the implications of such economic alternatives for the arctic system? (Page 43) 2. Social: What kinds of institutions can be designed to promote sustainability, guide sustainable use of resources, mediate resource conflicts, *etc.*? (Page 43) 3. Ideological: What are the impacts of shifting ideologies, within and outside the Arctic, on resource use and the arctic environment? (Page 44) 4. Political and legal: How effective are current political systems and policies for responding to large-scale environmental change? (Page 44)	1. How does human harvesting in the Arctic affect resource availability in the mid-latitudes? (Page 47)
Important, requiring further planning and integration	5. Health: What are alternative approaches to improving the health of people in the Arctic? How might these approaches affect the development and spread of diseases and, thus, the effect of disease on arctic and global systems? (Page 45) 6. Historical: Can we identify successful sociocultural adaptations to past change that have relevance for adapting to global change, including climate change as indicated by ARCSS research? What new institutions might help communities adapt to environmental change and mediate resource conflicts? (Page 45) 7. Ecological: What factors might predict the resilience or adaptability of individuals and communities facing ecological change (and the regulatory changes that often accompany sudden ecological declines)? (Page 46)	2. How do changes in North Atlantic deep-water formation, as influenced by the hydrology of the Arctic Basin, affect climate and fisheries outside the Arctic? (Page 47) 3. Under what circumstances would changes in surface-energy budgets or in trace-gas fluxes within the Arctic be large enough to affect climate beyond the Arctic? (Page 48)
Important, needing further conceptual development and integration		4. What are the impacts on people outside the Arctic of migratory birds and fish that accumulate arctic contaminants? (Page 48)

The HARC initiative provides a unique opportunity to meld ecosystem and climate studies with the social sciences. This will improve our overall understanding of arctic systems, of which humans are an integral part.

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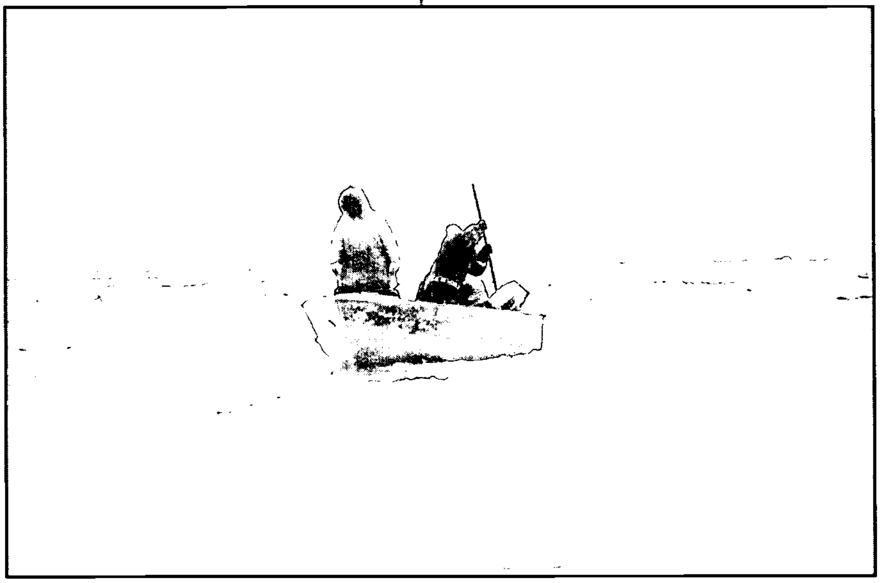
"Chuki" (Lucy) George at Umkumiut, Alaska fishcamp (© James H. Barker).

Chapter 7 emphasizes the importance of adapting the methodologies of diverse science disciplines that will contribute to HARC so that the methods and data they generate can be linked with other social and biophysical science findings to address arctic system concerns. This includes methodologies used in the social sciences such as surveys, oral histories, census data, health records, ships' logs, and artifacts, as well as those more commonly used in the natural sciences such as modeling and Geographic Information Systems (GIS).



Nelson Island hunters push through the ice toward open water. Hunters judge ice conditions from many miles away; open water reflects practically black in the sky (© James H. Barker).

Modeling offers a useful way to integrate observations and results generated by other ARCSS Program components. The approaches of both system modeling and spatial modeling are relevant to HARC. The challenge of effectively modeling changes over a period of decades (transient dynamics) at a regional scale, however, is still largely unresolved; as with all modeling, a tension exists between simplicity and detail. While many ARCSS projects include developing models of system components, the introduction of human dimensions to arctic system models entails a substantial increase in complexity. The challenge to modelers is to combine the interactions between different subsystems (*e.g.*, terrestrial hydrology, fisheries ecology, human economics, human population) over a regional scale in a way that effectively addresses larger-scale problems relevant to predicted global change scenarios.

The challenge to modelers is to combine the interactions between the different subsystems, such as vegetation ecology, caribou ecology, human economics, and human population over a regional scale in a way that effectively addresses policy questions.

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All data and research findings, whether they pertain to the Arctic as a whole or to an individual organism, have a spatial component. Geographic Information Systems (GIS) play an important role in synthesizing, integrating, analyzing, and retrieving multiscalar and interdisciplinary work.

Chapter 8 addresses HARC data-management concerns. Because ARCSS is a broad-based program aimed at synthesis of arctic system science, access to data is a high priority. The goal for long-term archiving of ARCSS data through the ARCSS Data Coordination Center at the National Snow and Ice Data Center (NSIDC) includes all HARC data. There are specific concerns, however, when dealing with human subjects, including whether:

- informed consent has been granted,
- communities have been informed about ongoing research,
- results are being returned in an understandable form, and
- anonymity and credit have been provided as is appropriate.

Regulations addressing these concerns pertain to the unanticipated use of data. When a researcher wishes to make use of data in a way that was not foreseen when the data were collected, they must obtain informed consent from the individuals and communities that were originally involved, document the process by which consent is obtained, and provide research results in a form comprehensible to the individuals and their communities.

These issues of informed consent and other issues relating to responsible research activities are addressed in the *Principles for the Conduct of Research in the Arctic* in Chapter 5. This is just one example of the ways in which collaboration between HARC and other ARCSS programs has the potential to raise the standards guiding all ARCSS researchers and archivists.

HARC data will be archived and made accessible for scientific use specifically. For any other use, the data are considered proprietary and are subject to any intellectual property rights that the original research participants may claim. Indigenous peoples around the world are reaffirming their authority to determine the relevance, utilization, and stewardship of traditional knowledge and wisdom (TKW). In general, indigenous peoples of the Arctic have consistently recommended that, in order to incorporate TKW, researchers must actively involve Native residents of the region in planning, implementation, and decisions about the use of data and information, as their wisdom and knowledge is dynamic and alive within them.

Chapter 9 discusses the opportunities for HARC to contribute to education efforts and the development of collaborative relationships with arctic communities, as well as to national and international research programs (*e.g.*, the science agenda of the International Arctic Science Committee [IASC], the core and related projects of the International Geosphere-Biosphere Programme [IGBP], and the Human Dimensions Programme [HDP]). HARC will also benefit through collaboration with other programs. For instance, links with programs of the Arctic Council have the potential to help inform researchers about international policies and developments that are relevant to HARC projects. HARC contributions will include strengthening the links between biophysical and social sciences, and broadening the range within which their respective findings are applied.

The HARC initiative demonstrates a commitment to developing strong and broad educational components that link scientists and research in ARCSS projects with students and other members of the Arctic community.

The HARC initiative demonstrates a commitment to developing strong and broad educational components that link scientists and research in ARCSS projects with students and other members of the Arctic community. This commitment to education will be reflected in proposal designs, grant awards, implementation, and dissemination of results. Where research is related to the lives of people in northern communities, those communities will have a primary role in development of the educational components. This cooperation will contribute to a better understanding of arctic systems and to the active development of northern sciences through traditional knowledge and experience.

Efforts by policymakers to guide the management of resources and social institutions in the Arctic, and elsewhere in the world, have suffered in the past for want of interaction between natural and social scientists and historians. Basic science has a fundamental role to play in policy formulation and policy questions can point to the need for specific types of studies. Such studies have greater potential impact and lead to more firmly grounded policies than segregated studies can achieve. For their part, social scientists are now challenged to make good use of biological and physical data to identify the linkages between human and environmental variables.

Yup' ik students in a school on the lower Kuskokwim River study characteristics of plants that grow near their community (photograph by David R. Klein).

ARCSS research has matured sufficiently so that arctic scientists are now applying their findings to improve our understanding of human and environmental interactions and to assess the implications of global changes for residents of the arctic and other affected regions of the world. The HARC initiative provides a unique opportunity within the ARCSS Program to meld ecosystem and climate studies with a broad range of social sciences study. The focus of the HARC initiative on comparative and place-based study of the Arctic is an important contribution toward the regional and integrative syntheses that are universally sought but not yet widely achieved.

A fishing vessel at anchor in Qeqertarsuaq, Greenland. Icebergs from Jakobshavn Glacier can be seen in the background. HARC research will look at the interface between the terrestrial and marine environments; human activities, such as those illustrated here, are a vital link among the terrestrial, marine, and climatic subsystems (photograph by Richard A. Caulfield).

The HARC Prospectus outlines a dynamic plan that will be subject to continual evolution, strengthening, and changing priorities, as is the case with other ARCSS Program studies. Some issues, possibilities for integration, and disciplinary links identified are not confined to the ARCSS Program. The examples provide an excellent model, however, for such integrated studies and lay the groundwork for interdisciplinary, multi-agency, and international collaborations. Studies such as those proposed in this prospectus represent the longstanding commitment of arctic researchers to improving our comprehensive understanding of arctic and global systems, of which humans are an integral part, and to enhancing our ability to prepare for the future.

Chapter 1. Humans and the Arctic

The Arctic, unlike the ice-bound Antarctic, has been a home to humans for more than 10,000 years. Today the region is culturally, demographically, politically, and economically diverse. Its settlements range from small indigenous communities dependent on local resources to modern industrial cities such as Narvik, Norway and Norilsk, Russia. Arctic communities also include fishing ports, mid-sized towns with mixed indigenous and immigrant/southern-origin populations, and complexes developed for mineral and energy extraction.

The Arctic's long winters, limited soil fertility, and vast distances challenge the people who live there. Arctic environments tend to change dramatically, for example in climatic variables or in the distribution and abundance of animal populations. Such changes can occur on many time scales, from seasonal to annual, decadal, and longer. These conditions place a premium on human adaptability; individual and community survival may depend on altering patterns of resource exploitation or actually leaving an area in response to environmental change. Reactions to change in the past were sometimes inadequate, and cultural groups (such as the medieval Norse in Greenland) disappeared. Modern communities are, for their own reasons, less capable of change or relocation. Igor Krupnik (1993) said of the traditional cultures of Siberia,

> *In an environment that changes so regularly and radically as the Arctic, an equilibrium between humans and their environment is effectively impossible.*

The environment dominates many aspects of daily life in the Arctic; environmental changes are likely to have immediate, important consequences to arctic peoples. Human activities themselves may be a cause of environmental change in the region. For example, archaeologists have found evidence of prey overkill by prehistoric hunters and fishers, followed in some instances by local population declines and site abandonments. More contemporary versions of this dynamic include the boom-and-bust cycles of Russian and Canadian fur trades, Yankee whaling, gold-rush mining and, most recently, oil-field development. In addition to consuming resources, settlements may generate contamination on scales ranging from local to region-wide areas (*e.g.*, the presence of nuclear waste in the Arctic Ocean). Such problems may alter the trophic dynamics of the arctic system, affecting the abundance and safety of terrestrial and marine food resources upon which many arctic peoples depend.

The greatest potential for arctic environmental change, however, does not originate in the Arctic. Long-range transportation of contaminants from the South, the global build-up of greenhouse gases, and stratospheric ozone depletion all have the potential to alter environments on a very large scale. Arctic ecosystems are particularly sensitive to such alteration and may see relatively early and substantial changes. The natural variability and vulnerability of arctic biophysical systems, combined with humans' close dependence on those systems, magnify the potential importance of global change for arctic residents. Furthermore, human impacts on arctic and subarctic environments (*e.g.*, large-scale development, large-scale pollutant inputs, logging, river diversions, altered fire regimes) are likely to be the largest and fastest changes in these regions in the coming decades. Accurate predictions of future changes require the inclusion of humans as critical elements in the arctic system.

Arctic conditions place a premium on human adaptability; individual and community survival may depend upon altering patterns of resource exploitation or actually leaving an area in response to environmental change.

For these reasons, the human dimensions of large-scale change in the Arctic system present an urgent topic for research. The Arctic may constitute an early warning system for emerging global changes that will ultimately affect non-arctic areas too. For example, recent analysis of satellite vegetation data suggests that plant cover in the Arctic appears earlier and remains longer than it did a decade ago. This data indicates an ecological response to climate changes over a broad region and may be an early sign of human-caused global warming (Myneni *et al.* 1997).

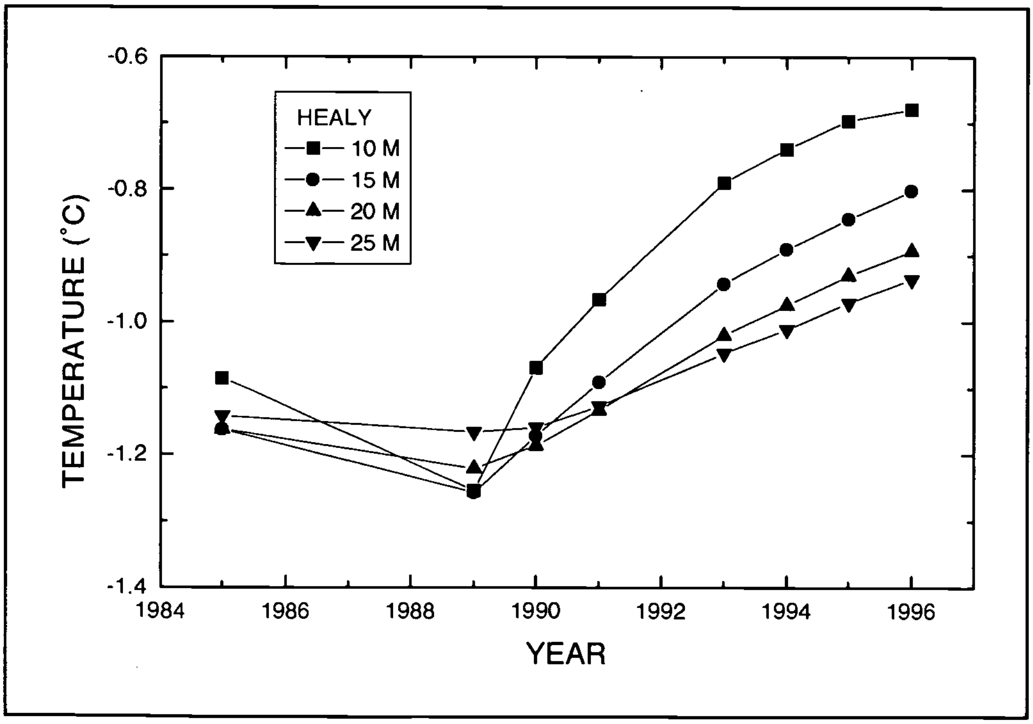
Moreover, changes begun in Arctic and sub-Arctic waters have spilled over into the mid-latitudes and are implicated in bringing cold weather, changing sea temperatures, and affecting human livelihoods dependent on the environment, such as fishing (Beamish 1995, Laevastu 1993). The changes in the climate and oceans of the Arctic have been tied into both local and global processes (Manabe 1995, Rahmstorf 1995).

Understanding the global processes that affect the physical and biological environment of the Arctic, and *vice versa*, requires a systems approach—an approach that includes the relationships among the physical, biological, and human features of the environment. This approach connects local conditions to global processes, crosses disciplinary boundaries, and addresses feedbacks within and between systems. Understanding these interconnections can aid effective human control over the causes of the conditions and adaptation to their effects.

Thermokarst, Communities, and Local Knowledge

Permafrost temperatures in northern Alaska have warmed 2-4°C during the last century. A short-term warming of about 4°C has occurred in the last dozen years in the area near Prudhoe Bay. During the summer of 1995, ice cellars in Anuktuvuk Pass were too warm to keep foods frozen. The hospital in Kotzebue had to be abandoned because of ground settlement associated with thawing ice-rich permafrost. The figure below shows that permafrost temperatures near Healy, Alaska have warmed significantly since 1989 (Osterkamp 1994). Thaw subsidence and thermokarst have developed in this area where the permafrost was ice-rich.

Further thawing of ice-rich permafrost will continue to alter the ecosystems on which subsistence depends and affect societal infrastructures. Studies that link predicted warming scenarios with localized changes in the permafrost would aid community planning and development and would illuminate questions about subsistence and economic alternatives.



Time series of permafrost temperatures near Healy, Alaska showing the warming that has occurred since 1989 at this undisturbed site. Ground subsidence and thermokarst are developing where the ...afrost is ice-rich (figure by Tom Osterkamp).

Chapter 2. The Arctic System and Global Change

Concern about the importance and sensitivity of the polar regions in a changing global environment led, in the mid-1980s, to several recommendations by the U.S. Arctic Research Commission and the Polar Research Board for increased scientific research aimed at understanding the Arctic in the context of global change. Building on this groundwork by the scientific community, in 1989 the National Science Foundation (NSF) created the Arctic System Science (ARCSS) Program as part of its contribution to the U.S. Global Change Research Program (USGCRP). The USGCRP addresses the key scientific uncertainties associated with documenting, understanding, and predicting the behavior of the Earth system with the goal of developing reliable scientific projections upon which sound policy strategies and responses can be based.

Efforts to document and understand the Earth system have focused attention on sensitive areas of the world where anticipated changes will be greatest and where changing processes have global consequences. The Arctic is both highly sensitive to climate perturbations and smaller in area than low- and mid-latitude zones. For these reasons, it offers opportunities for modeling a regional approach to issues common to all global change research, synthesizing multivariate information that spans a wide range of spatial and temporal scales. Through synthesis, a deeper scientific understanding of the globe may be achieved. Such an understanding provides the basis for improving global models. The NSF-ARCSS Program was created to meet this challenge.

The ARCSS Program focuses on the role of the Arctic in global change, with respect both to changes forced by the global system and to the global effects of arctic processes. Priorities within ARCSS have been established on the basis of the potential impact of research on a given topic, relevance to global change, and particularly, the extent to which a project would address major gaps in current knowledge. An early emphasis in ARCSS has been on acquiring an understanding of arctic climate and the effects of climate change on the biogeochemical cycles and components of the arctic system. While this research remains vital, it is only one of several scientific thrusts of ARCSS, including the arctic climate system and its variability, the role of the Arctic in biogeochemical cycling, the structure and stability of arctic ecosystems, and the links between environmental change and human activity.

Current ARCSS research activities fall into three general categories. The Paleoenvironmental Studies is composed of GISP2 (the Greenland Ice Sheet Project–Two) and PALE (Paleoclimates from Arctic Lakes and Estuaries). GISP2 has collected an ice core that records climate change in the Arctic as far back as 250,000 years, while PALE focuses on sedimentary records of the last 2,000, 20,000, and 150,000 years. The Studies of the Contemporary Environment component includes Land/Atmosphere/Ice Interactions (LAII) and Ocean/Atmosphere/Ice Interactions (OAII) which deal with modern interactions and processes in their respective realms.

U.S. Global Change Research Program Goals

The U.S. Global Change Research Program aims:

- To establish an integrated, comprehensive, long-term program of documenting the Earth system on a global scale.
- To conduct a program of focused studies to improve our understanding of the physical, geological, chemical, biological, and social processes that influence the Earth system and that govern the temporal trends of important variables on global and regional scales.
- To develop integrated conceptual and predictive Earth system models.
- To carry out integrated assessments.

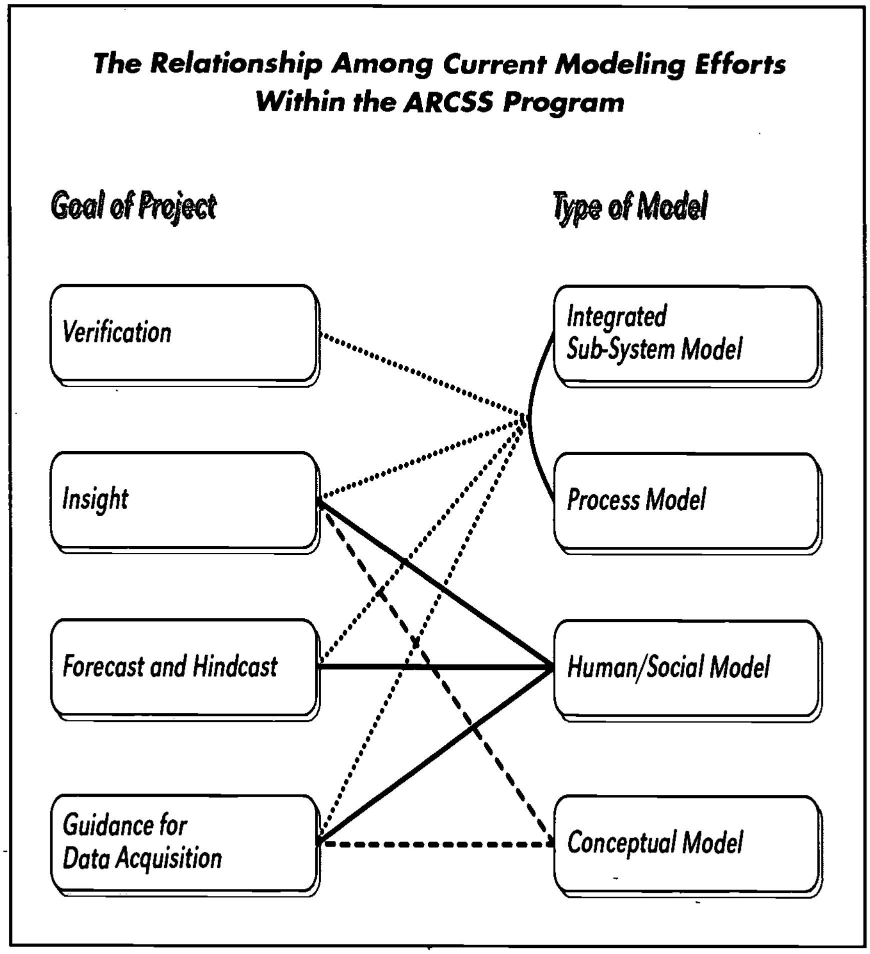
ARCSS Program Goals

The goals of ARCSS are articulated in the following two statements:

- To understand the physical, chemical, biological, and social processes of the arctic system that interact with the total Earth system and thus contribute to or are influenced by global change; in order
- To advance the scientific basis for predicting environmental change on a decade-to-centuries time scale and for formulating policy options in response to the anticipated impacts of changing climates on humans and social systems.

The third category includes research that integrates and synthesizes across programmatic, disciplinary, and geographic boundaries. Both research thrusts emphasized in this category—Synthesis, Integration, and Modeling Studies (SIMS) and the Human Dimensions of the Arctic System (HARC)—bridge the paleoenvironmental and contemporary studies components through space and time. SIMS is neither a program nor a component, but rather a programmatic emphasis that considers the interaction of the Arctic with the global system and advances synthesis, integration, and modeling efforts across the major programs of ARCSS and with other large arctic research programs.

The Human Dimensions of the Arctic System initiative, described in the following pages, proposes to link the existing programs of ARCSS by considering how humans interact with physical and biological environmental change in the Arctic. HARC research considers human activity as a vital driver and as a link among the terrestrial, marine, and climatic subsystems.



Within Synthesis, Integration, and Modeling Studies (SIMS), it is important to achieve collaboration, not only among modelers, but between investigators involved in modeling and those involved in theoretical work and data acquisition. The ARCSS Modeling Working Group has identified the structure shown above for current modeling efforts within the ARCSS Program. Clearly, some aspects of modeling within the various components of ARCSS are more mature than others. For example, the projects within the HARC area are still very new and full use of tools such as integrated assessment models is still in the future. This is not a barrier to collaboration between the modeling efforts in the various components, however, since integration among the various projects need not involve the actual coupling of models (figure by Amanda Lynch).

Chapter 3. Human and Environmental Interactions in the Arctic System

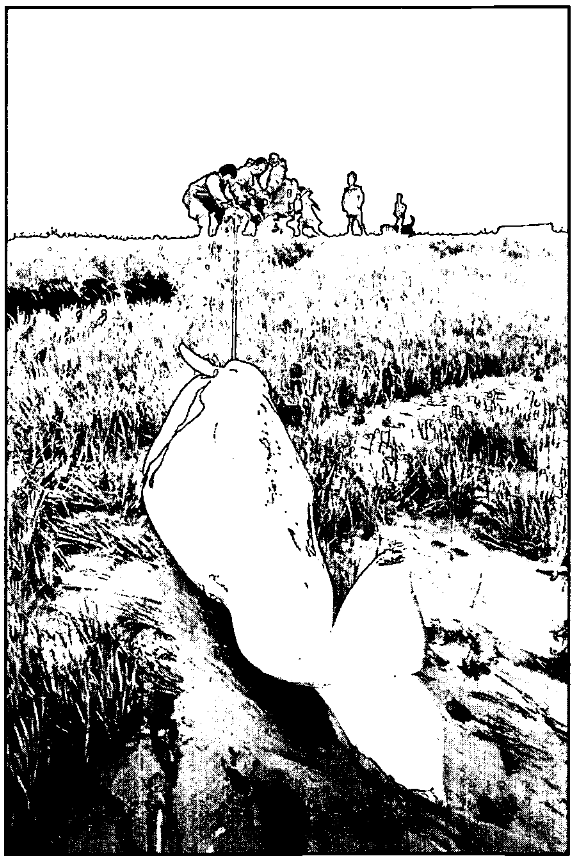
The NSF-ARCSS Program was designed to increase our understanding of the physical, chemical, biological, and social processes of the arctic system. The ultimate goal of the program is to help formulate policy options that will minimize the negative impacts of the changing biosphere on humans and social systems (see box page 11). Much ARCSS research has been directed at understanding the physical and natural elements of the arctic system—for example, how these elements will be affected by climate change, and how feedbacks from the arctic system will in turn affect global change.

The intent of the Human Dimensions of the Arctic System (HARC) initiative, as presented in this prospectus, is to illuminate the linkages among the physical, natural, and human components of the arctic system.

The results of HARC research will help policy makers respond to the effects of large-scale changes in the Arctic. In addition to climate change, examples of large-scale changes affecting humans and social systems include contamination of resources, habitat loss, elevated levels of ultraviolet radiation, competition for fish and wildlife, shifting cultural values, world-market effects on local economies, and increased resistance of diseases to treatment.

The focus on comparative and place-based study of the Arctic is an important effort in working toward the regional and integrative syntheses that are universally sought but not yet widely achieved.

A major thrust of the HARC initiative is to assist arctic peoples to understand and respond to the effects of large-scale changes. In addition, just as the ARCSS Program as a whole is concerned with the effects of the arctic system on global climate, the HARC component is also concerned with the effects of changes in the arctic system on people who live outside the Arctic. For example, major Atlantic and Pacific fisheries depend on ocean-circulation patterns influenced by Arctic Ocean currents which are, in turn, affected by changes in climate. Ten percent of U.S. oil supplies come from arctic petroleum developments that are designed to perform under current climate conditions. Changes could affect millions of people dependent on oil within and outside the Arctic.



Pulling a beluga whale onto shore at Black River, Alaska fishcamp (© James H. Barker).

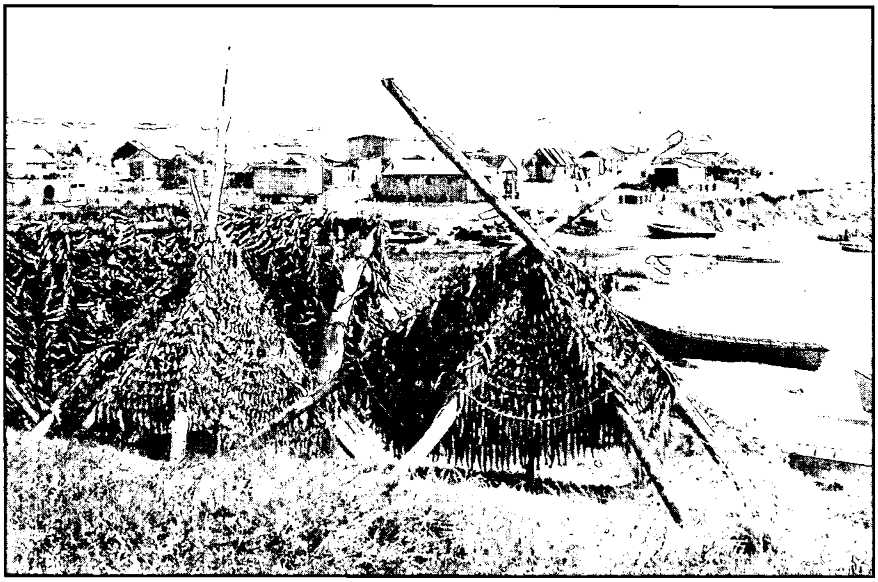
Each project in the ARCSS Program, including each HARC project, is expected to contribute to our understanding of the arctic system as a whole. Since an important intent of the ARCSS Program is to help in the formulation of policy, HARC projects are expected to increase our capability to project future conditions in large geographic areas. The historical ecologist Carole Crumley (1994) has commented,

> *There can be no sustainable future without a well understood past.*

ARCSS studies of past changes in climate and in the condition of physical and natural (including human) systems have already provided important insights that will help to project future conditions.

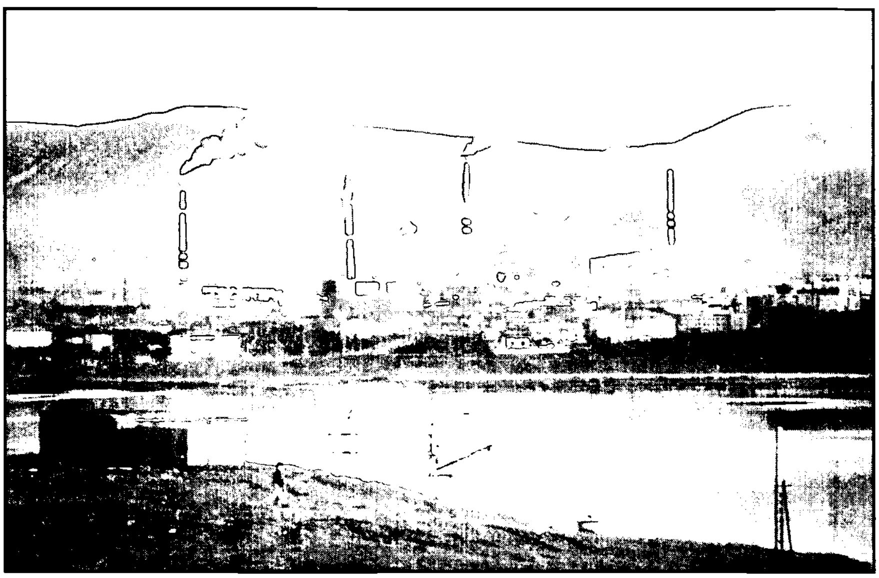
The role of basic science in developing policy for management of resources in the Arctic has been hampered in the past by the lack of interaction between natural scientists, social scientists, and historians. This lack inhibited the process of designing specific biophysical studies to directly address policy questions. Such studies would have greater potential impact and lead to more firmly grounded policies than segregated studies can achieve. For their part, social scientists have not made good use of biological and physical data to specify the linkages between human and environmental variables.

ARCSS research has matured sufficiently so that scientists can apply their understanding of the arctic system to better understand past human and environmental interactions and to assess the implications of global changes to the present and future lives of arctic residents. The HARC initiative provides a unique opportunity, within the ARCSS Program, to meld ecosystem and climate studies with a broad range of the social sciences. The focus of the HARC initiative on comparative and place-based study of the Arctic is an important effort in working toward the regional and integrative syntheses that are universally sought but not yet widely achieved.



Herring drying at Toksook Bay, Alaska (© James H. Barker).

The HARC Prospectus outlines a dynamic plan that will be subject to continual evolution, strengthening, and changing priorities, as is the case with other ARCSS Program studies. Some of the issues, possibilities for integration, and disciplinary links identified throughout this prospectus may not necessarily be included in the ARCSS Program. They provide, however, an excellent model for such integrated studies and lay the groundwork for interdisciplinary, multiagency, and international collaborations. Studies such as those proposed in this prospectus will continue to improve our overall understanding of the arctic system, of which humans are an integral part.



Mining and metal-processing facilities in Norilsk, Russia. Pollution from the Norilsk facilities, built with 1930s technology, can be detected as far away as northern Alaska (photograph by Henry Huntington).

Chapter 4. Existing ARCSS Research and HARC

During the first eight years of the ARCSS Program, the research focus has been to understand the physical and natural science components of the arctic system. Integration and synthesis are considered to be the highest general priorities of ARCSS; efforts integrating research conducted by the various component projects have received priority emphasis, both scientifically and programmatically, as ARCSS has evolved.

Although a focused research program addressing the human dimensions has not existed until now, the ARCSS Program has been responsive to the human dimensions of global change from its inception. Following is a review of ARCSS research and the existing and potential integration and links with human-dimensions research.

Integration and synthesis are considered to be the highest general priorities of the Arctic System Science Program.

Studies of the Contemporary Environment

Potential Links Between HARC and LAII

The overall goal for the LAII (Land/Atmosphere/Ice Interactions) program is to enhance understanding of land-atmosphere-ice interactions in the arctic system, the role that these processes play in the whole Earth system, and the effect that global change may have on the Arctic.

The LAII program has been in existence since 1991. It has, thus far, funded 28 projects, 14 of which are integrated through the Flux Study, a research program that has focused on the question of whether the emission of carbon dioxide (CO_2) and methane (CH_4) from the arctic tundra may accelerate global warming. The Flux Study is investigating the variables and processes controlling the fluxes of CO_2, CH_4, water, energy, and nutrients between arctic terrestrial ecosystems and the atmosphere and oceans. LAII scientists are now completing data collection in the first phase of the Flux Study and are beginning to construct a systems model on a watershed scale. Future LAII work is likely to extrapolate this model to larger scales.

The human dimensions of the LAII program derive principally from the effects of global changes on arctic ecosystems that in turn impact resource use by people living and working in the Arctic. Both traditional and industrial resource uses (*e.g.*, costs of developing and transporting energy or mineral resources) would be affected.

Rommel Zulueta and Rob Richardson from San Diego State University determine the effects of alteration in temperature and soil water status on net ecosystem CO_2 flux in the coastal tundra at West Dock (within the Prudhoe Bay, Alaska oil field) in 1996. The water table was manipulated by float-activated pumps; temperature was manipulated by solar heating from solar panels and small greehouse barriers. Results show the sensitivity of CO_2 balance in tundra ecosystems to both temperature and soil moisture content, as well as the complex interactions between the two (Oechel et al. *in press) (photograph by KUAC TV).*

Scientists are identifying key relationships connecting vegetation, caribou, and human subsistence in the Arctic to better understand relationships among policies, environmental change, and sustainability of human communities in the Arctic.

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A principal question of policy interest for LAII is:

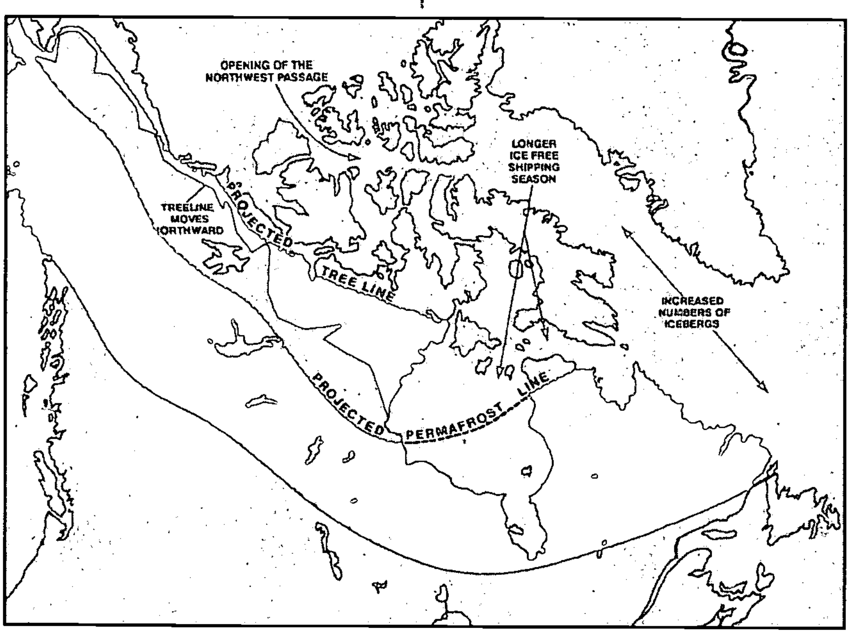
- Will feedbacks from the arctic environment increase the rate of global warming?

The principal policy-related questions for HARC are:

- How will increased rates of change in the Arctic affect people in the global system?
- How will changes in land-based resources affect the lives of arctic residents?
- Can people shape the effects of global changes to the benefit of arctic residents and others dependent upon arctic resources?
- Will changes in human activities (*e.g.*, logging) alter climate feedbacks from the Arctic to the global system?

In LAII, processes under study that are likely to affect humans and social systems include changes in the permafrost, active layer, soil moisture and temperature, snow depth and snow conditions, vegetation respiration and photosynthesis, and nutrient runoff. Some specific examples are:

- A current ARCSS project, *Sustainability of Arctic Communities*, builds on LAII vegetation research to link climate changes with caribou and human subsistence. Natural and social scientists are identifying key relationships between vegetation, caribou, and human subsistence in the Arctic. The project's broader aim is to understand relationships among policies, environmental change, and sustainability of human communities in the Arctic. Climate is not the only force driving change; others include oil and mining development, tourism, and non-local hunting. The project also seeks to identify points at which local communities and regional institutions can intervene to affect such forces.



The map indicates the projected northward movement of the permafrost boundary and treeline after a doubling of atmospheric CO_2 (from Environment Canada, extrapolated into Alaska).

- Thermokarst terrain resulting from the thawing of ice-rich permafrost and subsequent settling of the ground surface is a serious climate-change problem; it may disrupt construction, engineering, and surface transportation. It also has the potential to substantially modify or totally destroy current ecosystems on which subsistence activities depend. Warming in the polar regions could significantly affect such activities, particularly in locations where permafrost contains a substantial amount of subsurface ice.
- The International Tundra Experiment (ITEX) project focuses on understanding how tundra plants, vegetation, and soils will change in response to global climate change. In particular, it is an experiment which manipulates (*e.g.*, warms) tundra to determine short- and long-term plant and soil responses. ITEX operates 26 sites in 11 countries using a standard experiment

and standard set of measurements. In recognition of the need to look at how populations of plant species are important to humans or to grazing animals, ITEX is coordinated under the UNESCO Man and the Biosphere Programme (MAB). Closely affiliated and modeled after ITEX is a program called CALM (Circumpolar Active Layer Monitoring). CALM is coordinated under the aegis of the International Permafrost Association. ITEX and CALM are providing some of the initial physical and biotic data invaluable to modeling and predicting the consequences of global change.

- LAII studies have focused primarily, but not completely, on physical and biological processes at trophic (food-chain) levels at or beyond the level of primary producers. Such studies are essential first steps in understanding the effects of changes in the arctic ecosystem on humans. Other studies at higher trophic levels, such as browsing animals, carnivores and fish, are necessary, since these species are directly consumed by humans and influence the productivity of natural ecosystems through feedback effects on the lower trophic levels. One study of trophic interactions involving geese, their food plants, and biophysical controls over vegetation indicates that human harvest of geese both in and beyond the Arctic can have decadal effects on vegetation through harvest impacts on vegetation and interactions between geese and their food.

One study indicates that human harvest of geese, both in and beyond the Arctic, can have decadal effects on vegetation.

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One strategy for linking the HARC and LAII programs is to develop specific linkages to resources used by people on Alaska's North Slope, the major regional focus of LAII. Further work should explore the implications of arctic system changes on resources used by humans in other locations and at larger geographic scales. Researchers may find, for example, that climatic change produces different effects on islands or peninsulas than on continental areas.

Frank Woods hunting at Toksook Bay, Alaska. Legal goose hunting in the Arctic has been restricted to a very short period in the autumn between an international treaty-set opening day and the beginning of the southward migration (© James H. Barker).

Considerable progress in the first six years of collaboration within LAII has demonstrated the productivity of the interdisciplinary system-science line of inquiry that is characteristic of all ARCSS programs, stimulated new ways of viewing the arctic system and accordingly, generated new scientific questions that were not previously recognized as important. Current LAII research is designed to serve as a foundation for further studies incorporating year-round research, greater spatial scales, and human dimensions. The recently updated LAII Science Plan assesses progress, sets new research direction, and expands the human-dimensions component of LAII. By articulating the connections now, we stand a greater chance of ensuring that the relevance of LAII work to arctic peoples is thoroughly explored.

Potential Links Between HARC and OAII

The Arctic Ocean and its adjacent seas strongly influence the present-day climate of the Earth, and they respond sensitively to climate perturbations through complex interactions among constituents of the arctic marine, atmospheric, and sea-ice environment. The goals of the OAII (Ocean/Atmosphere/Ice Interactions) program are to understand how these interactions occur at the present time and how they might respond to an evolving global climate. Most OAII science priorities seek to reduce uncertainty in the simulation and prediction of future climate over the Arctic. Research in OAII investigates a set of distinct but closely connected topics. These are:

- Circulation of the Arctic Ocean.
- Surface Energy Budget, Atmospheric Radiation, and Clouds.
- Hydrologic Cycle of the Arctic Basin.
- Productivity and Biogeochemical Cycling in the Marginal and Adjacent Seas.
- Coupled Modeling of the Air-Sea-Ice System.
- Paleoceanography of the Arctic.

Clearly, humans are an integral component of the arctic ecosystem. Examples of potential OAII linkages with HARC research include:

- Simulations of the response of global climate to anthropogenic greenhouse-gas emissions show the maximum changes of surface temperature over the Arctic, where sea-ice thickness and extent play a critical role. Furthermore, variations in simulated responses are greatest in the Arctic; human planning in the region must address changes that are likely to be larger and more difficult to predict than at lower latitudes.
- Many investigations of past distributions of arctic animals and sea ice have integrated historical accounts (*e.g.*, early catch records, ships logs, trading company records, missionary accounts) with long-term records provided by bioarchaeology (Amorosi *et al.* 1994). Together, these have documented shifts, some apparently cyclical, in marine biogeography. These shifts may indicate changes in the ocean environment.
- A better understanding of the role that the arctic littoral and marine environments have played in past and present patterns of subsistence use would shed light on historical human migrations. This knowledge could help model and predict how climate change might impact the sociocultural fabric of arctic communities.

Northern Atlantic Fisheries Today

Throughout the northern Atlantic, many fisheries are presently in decline. The primary cause of this decline has been over-fishing, complicated by other large-scale environmental changes.

Fishing pressure has obvious effects on commercial fish stocks, but these effects often combine with those of large-scale variations in the ocean environment. In Greenland (1960s) and Newfoundland (1990s), codfish population declines coincided with generally cooling water temperatures (Laevastu 1993; Martin 1995). In Norway (late 1980s), codfish nearly collapsed, but then rebounded as climate improved (Hannesson 1996). On New England's Gulf of Maine and Georges Bank fishing grounds, valuable groundfish have been largely fished out and their ecological niche taken over by less valuable species such as dogfish and skates (Collins 1994). Other interactions involving water current/temperature fluctuation, such as the North Atlantic Oscillation, and fish larvae and prey species, such as copepods, are currently under study for their role in commercial fisheries change (Kerr 1997).

The human consequences of these changes have been substantial, ranging from the loss of livelihoods in hundreds of Newfoundland fishing communities, to international conflicts involving the United States, Canada, Norway, Russia, Spain, and other countries. Greenlanders' aspirations for full independence from Denmark have been sidetracked by their economic dependence on a limited fishery. Canada and Norway applied federal subsidies to aid their depressed fishing communities. The Icelandic fishing industry has become more concentrated in ownership and capital-intensive, as fishermen must range further to find fish. Increases in black-market activities, unemployment, and other social problems plague some fishing areas.

More positively, programs seeking economic diversification into new ventures such as ecotourism and aquaculture are widely underway. This story of human adaptation to large-scale ecological change is still unfolding.

- A better understanding of present-day ocean circulation bears directly on pollutant-transport pathways, the connection between the Arctic Ocean and the Atlantic and Pacific oceans, and the development of models with a predictive capability. Such information bears directly on human health and cultural issues and has important implications for future policies and planning.
- One consequence of global warming may be a prolongation of the ice-free season on arctic continental shelves. This would profoundly influence marine transportation and offshore oil- and gas-development costs as well as disruption of traditional hunting opportunities. OAII model predictions concerning arctic sea-ice environments would be useful in developing plausible economic scenarios.

Bering Sea Changes

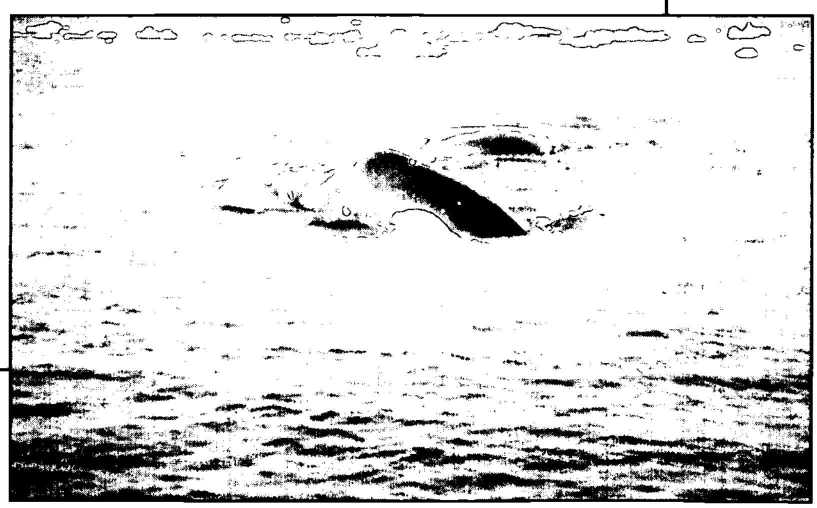
Two recent reports found three causal factors that may have contributed to the 20-year decline in numbers of Bering Sea fur seals, sea lions, seabirds, pollock, and several other fish species (Balsiger 1995, National Research Council 1996). These population declines have had a significant impact on commercial operations in this region of the North Pacific as well as on the Alaska Native communities and their subsistence activities.

The Aleutian Low Pressure system migrated southward affecting winds, air temperatures, and precipitation in the Bering Sea. Changes in atmospheric forcing can influence primary productivity and therefore the trophic composition. The declines in several Bering Sea populations that began 20 years ago now appear to be slowing or leveling out as the Aleutian Low migrates northward once again.

The removal of baleen whales by the Japanese and Russians in the 1950s, '60s, and '70s may have a prolonged effect on the Bering Sea's trophic assemblage. Virtual elimination of these populations of large predators that fed on lower trophic levels may be disturbing the entire ecosystem. Because whales are long-lived, they may not be able to re-establish themselves as a significant predator in the ecosystem for many years. The abundance of whale prey, however, could allow the expansion of other species and predators whose numbers were relatively small when whales were a more prominent component of the ecosystem. In the meantime, the productivity of their prey has allowed the expansion of animal populations that feed at the lower level and, in turn, the predators that feed on them.

Another change stems from commercial fishing where man-as-predator has been removing unprecedented levels of pollock from the ecosystem. Pollock is now the largest single-species fishery in the world. There is concern that removal of large amounts of pollock, and other fish *via* by-catch, is detrimental to the system. Indeed, the pollock fishery is suspected by some to be contributing to declines in juvenile marine mammals in the Bering Sea.

Although none of these effects has been conclusively proven, alone or in aggregate, each factor clearly has the potential for making significant impacts on the Bering Sea system.



The bowhead whale is an important subsistence food item for people living along the coast of the Chukchi and Beaufort seas. These whales overwinter in the Bering Sea, then migrate in spring across the Chukchi Sea and into the Beaufort Sea where they feed until early fall before returning to the Bering Sea (photograph by Donna McDonald).

Paleoenvironmental Studies

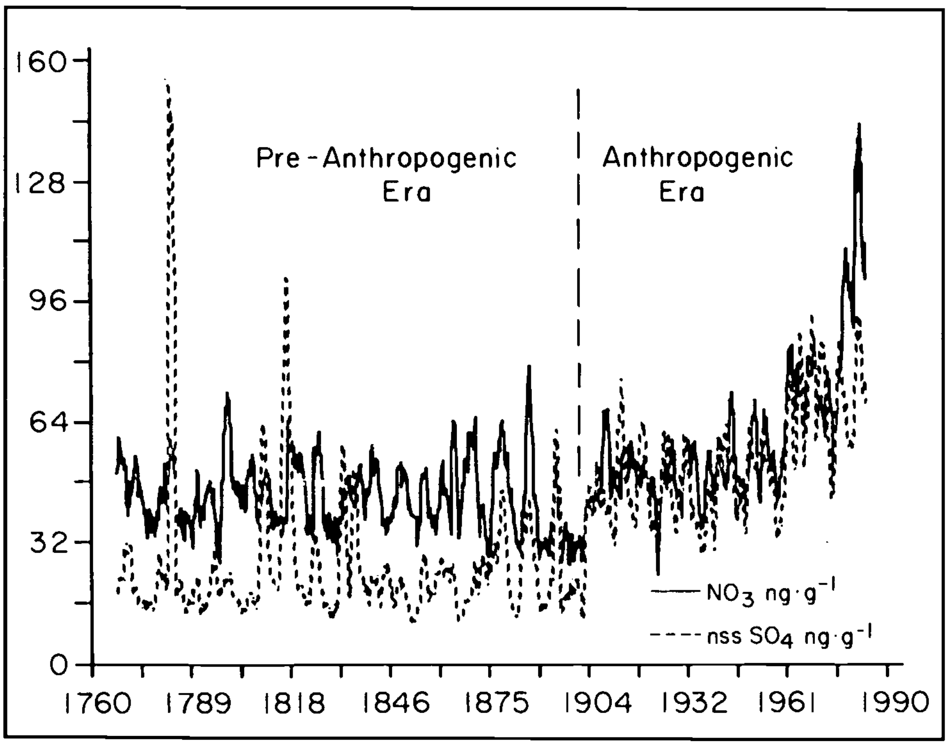
Potential Links between HARC and GISP2

The GISP2 record shows that both agrarian and industrial societies developed during a period which has by far the most stable climate of the past 110,000 years.

The GISP2 (Greenland Ice Sheet Project –Two) obtained an ice core from central Greenland that provides a window on at least 110,000 years of Earth system history. Data series available from GISP2 range from continuous surface-weather data, to a resolution of seasons and millennia, depending on depth in the core. Together with the parallel European Greenland Ice Sheet Project (GRIP), GISP2 provides the most extensive and detailed ice-core record of climate available for the northern hemisphere. This proxy climate data, together with appropriate historical and archaeological information will provide insight into societal impacts of climate change in the past.

By utilizing the results from GISP2, HARC may be able to address several important questions. Climate reconstructions from ice cores provide evidence of a wide variety of environments, revealing histories for example, of biomass burning, sea-ice extent, volcanic activity, and storminess.

- How will arctic inhabitants respond to greater climate variability and long-term warming induced by the global build-up of greenhouse gases? The GISP2 record shows that both agrarian and industrial societies developed during a period which has by far the most stable climate of the past 110,000 years. It is clear, however, that major changes in climate have occurred during the period of human occupation in the Arctic. It is evident as well that climate change is amplified in the arctic region relative to lower latitudes. Ice cores provide crucial data on how the region's climate has varied in the past, including both the frequency and magnitude of extreme events and its elusive, but real, cyclical components.
- The influence of anthropogenic variability is clearly seen in the ice-core record (see figure). What are the spatial implications of different policy initiatives aimed at altering future anthropogenic contributions to the atmosphere (*e.g.*, sulfur dioxide)? What are the consequences of a warmer Arctic serving as a sink for pollutants and contaminants?



This figure shows sulfate (SO_4^{2-}) and nitrate (NO_3^-) in the ice core against time, illustrating the impact of the industrial revolution, Great Depression, and post-WWII boom. Major changes in the natural balance of these two chemical species have occurred due to human activity (modified [illegible] Mayewski et al. *1990).*

The extensive GISP2 surface-snow and atmospheric studies, together with the upper part of the core, provide a detailed record of anthropogenic influences in the arctic region. Analyses of historical atmospheric circulation patterns indicate both the source regions for pollutants that are being deposited in the Arctic, and the extent to which anthropogenic influences are likely to be spread over the arctic region (Mayewski *et al.* 1994).

Potential Links Between HARC and PALE

The PALE (Paleoclimates from Arctic Lakes and Estuaries) initiative began in 1991 with the goal of reconstructing past arctic climate from lacustrine and marine sediment cores. In conjunction with GISP2, PALE seeks to describe the temporal and spatial variability of climate in the Arctic. When coupled with studies of modern processes that attempt to understand the interactions of the cryospheric, atmospheric, terrestrial, and marine systems, paleoclimate studies will improve our ability to predict how the environment will respond to future climate change at high latitudes and how society can prepare for and adapt to these changes. Three time scales have been identified for PALE research:

- 0 to 2,000 before present (BP),
- 0 to 20,000 BP, and
- 0 to 150,000 BP.

In general, the resolution of the sediment records in the three time streams decreases from annual (or even seasonal), to decadal, to century and millennial. Thus, changes in climate from short-term annual variability to long-term gradual change may be interpreted from the proxy records.

Lakes and near-shore marine basins occur widely across the circumpolar region; PALE research consequently has the potential to contribute to many other ARCSS investigations. Although circum-polar in perspective, PALE has focused its short-term research activities on two regions. These are Beringia (Alaska/Siberia) and the northwest North Atlantic (eastern Canadian Arctic, Greenland, and Iceland). International collaborations have been strengthened by the formation of CAPE (CircumArctic Paleo-Environments) which brings PALE researchers together with their counterparts from the European and Asian arctic communities.

Linkages between HARC and PALE center on understanding the impact of climate change on the peoples of the circumpolar North. Several examples of such interaction are listed below.

- The wide distribution of lakes and near-shore marine basins across the Arctic allows access to detailed archives of climate change adjacent to present and past settlements. Comparison of archaeological and paleoclimate data sets from adjacent areas is valuable for both research communities.
- Paleovegetation maps constructed from regional syntheses of pollen records from lakes may facilitate evaluations of past settlement and migration which, in turn, were controlled by subsistence hunting strategies and the availability of game in the terrestrial ecosystem.

The Impact of Variations in Sea-Ice Incidence Off the Coasts of Iceland

Early accounts of the settlement of Iceland in the late 9th century tell the story of how the country was named for the sea ice that was observed by one of the first Norse visitors. From that time on, the major impacts that the sea ice had on the lives of the Icelandic peoples were recorded in a wide variety of historical sources (Ogilvie 1992).

Sea ice is brought to the coasts of Iceland from the Greenland Sea area by the East Greenland current, but its causes and origins are a complex amalgam of general oceanic and atmospheric conditions, as well as local winds and currents. Ice is most common off the coasts of Iceland during the winter, spring, and summer, and usually affects the northwestern, northern, and eastern coasts. The historical sea-ice record demonstrates its variability on an annual-to-century time scale (Ogilvie 1992, 1996).

Sea ice has not been as frequent a visitor to the shores of Iceland during the 20th century as in the past. In some years, particularly in the 18th and 19th centuries, ice often blocked harbors or whole regions, preventing trading vessels from docking or fishing boats from going out to sea.

The marginal nature of the Icelandic farming and fishing economy meant that even a minor perturbation in the food supply could result in major starvation. The consequences included disease and deaths due to malnutrition, and the desertion of farms leading to an increase in crime and begging.

The presence of sea ice had a further impact that was perhaps even more important to food supplies. Up until the latter part of the 19th century, the mainstay of the economy was animal husbandry based primarily on cattle and sheep. Deeply stratified farm middens in Northeastern Iceland indicate farmers began to take substantial numbers of harp seals from the drift ice around AD 1500, just as the mortality of young lambs increased. Adverse spring weather connected to the cooling effects of drift ice may have been the cause of this increased lamb mortality (Amorosi 1992). The effect of the ice in blocking the ocean as a heat sink would have caused the lowering of temperatures on land, adversely affecting the all-important grass crop.

The wide distribution of lakes and near-shore marine basins across the Arctic allows access to detailed archives of climate change adjacent to present and past settlements.

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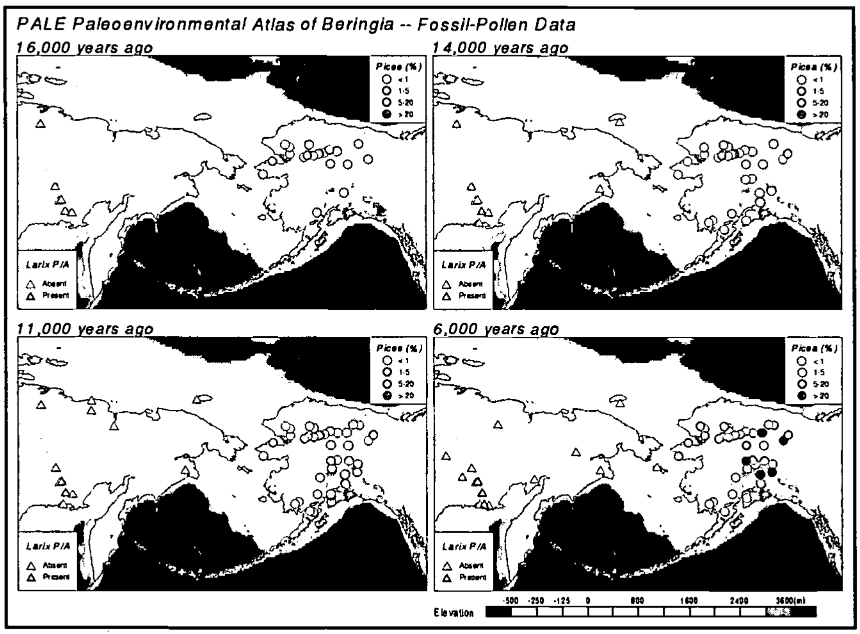
- Sea-ice patterns can be reconstructed from proxies in marine sediments such as diatomaceous or foraminiferal assemblages. These patterns may be used in conjunction with information from the social sciences in an analysis of marine-mammal subsistence hunting and fishing patterns for marine-based communities. The social-science sources would include recent observations, satellite imagery, traditional knowledge, and archaeological information.
- The impacts of human activities on the landscape are often well preserved in the lacustrine sediment record. For example, agriculturally exacerbated erosion in a watershed is commonly illustrated by increases in sedimentation rates in lacustrine basins, and detailed by changes in pollen flora and mineralogical composition of the sediments.
- The configuration of the arctic coastline over the last 150,000 years has reflected changes in sea level influenced mainly by eustatic and glacioisostatic processes. Both past and present marine-based arctic cultures have inhabited coastal settlements and used marine resources. Sea-level fluctuation is documented by archaeological sites on former shorelines that are located above present sea level. In addition, the timing of sea-level changes may be determined from sediment records of coastal lakes which were formerly marine inlets.
- As sea-level rises and land subsides with thermokarst development, communities will face relocation decisions. What considerations will influence their decisions? Documentation about how communities have made decisions in the past would be valuable. Current information and predictions, such as habitat changes within a village's greater area, would help residents select an appropriate new location.



*Vegetation and shoreline changes across Beringia. Fossil-pollen data from the PALE database show the persistence of essentially treeless vegetation across Beringia until the early Holocene (11,000 years ago). By 6,000 years ago, spruce (*Picea*) forests had spread across Alaska, while in eastern Siberia, the cold deciduous woodland characterized by larch (*Larix*) became established. The shaded background on these maps also illustrates the disappearance of the land bridge after 11,000 years ago (figure by Patrick Bartlein).*

Chapter 5. Research Principles and Objectives

Objectives for Research on the Human Dimensions of the Arctic System

The major goal of the HARC initiative is to understand the dynamics of linkages between human populations and the biological and physical environment of the Arctic, at scales ranging from local to global. To accomplish this goal, HARC seeks to develop an integrated understanding of the following:

- The biophysical basis for past, present, and future human impacts on the functioning of the arctic system.
- Past and present patterns of habitat use (including land, water, and ice) and resource use (including subsistence, land tenure, domestication, farming, fishing, and resource extraction).
- Patterns of human response and adaptation to environmental change (including settlement decisions, shifts in resource use, migration, diversification, and economic transitions).
- The basis for sustainability, viability, resilience, and vulnerability in interactions between humans and their environment.
- Development and implementation of an educational framework that offers feedback and learning opportunities for local stakeholders, scientists, and decisionmakers.

To qualify as HARC research, a project must be related to the role of humans in the arctic system and must deal with global change. Within HARC, research projects should be considered higher priority if they:

- Illuminate the role of humans in the arctic system.
- Exhibit maturity by building upon the presence of an existing body of research that increases the productivity of new work, in their use of or contribution to other ARCSS research projects.

While the majority of support will focus on the priorities outlined above, HARC will also consider exploratory research that may lead to important breakthroughs in our understanding of the role of humans in the Arctic. Proposals in this category should:

- examine new topics for research, or create a new synthesis from current HARC and ARCSS topics; and
- seek to establish new conceptual or institutional foundations for future HARC and ARCSS research.

The HARC initiative will also consider exploratory research that may lead to important breakthroughs in our understanding of the role of humans in the Arctic.

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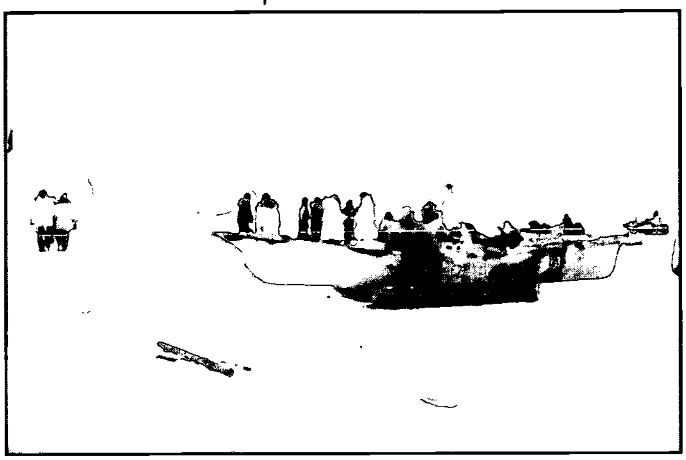
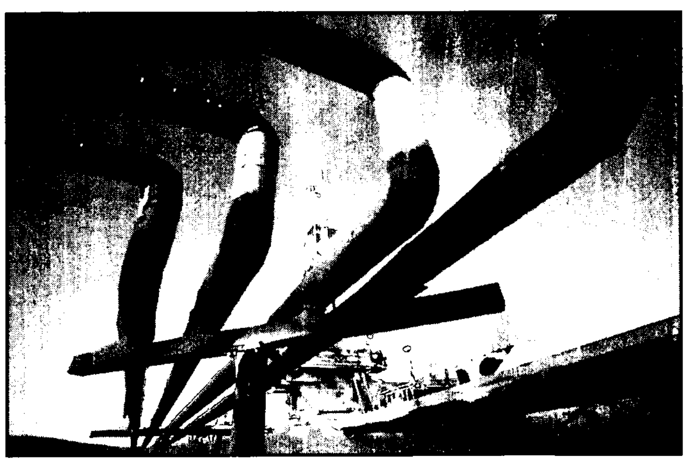


An umiak, placed on a sled, is towed by snowmachine to the spring lead for whaling near Barrow, Alaska (photograph by Lori Quakenbush).



A drilling rig in the Prudhoe Bay oilfield on the North Slope of Alaska in December 1994 (© James H. Barker).

Principles for the Conduct of HARC Research

To accomplish its objectives, HARC research will be conducted according to the established principles of the social and natural sciences. In addition, HARC research should seek, where possible, to:

- integrate methods and principles from the natural and social sciences, and humanities;
- interpret scientific results on temporal and spatial scales that are relevant to policy decisions made at local to global levels;
- incorporate traditional and indigenous knowledge;
- involve indigenous peoples in the design and implementation of the research; and
- interact with and complement the activities of other ARCSS projects.

All researchers working in the North have an ethical responsibility toward the people of the North, their cultures, and the environment.

The Guiding Principles for the Conduct of Research in the Arctic

The *Principles for the Conduct of Research in the Arctic*, included here in total, were prepared by the Social Science Task Force of the U.S. Interagency Arctic Research Policy Committee (IARPC) and approved by IARPC on June 28, 1990. These principles are to be observed when carrying out or sponsoring research in Arctic and northern regions or when applying the results of this research.

Researchers conduct a visual survey of whales passing through a lead north of Barrow, Alaska in Spring 1987. The survey was part of the Bowhead Census, a 10-year project initiated by the Alaska Eskimo Whaling Commission and conducted by the Alaska North Slope Borough Department of Wildlife Management to estimate the bowhead population. Acoustic surveys conducted simultaneously with visual counts confirmed that many more whales pass through the lead than are visible to observers (photograph by Quakenbush).

Principles for the Conduct of Research in the Arctic

Introduction

All researchers working in the North have an ethical responsibility toward the people of the North, their cultures, and the environment. The following principles have been formulated to provide guidance for researchers in the physical, biological, behavioral, health, economic, political, and social sciences and in the humanities. These principles are to be observed when carrying out or sponsoring research in arctic and northern regions or when applying the results of this research. This statement addresses the need to promote mutual respect and communication between scientists and northern residents. Cooperation is needed at all stages of research planning and implementation in projects that directly affect northern people. Cooperation will contribute to a better understanding of the potential benefits of arctic research for northern residents and will contribute to the development of northern science through traditional knowledge and experience. These *Principles for the Conduct of Research in the Arctic* were prepared by the Interagency Social Science Task Force in response to a recommendation by the Polar Research Board of the National Academy of Sciences and at the direction of the Interagency Arctic Research Policy Committee. This statement is not intended to replace other existing Federal, State, or professional guidelines, but rather to emphasize their relevance for the whole scientific community. Examples of similar guidelines used by professional organizations and agencies in the United States and in other countries are listed in the publications (Page 27).

Implementation

All scientific investigations in the Arctic should be assessed in terms of potential human impact and interest. Social science research, particularly studies of human subjects, requires special consideration, as do studies of resources of economic, cultural, and social value to Native people. In all instances, it is the responsibility of the principal investigator on each project to implement the following recommendations:

1. The researcher should inform appropriate community authorities of planned research on lands, waters, or territories used or occupied by them. Research directly involving northern people or communities should not proceed without their clear and informed consent. When informing the community and/or obtaining informed consent, the researcher should identify:
   a. all sponsors and sources of financial support;
   b. the person in charge and all investigators involved in the research, as well as any anticipated need for consultants, guides, or interpreters;
   c. the purposes, goals, and time frame of the research;
   d. data-gathering techniques (tape and video recordings, photographs, physiological measurements, and so on) and the uses to which they will be put; and
   e. foreseeable positive and negative implications and impacts of the research.
2. The duty of researchers to inform communities continues after approval has been obtained. Ongoing projects should be explained in terms understandable to the local community.
3. Researchers should consult with and, where applicable, include northern communities in project planning and implementation. Reasonable opportunities should be provided for the communities to express their interests and to participate in the research.
4. Research results should be explained in nontechnical terms and, where feasible, should be communicated by means of study materials that can be used by local teachers or displays that can be shown in local community centers or museums.
5. Copies of research reports, data descriptions, and other relevant materials should be provided to the local community. Special efforts must be made to communicate results that are responsive to local concerns.
6. Subject to the requirements for anonymity, publications should always refer to the informed consent of participants and give credit to those contributing to the research project.
7. The researcher must respect local cultural traditions, languages, and values. The researcher should, where practicable, incorporate the following elements in the research design:
   a. Use of local and traditional knowledge and experience.
   b. Use of the languages of the local people.
   c. Translation of research results, particularly those of local concern, into the languages of the people affected by the research.

Researchers should consult with and, where applicable, include northern communities in project planning and implementation.

Ralph Segock Sr., Sankey Charles, and Lynn Takak Sr. participate in the development of a map documenting certain aspects of traditional ecological knowledge about beluga whales in Koyuk, Alaska in April 1995 (photograph by Henry Huntington).

When possible, research projects should anticipate and provide meaningful experience and training for young people.

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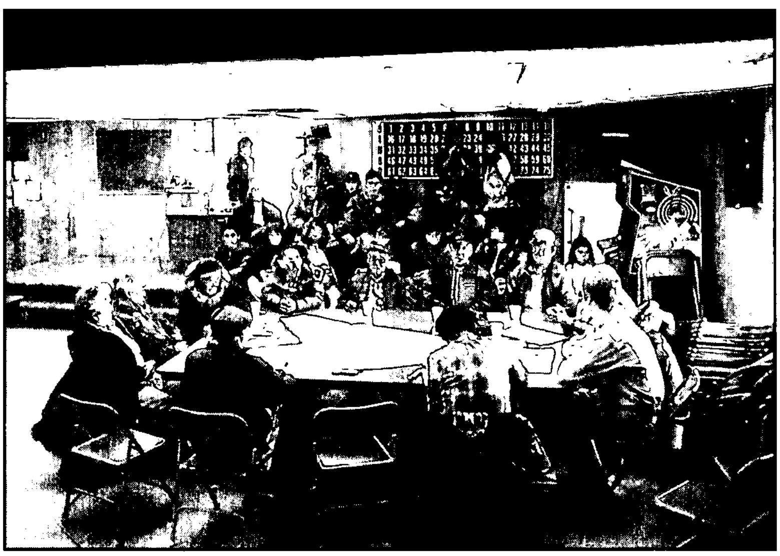
8. When possible, research projects should anticipate and provide meaningful experience and training for young people.
9. In cases where individuals or groups provide information of a confidential nature, their anonymity must be guaranteed in both the original use of data and in its deposition for future use.
10. Research on humans should only be undertaken in a manner that respects their privacy and dignity:
    a. Research subjects must remain anonymous unless they have agreed to be identified. If anonymity cannot be guaranteed, the subjects must be informed of the possible consequences of becoming involved in the research.
    b. In cases where individuals or groups provide information of a confidential or personal nature, this confidentiality must be guaranteed in both the original use of data and in its deposition for future use.
    c. The rights of children must be respected. All research involving children must be fully justified in terms of goals and objectives and never undertaken without the consent of the children and their parents or legal guardians.
    d. Participation of subjects, including the use of photography in research, should always be based on informed consent.
    e. The use and disposition of human tissue samples should always be based on the informed consent of the subjects or next of kin.
11. The researcher is accountable for all project decisions that affect the community, including decisions made by subordinates.
12. All relevant Federal, State, and local regulations and policies pertaining to cultural, environmental, and health protection must be strictly observed.
13. Sacred sites, cultural materials, and cultural property cannot be disturbed or removed without community and/or individual consent and in accordance with Federal and State laws and regulations.

In implementing these principles, researchers may find additional guidance in the publications listed below. In addition, a number of Alaska Native and municipal organizations can be contacted for general information, obtaining informed consent, and matters relating to research proposals and coordination with Native and local interests. A separate list is available from NSF's Office of Polar Programs.



Elders from Koyuk, Elim, and Shaktoolik, Alaska participate in documenting traditional ecological knowledge about beluga whales in the Koyuk Community Hall in April 1995. High school students seated in the background are observing the process and recording the discussions on videotape as part of a leadership training program (photograph by Ricky Nassuk, Sr.).

Publications

Arctic Social Science: An Agenda for Action. National Academy of Sciences, Washington, DC. 1989.

Draft Principles for an Arctic Policy. Inuit Circumpolar Conference, Kotzebue, AK. 1986.

Ethics. Social Sciences and Humanities Research Council of Canada, Ottawa. 1977.

Nordic Statement of Principles and Priorities in Arctic Research. Center for Arctic Cultural Research, Umeå, Sweden. 1989.

Policy on Research Ethics. Alaska Department of Fish and Game, Juneau, AK. 1984.

Principles of Professional Responsibility. Council of the American Anthropological Association, Washington, DC. 1971, rev. 1989.

The Ethical Principles for the Conduct of Research in the North. The Association of Canadian Universities for Northern Studies, Ottawa. 1982.

The National Arctic Health Science Policy. American Public Health Association, Washington, DC. 1984.

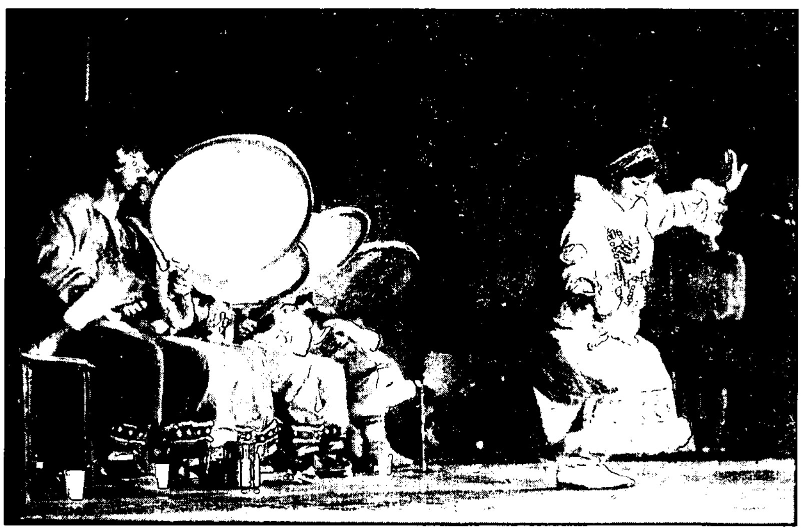
Protocol for Centers for Disease Control/Indian Health Service Serum Bank. Prepared by Arctic Investigations Program (CDC) and Alaska Area Native Health Service. 1990. (Available through Alaska Area Native Health Service, 255 Gambell Street, Anchorage, AK 99501.)

Indian Health Manual. Indian Health Service, U.S. Public Health Service, Rockville, MD. 1987.

Human Experimentation. Code of Ethics of the World Medical Association (Declaration of Helsinki). Published in *British Medical Journal* 2(177). 1964.

Protection of Human Subjects. Code of Federal Regulations 45 CFR 46. 1974, rev. 1983.

Cooperation will contribute to a better understanding of the potential benefits of arctic research for northern residents and will contribute to the development of northern science through traditional knowledge and experience.



Kavra Niklayevna and the Rising Sun Dancers, from New Chaplino in the Russian Far East, perform at the 1992 Inuit Circumpolar Conference (ICC) meeting in Sissimiut, Greenland. The 1992 meeting was the first at which the Russians were allowed to participate; they were not allowed by their government to participate as delegates. Russia is now a full-fledged member of the ICC (© Bill Hess, Running Dog Publications).

Chapter 6. Questions for Research

Five primary questions about the human dimensions of the arctic system are discussed in the following section. Scientists as well as other groups may hold divergent views concerning the priorities that should be assigned to various questions. Global change research programs generally see understanding the feedbacks in the system as the paramount concern. Arctic residents may be most concerned about the effects of global change on the resources they use. Policymakers may emphasize the effects of changes in the arctic system on the rest of the globe. Others emphasize the importance of exploratory research that may lead to important breakthroughs in our understanding of the role of humans in the Arctic. As discussions progress, these perspectives will become more clear, and revised priorities will emerge. The HARC prospectus now describes current, relevant, and high-quality research that will answer many important questions.

Each primary question is followed by a discussion of why the question should be asked and specific recommendations for needed research. The recommendations are based upon the two qualitative characteristics of relevance and maturity. Maturity, the presence of an existing body of research that increases the productivity of new work, is central to high-quality research. The research areas listed in Table 1 on pages 4-5 are ranked according to the following scale:

- Highly appropriate for immediate research funding.
- Important research area requiring further planning and integration.
- Important research area needing additional conceptual development and integration.

Although some of the most dramatic anthropogenic impacts on the arctic system originate outside the Arctic, substantial human-caused impacts also originate within the Arctic.

A. What are the Impacts of Human Activity on Arctic and Global Systems?

An understanding of the functioning of the arctic system must be based on an understanding of the feedbacks among the components of this system. The system must be understood before the consequences of changes in it can be assessed. The theoretical basis for predicting impacts of human activities on the arctic system is poor. Research must document the cultural, economic, and ecological basis of past and present anthropogenic environmental changes as aids in predicting future impacts.

Although some of the most dramatic anthropogenic impacts on the arctic system originate outside the Arctic (*i.e.*, global warming and depletion of fisheries stocks), substantial human-caused impacts also originate within the Arctic. Much arctic haze comes from industrial plants throughout the arctic region. Large dams are changing the patterns and amount of river runoff—and possibly the entire freshwater balance in the Arctic. Military activities and industrial activities have introduced radionucleides into the arctic environment that may become concentrated in the food chain. Deforestation in the northern boreal forest may alter the climate of neighboring arctic regions. Population growth, economic development, and cultural change may place increasing pressure on arctic ecosystems. In short, the Arctic may be a source for anthropogenic changes in both the arctic and global systems. We need to know both the factors controlling these arctic impacts and their consequences for the functioning of the arctic system as a whole.

Salmon fishing on the Yukon River near Alakanuk, Alaska (© James H. Barker).

Unresolved Scientific Issues

Heavy metals, soot, organochlorines, and other pollutants tend to accumulate at high latitudes because of atmospheric and oceanic circulation patterns and subsequent concentration in food chains and organic soils.

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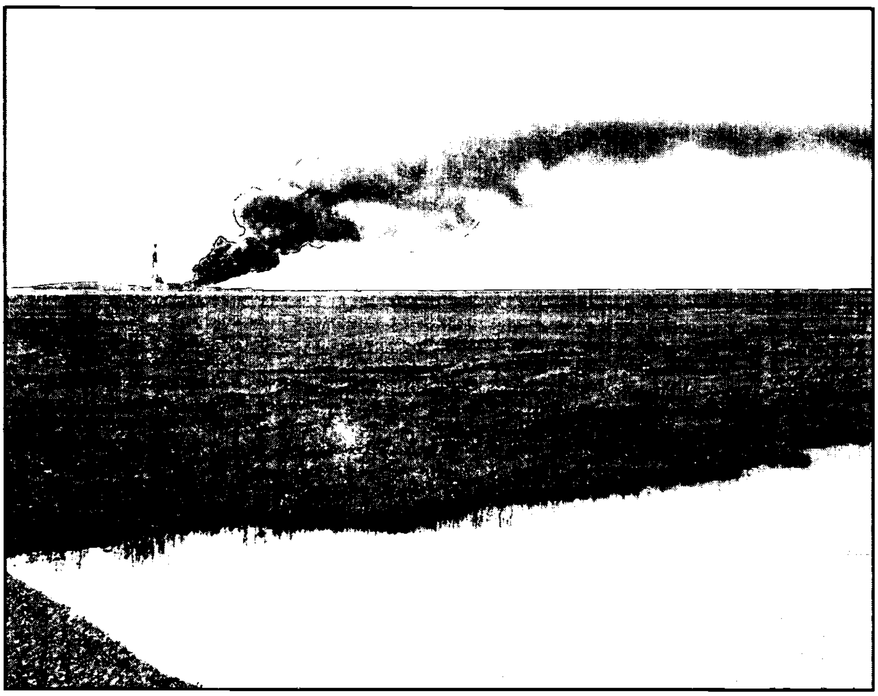
1. *What are the cumulative impacts of large-scale development on arctic ecosystems?* The Arctic is a vast source of renewable and non-renewable resources such as timber, oil and gas, and minerals. The direct impacts of large-scale resource extraction (*e.g.*, building of roads, melting of permafrost) are often pronounced and dramatic; they are usually restricted to the area being developed, however, so that their overall impact on the regional system may be relatively small. The indirect impacts of these developments, on the other hand, are often extensive and poorly documented. Although many of the specific ecological consequences of industrial activity have been documented, these impacts have not been evaluated at the regional scale, nor have the secondary effects been considered in a systems context. Oil development, for example, can indirectly alter drainage and therefore vegetation composition, permafrost integrity, and biogeochemical cycling over areas that are orders of magnitude larger than the areas that are directly affected. Oil development literally fuels fossil-fuel combustion elsewhere in the world, thereby exacerbating global warming, and many long-lived petroleum-based products are migrating to the Arctic and accumulating in the food chain.

Relevance: Resource extraction often has strong impact on vegetation, streams, and biogeochemical cycling. If these impacts are extensive, they can alter trace-gas fluxes, surface-energy budgets, and the transfer of carbon and nutrients from the land to the ocean.



Testing flow rate of an exploratory well during development of the Prudhoe Bay oil field in Alaska (photograph by David R. Klein).

Maturity: The distribution and localized impacts of existing development are well known, as are the general climatic implications. This research topic is poised to explore the more widespread, low-level impacts of these developments and their climatic consequences. The importance and risks of cumulative and indirect impacts were demonstrated by Walker and others (1987), but little further progress with the development of theory or extension of this critical issue to regional impacts has been made. This research would integrate both LAII research on climatic feedbacks and human mechanisms of regional changes in ecosystem processes.

2. *How has the spread of contaminants changed the functioning of arctic ecosystems?* Anthropogenic contaminants are known to be accumulating in arctic ecosystems. Radioactive isotopes from atomic testing have been detected in Scandinavian lichen and reindeer; organochlorines from pesticides used far to the South reach unsafe levels in some arctic marine mammals. Heavy metals, soot, organochlorines, and other pollutants tend to accumulate at high latitudes because of atmospheric and oceanic circulation patterns and subsequent concentration in food chains and organic soils. Much

of this contamination is a legacy of the Cold War and of industrial development in the South, but major additions continue from within and outside the Arctic. Many of these contaminants are physically hazardous to humans, and have potential sociocultural and economic impacts as well. Little is known about how such contaminants are processed, sequestered, or concentrated in arctic ecosystems.

Relevance: Contaminants such as radionucleides and organochlorines can substantially alter trophic dynamics and the extent to which plants and animals are harvested by humans. Human harvest, in turn, affects the productivity and trophic dynamics of natural systems in ways that can alter land-atmosphere exchanges and nutrient circulation in marine and terrestrial systems.

Maturity: Contamination in arctic ecosystems is scantily documented; such data would influence policies regarding human consumption. The system consequences remain to be explored; the individual and synergistic effects of observed contaminants are unknown. This research builds on past research in OAII and LAII; study of contaminants documented in these research programs would increase the policy relevance of OAII and LAII to humans.

3. How has human use altered arctic food chains and resulting ecosystem processes in terrestrial, freshwater, and marine ecosystems? Harvesting both within and outside the Arctic has dramatically altered many marine fisheries stocks, for example reducing pollock populations to low levels. Similarly, commercial hunting of whales outside the Arctic has had substantial impacts on arctic populations of whales; and hunting of waterfowl, caribou, and marine mammals has at times substantially reduced their population sizes. Anadromous fish, such as salmon, play a crucial role in the culture and economy of both indigenous and industrial societies in arctic and subarctic regions, but they have been drastically decreased by fishing and hydroelectric developments in many parts of the world.

Over-harvesting of animals by people can have ecosystem-wide effects. For example, salmon import nutrients to streams and are critical to the biogeochemical cycles of freshwater and terrestrial ecosystems. Similarly, pollock abundance and associated predation by seabirds influence the transfer of nutrients from marine to terrestrial ecosystems. Vegetation, released from grazing by substantial reductions in geese populations more than a decade ago, has not yet returned to its original state. Changes in reindeer abundance influence lichen cover, altering biogeochemical cycles and surface-energy budgets of large regions. C' anges in populations of animals on which indigenous people depend have

Large-Scale Development

Large-scale development in the Arctic is relevant to at least four questions. What are the effects of large-scale development on the arctic and global systems? In what ways do industrial activities, themselves consequences of the global economy, act as a catalyst of global change? If large-scale environmental changes take place in the Arctic, how will they affect large-scale resource extraction activities? To what extent do governments and arctic residents see industrial developments as significant alternatives to climate-affected resources?

In addition to their effects on the local landscape, large-scale developments—through their influx of people, infrastructure, and money—transform local community life. Some consequences for arctic residents appear positive, such as needed improvements in roads and waste management, new job opportunities, increased community revenues and services. Others, such as pollution, interference with animal migration and subsistence hunting, cultural erosion, and dependency upon a single externally controlled revenue source, appear more negative. Research that assesses the actual outcomes, in retrospect or in the future, is urgently needed.

Because northern areas tend to be less developed than mid-latitudes, scientists can examine resource use and development in an integrated, systematic manner with fewer confounding variables. The circumpolar North thus offers possibilities for more controlled, comparative, and longitudinal studies to provide cumulative knowledge about the positive and negative environmental, social, cultural, and economic changes that arise from large-scale resource extraction.

To address the broad questions raised by industrial development, we need detailed research to answer the following questions: What are the ecological, economic, and sociocultural impacts? What factors mitigate adverse impacts and enhance benefits? How can institutions and local communities effectively participate in the planning and review process? How predictive were the required impact studies? How do the answers to the previous questions vary with biophysical and sociocultural context, government and developer policies, type of development, and other variables?

been critical to human survival in the past and remain important to the cultural and economic structure of villages.

Despite the clear impact of human harvest on the abundance of animals and subsequent effects on ecosystem processes, there is little understanding of the interconnections and feedbacks among these processes. If marine fishing reduces stocks of pollock, thereby altering marine food chains on which marine mammals depend, how does this influence the cultural and economic life of villages that depend on these resources for subsistence or commercial use, and the regional impact of these villages on other processes? How important are the transfers of nutrients from ocean to land in the productivity of riparian ecosystems that are critical habitats for wildlife?

Paul Hugo of Anaktuvuk Pass shot this caribou on a -36° F day in November of 1989. As always, the first thing Hugo did after killing the caribou was remove its head. Traditional Iñupiat teachings tell that in this way the spirit of the caribou is set free. It will return to the herd, put on another caribou parka, and come back again (© Bill Hess, Running Dog Publications).

Human use does not always have a significant effect on animal population dynamics. Current harvests of most large caribou herds, for example, are too small to significantly affect herd size. Exceptions are evident in the Taimyr population and commercial harvest of Canadian herds. Understanding the role of human use under varying ecological conditions is critical to the design of effective management systems.

Relevance: Human harvest can affect the productivity and trophic dynamics of natural systems in ways that can alter land-atmosphere exchanges and nutrient circulation in marine and terrestrial systems.

Maturity: This research builds on extensive research in the social and natural sciences on factors governing harvest of animals and on the impacts of animals on trophic systems. This research would build on past research in the NSF-funded Long-Term Ecological Research (LTER) program and in the social sciences.

Using block and tackle, whalers land a whale on the ice in 1990, approximately five miles ore and 12 miles south of Barrow, Alaska (© Bill Hess, Running Dog Publications).

4. How have anthropogenic changes in the surface-energy balance of arctic and subarctic regions and changes in river runoff affected the water balance and regional climate of the Arctic? Vegetation has a strong influence on regional climate through its effects on surface-energy budgets. Forests cause greater warming of regional climate than does tundra, at least in part because their relatively dark colors absorb heat and because their thick canopies insulate the Earth from radiant heat loss. Changes in vegetation cover resulting from human activities could feed back to climate. Northward expansion of the treeline due to global warming should act as a positive feedback to regional warming in the Arctic. Conversely, logging and related land-use changes in subarctic forests could lead to regional cooling. These vegetation-induced changes in climate in turn induce further changes in ecosystem processes and in the use of these ecosystems by humans. Although it is well established that the climate feedbacks from these human-induced changes in vegetation should be large, we know less about what factors influence human decisions leading to land-use change than we know about the feedbacks within the vegetation-climate system.

A second major impact of human activities at high latitudes has to do with hydroelectric developments that alter river runoff. These changes can significantly affect regional hydrologic cycles. Again, the factors that influence decisions about hydroelectric developments, and their consequences for northern hydrologic systems, are poorly understood.

Relevance: Human impacts on surface-energy budgets and on hydrologic budgets are likely to be as large or larger than those caused by changing climate and will likely have strong feedbacks to regional climate and to ocean-circulation patterns.

Maturity: This research would build directly on current research on surface-energy budgets and arctic hydrology and on social science studies of factors governing human impacts. The project would be a logical follow-up to current research in LAII, LTER, and community sustainability.

Large areas of the Arctic are underlain by ice-rich permafrost that is within a few degrees of the melting point. Small disruptions are capable of producing landscape-scale alterations of wildlife habitat and unstable substrates for roads, pipelines, and buildings.

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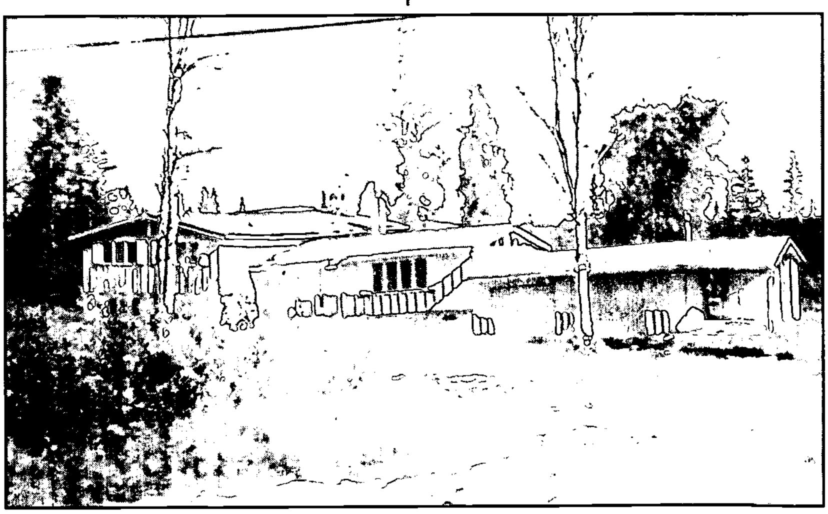
5. How will the effects of human disturbances on the landscape, and climate change, interact in areas of ice-rich permafrost? Large areas of the Arctic are underlain by ice-rich permafrost that is within a few degrees of the melting point. Small disruptions of the insulating organic layer of the tundra are capable of producing landscape-scale alterations of wildlife habitat and unstable substrates for roads, pipelines, and buildings. More information is needed about the distribution of ice-rich permafrost and its relationship to existing and planned human activity.

Relevance: Degradation of permafrost is one of the most important consequences of global warming to large-scale development and its resulting impacts on the arctic system.

Maturity: Excellent point models exist describing the physical linkage of climate to permafrost, and the engineering consequences of permafrost degradation are well known. These disciplines have not been closely aligned, however. Communities are facing increasing maintenance costs associated with ground movement; they are beginning to look for engineering solutions. This builds on LAII research, thermal modeling, and engineering research.



This house was built on ice-rich permafrost. Heat from the house caused the permafrost to thaw and the ground surface to settle unevenly resulting in bending and twisting of the structure which was ultimately abandoned (photograph by Tom Osterkamp).

6. How do economic, cultural, social, and environmental factors govern the types, scale, and geographic variability of human impact within the Arctic? Perhaps the greatest uncertainty in predicting future changes in the arctic system results from an inability to predict human behavior and environmentally important decisions over long time scales. In the past, the range of human options was narrower, although traditional communities were more readily mobile. Today, arctic populations include mixed subsistence and cash-economy communities, as well as others based on high-technology natural resource extraction. The range of behavioral, educational, institutional, and technological options appears wider now and less predictable. There is great need for studies and models designed to predict future human impacts on northern systems.

Pilot Station, Alaska (© James H. Barker).

Relevance: The limited ability to predict human impacts on the arctic system is perhaps the greatest source of uncertainty in predicting the future state of the arctic system.

Maturity: A closer integration of natural and social sciences is needed to design appropriate research. Workshops and planning meetings involving natural and social scientists would facilitate development of this research area.

Young men from Alakanuk, Alaska traveling on the Yukon (© James H. Barker).

B. What are the Types and Sources of Global Change in the Arctic?

Many types of global change can affect people living in the Arctic. Human population growth and expansion, air pollution, contaminants in the food chain, over-exploitation of migratory species, expansion of world markets, and the emergence of diseases new to a region—all of these, along with climate change, affect human communities. Research challenges arise because so many factors are changing at once. Effects of several environmental changes may be confounded, as when ocean currents cool concurrently with overfishing. The effects may overlap, as when an animal species becomes less abundant and people are advised to reduce their consumption due to contamination. Responses may change through learning, or vary with the cultural and political meanings people attach to any given perceived environmental change. People may also respond similarly to a variety of different environmental changes.

The impact of global change, and climate change in particular, must be studied as part of interrelated external factors (Chichilnisky and Heal 1993). Human responses will provide clues to the nature and magnitude of many important feedbacks; humans are at the top of the food chain and have the greatest distribution of any arctic animal (Peterson and Johnson 1994).

Clyde Smith and Curtis Augline take a break from hunting on the frozen Yukon River near Alakanuk, Alaska. Sled dogs have been largely replaced by snow machines for transport in the winter in arctic Canada and Alaska (© James H. Barker).

Unresolved Scientific Issues

1. *How will the worldwide economy act as a global change agent in the Arctic?* While the cost of extracting arctic resources is likely to remain high, several factors including large concentrations of resources, political stability, government support, and the depletion of alternative resources elsewhere may nonetheless attract industrial attention to the region. Given the high cost of any arctic operation, government and industry decision-makers must weigh arctic investments against competing opportunities outside the Arctic. Smaller-scale economic development offering local employment opportunities also faces the constraints of competition in a global economy. Better understandings of how globalization affects investment decisions and the likelihood of business-venture success are needed for the development of sound policy (Nordhaus 1993, IPCC WGIII 1996).

The worldwide economy is increasingly characterized by a highly mobile labor force and by an even more highly mobile leisure population. Regional centers in the Arctic already have substantial numbers of residents who come from Asia and the South Pacific. To what extent will people fleeing from economic and political distress settle in the Arctic? At the same time, significant numbers of indigenous people, particularly women, are choosing to leave their arctic homes in favor of cities. The Arctic has also become an important destination for tourists seeking unique environments. As the climate warms, more people may choose to move northward. We do not know enough about the processes that influence migration and travel patterns to project them, nor have we examined the potential effects that these global changes may have on arctic communities and cultures.

New forms of communication and transportation are additional sources of global change in the Arctic. Television and snowmobiles have had major effects on culture and resource use in the region. Patterns and rates of diffusion of such technologies affect the economic opportunities of—and the repercussions for—communities and individuals. Although technological change is difficult to anticipate, we need to ask about its potential consequences.

Relevance: The world economy is one of the strongest external factors determining human impact on the arctic system.

Maturity: The factors governing both the world economy and ecological and climatic responses to human activities are reasonably well understood; a research program linking these fields could make rapid progress. There is also a well developed theory to predict regional consequences of changes in world economy; there has, however, been virtually no consideration of the consequences for the cultural and ecological processes that link human actions to the functioning of the arctic system. This study builds on economic studies by the social science community and on studies of the arctic system by OAII and LAII.

Whales and the European Fur Market

The fur-market closure in Europe is impacting populations of beluga whales and moose in Alaska. A reduction of beaver trapping is resulting in an increase in beaver populations. Associated changes in water levels are modifying habitat for fish and vegetation. This in turn is changing food availability for higher trophic-level consumers, including moose and whales.

Checking beaver snares under the ice with the snowmachine headlight (© James H. Barker).

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2. To what extent will decreases in external government support for communities act as a global change agent? The cash economies of many remote communities in the Arctic are based primarily on government transfers. Community health clinics, schools, airstrips, and resident housing often are built and maintained with non-local funds. The funds available to governments for such programs have declined and are likely to continue to do so. At the same time, indigenous people have expressed concerns that dependency upon externally provided cash and services is the root cause of many of the social problems they experience in their communities. Research should examine the quest for sustainable and self-supporting communities throughout the Arctic and the interrelationship with the process of global change.

Seal hunters on the sea ice in winter in Disko Bay, Greenland. Modern technologies blend with ancient traditions in northern indigenous communities (photograph by Richard A. Caulfield).

Relevance: Government investments buffer villages and industries from the impacts of the global economy and are, therefore, extremely important in determining the impact of humans on the arctic system.

Maturity: The maturity of this research is addressed in the following discussion.

Although climate change is often discussed in terms of gradual trends in temperature and precipitation, both indigenous knowledge and ice-core records paint a picture of more dramatically variable weather conditions.

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3. What is the relative contribution of changes in mean temperature and precipitation (as opposed to their variance or the frequency of extreme weather) on resource population dynamics and other aspects of arctic life? Although climate change is often discussed in terms of gradual trends in temperature and precipitation, both indigenous knowledge and ice-core records paint a picture of more dramatically variable weather conditions. Some biologists attribute low body fat in caribou to warm summers; others point to warm, wet winters, when ice crusts often form in the snow, making forage inaccessible to animals. Ice-core data reveal periods of large variation in circulation, temperature, and precipitation—sometimes over surprisingly short time scales of decades or less. Much more information is needed about what affects the probabilities of extreme weather events and how weather sequences, in turn, affect resource populations.

Relevance: Many ecological processes and human responses are more strongly influenced by extreme events than by average conditions. It is critical to identify these circumstances so that they can be incorporated into models designed to describe the future role of humans in the arctic system.

Maturity: Global and regional atmospheric circulation models typically collect (but do not report) data on extreme conditions; there have been no systematic studies of human responses to extreme events. With coordination between atmospheric and social scientists, a productive research program should be quite feasible. This research would build on climatological and ecological research in OAII and LAII, and human adaptability in the social sciences.

4. What is the carrying capacity of humans in the Arctic? How will the growth of human populations in the Arctic influence arctic ecosystems? These questions address issues fundamental to assessing the relative impact of global changes versus changes internal to the Arctic.

Relevance: Baseline estimates and future projections of carrying capacity are needed to determine the large-scale effects of global changes in the Arctic, including human population growth. Research in this area will serve as a link between gross measures of environmental productivity (*i.e.*, net primary productivity), large-scale human activities, and the feedbacks into the regional and global systems as one reacts to the other.

Maturity: Research continues to fuel debate regarding a definition of "carrying capacity." In the meantime, an understanding has developed that carrying capacity is not a single, stable number. Rather, it is a complex measure dependent upon varying circumstances and situations, some of which are related to climate change. More needs to be known about these before carrying capacity can be fully integrated into human-dimensions studies.

5. What is the relative importance of the various global changes to changes in the arctic environment? This question is fundamental to the development of policy. Relative importance may also vary greatly over time. Although the cumulative effects of development may be noticeable on a 10-20-year time frame, the effects of climate change may not be evident for 50 years or more. It is also important to consider the ultimate magnitude of change attributable to different global changes, since the development and implementation of policies may take many years and involve even longer periods to affect trends in global change.

Relevance: Differentiating between the relative magnitudes of environmental drivers in the Arctic will help to develop policies regarding resources exhibiting the most significant changes. This research could guide the future allocation of research funds.

Maturity: The relative importance of different sources of change are poorly understood in the Arctic.

Efforts to document and understand the earth system should focus special attention on sensitive areas of the world where anticipated changes will be greatest and where changing processes have global consequences.

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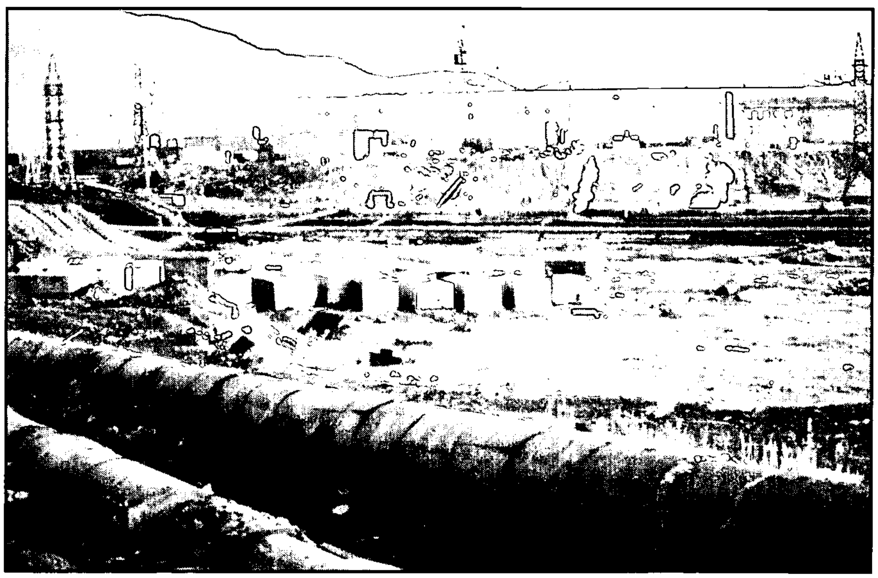

Ore-processing and other industrial facilities at Norilsk, Russia in August 1995. The metallurgical complex of Norilsk at 69°N in northern Siberia is the largest point source of atmospheric pollution in the Arctic (photograph by Henry Huntington).

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C. What are the Effects of Global Changes on Human Societies in the Arctic?

The Arctic Ozone Hole

Each spring for the past three years a depression in the ozone has formed and UV-B radiation has increased. Such events can impact micro-organisms. More recently, it has been shown that such events also can impact fish and amphibian eggs and larva in relatively shallow water.

In 1995, the ozone depression was over central Russia, in 1996 over western Greenland. Each occurred in the spring. If a similar event were to occur over Alaska in the spring, it could have significant impact on the herring spawn. If the herring are affected, there would be considerable disruption to the ecosystem and the local communities both commercially and in terms of subsistence. Understanding where, when, and how deep future ozone depletion may be, along with the associated increase in UV-B, will be vital.

UV-B has also been associated with depression of the immune system. There is documentation of immune-system problems associated with the presence of organochlorines, another major contaminant problem in the Arctic. The synergistic impacts are unknown.

This question links changes in the biophysical environment to impacts on, and responses from, the residents in the region. For example, what are the consequences of a decline in fish populations, and how do people respond to such declines? Among those responses may be activities that feed back into the arctic or global systems to catalyze greater change. When preferred fish species decline, for instance, fishers may switch to catching lower-value species (often representing lower trophic levels) at higher volumes—thereby increasing the fishery's net ecological impact. Similarly, terrestrial hunters may target other species or other economic activities, triggering further ecological changes, if the new primary game resource becomes less abundant.

Many northern communities contend with issues of economic diversification and sustainable development. Both are needed to support standards of living or to ensure more viable communities less dependent upon transfer payments from the South. How do large-scale environmental changes affect the prospects for economic activities? Climate shifts will have complex effects, some positive and some negative. Warmer weather might open new chances for cultivation and herding; more varied weather would make everything—from hunting to travel to entrepreneurship—riskier.

Ella Tulik taking down dried herring at Umkumiut, Alaska fishcamp (© James H. Barker).

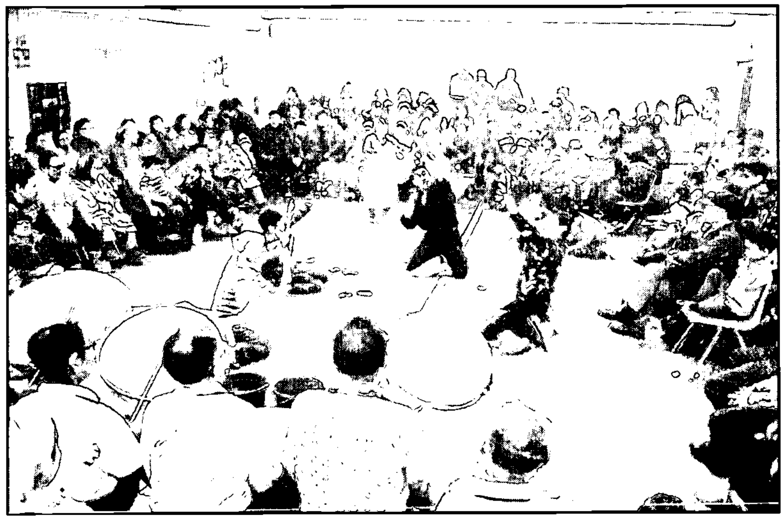
Traditional subsistence hunting and fishing, a major food source as well as a key aspect of cultural identity, may be affected by global changes. Prey species' abundance may shift with climate, runoff, and ocean temperature,current, and salinity changes. Marine mammals may move northward. Salmon, marine mammal, and other species' availability may change due to harvesting pressure or microbiological events outside of the Arctic, such as the recent seal die-offs in the North and Baltic seas. Contaminants such as mercury, once spread to arctic areas, tend to concentrate up the food chain. Subsistence hunters and fishers, at the top of this food chain, face increased health risks from contaminants originating thousands of miles away. Subsistence hunters of game such as walrus and bears face new competition; these animals have a high "black-market" value in the informal global economy.

Other health-related issues in the Arctic associated with global changes include high-latitude ozone depletion and its related physiological effects, the introduction of diseases new to the Arctic, the emergence of antibiotic-resistant strains, and increased mobility of disease vectors, including humans. Increased density of urban areas and deteriorated or minimal public sanitation, typical of arctic communities, exacerbate the spread of disease.

HARC research must also consider important indirect effects of global change. If environmental changes disrupt peoples' subsistence or cash-economy livelihoods, arctic communities may see increases in poverty and in social problems such as substance abuse, suicide, and domestic violence. The extent to which we can predict future responses to climate or global changes must also be considered. Research related to these questions will, at least, help us to compile an inventory of the possible responses from known past instances where societies have experienced large-scale change.

Unresolved Scientific Issues

1. How will global changes affect the size, distribution, and condition of fish and wildlife resource populations and their use by arctic residents? How do cultural affinities and variants of arctic peoples differentially affect the capability of arctic communities to deal with global change? To what extent will indigenous populations continue to be able to derive a substantial part of their life support from the harvest of local fish and wildlife? What ability will management institutions have to respond to changes in wildlife populations brought about by climate changes?



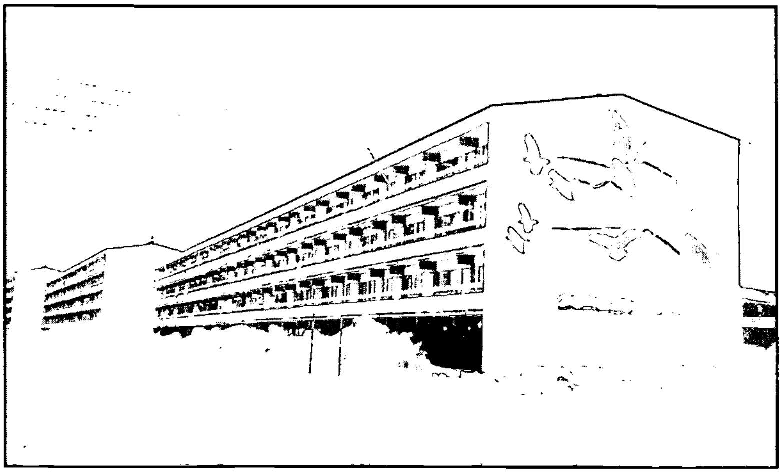
The Yup'ik Eskimo village of Pilot Station, Alaska hosts nearby St. Mary's village for a potlatch. These yearly shared events include much story-telling dance and are a celebration of traditions between the communities. They also pass on knowledge and values to the next generations (© James H. Barker).

Relevance: The subsistence economy of arctic residents is one of their strongest ties to their environment. Changes in wildlife populations can have large effects on the social and economic processes that govern human impact on the arctic system.

Maturity: There is substantial research on the impact of climate change on arctic ecosystems, on the response of wildlife to ecosystem productivity, and on human use of wildlife (*e.g.*, the Sustainability of Arctic Communities project, page 16). This research would build on well established research programs in the social sciences, wildlife biology, and ecosystem studies. These areas of research, however, have not yet been linked.

Each year, around July 4th, the community of Point Lay, Alaska joins together in a beluga hunt during which, over the course of a day, they take their year's supply. In 1990, after the hunters had been out for nearly 24 hours, they were joined by the women and children who boated over to the spit from the village to do their part (© Bill Hess, Running Dog Publications).

2. How will community resilience and vulnerability respond to global changes in the environment, the economy, and society? Measurement and prediction of community vitality and viability must address a number of dimensions including physical, environmental, cultural (including linguistic and spiritual), social, political, economic, and technological.



Apartment complexes in Nuuk, Greenland in March 1997. Nuuk is the capital of Greenland and has a population of about 13,000 (photograph by Gail Fondahl).

Relevance: The resilience and vulnerability of cultural and social values in response to environmental and social change is central to determining the role of humans as a critical component of the arctic system; this is the set of processes that translates human response into human impacts on the arctic system.

Maturity: This research will build upon several years of basic social science research, including that of the NSF Arctic Social Science program. It will be necessary to develop a measure for resilience applicable to human communities.

3. How will global changes affect the possibilities for economic diversification and sustainable development? Will the changed possibilities, in turn, affect the arctic system? What constitutes a sustainable state in a highly variable environment? How does one measure it? Is it possible to have sustainable flexibility? To what extent has any arctic community been successful in making the transition from a sustainable subsistence economy to a sustainable cash or mixed economy?

Relevance: Economic diversification and concerns over sustainable development strongly determine the environmental impact of a given economic investment. Therefore, this issue is critical to an understanding of the feedback between external economic inputs and their consequences for the arctic system.

Maturity: Because factors influencing economic diversification and sustainable development are changing rapidly in the Arctic, this is an opportune time to study this question. This research would build strongly on previous economic studies. Links to ecological and climatic research on the arctic system also must be explored.

4. How will global changes affect indigenous control of local and regional institutions and the ability of arctic peoples to influence the pattern of human activities in the Arctic? To what extent do the various institutional arrangements, particularly the economic and political relationships between different levels of government, act as a global change agent? What are the inducements and constraints on cooperation?

Relevance: The extent of indigenous control over local and regional institutions strongly affects the magnitude and nature of human impacts on the arctic system in response to

Community Viability and Vulnerability

An understanding of arctic communities is essential to understanding the arctic system. Examination of historical records indicates that hardships have been experienced regularly by most arctic settlements. These hardships occur due to movements and availability of animals upon which people depend, unusual weather, geologic change, and natural and human-caused environmental change. Some changes have taken place over hundreds and thousands of years, others have occurred within a generation. Among the vast array of indigenous and western cultures spanning both history and the circumpolar North, there are similarities and differences in community vitality and vulnerability. Some communities have flourished, others have disappeared. Some have maintained cultural and spiritual traditions, others have embraced or been engulfed by technological change. Understanding how communities form, survive, change, and die, as well as the place of the individual within the community, are necessary components to understanding the arctic system.

Answers to these questions will help in the development of measures for community vulnerability and resilience that will allow predictions. The links between global change processes, including climate change, and their effects on northern communities will then be forged.

Research projects should, where possible, employ methodologies that are circumpolar, comparative, cumulative, longitudinal, interdisciplinary, and integrative. They should involve Native peoples as partners in planning, data collection, and interpretation of results. Research questions should be initiated by and through Native peoples and organizations. Community vitality and vulnerability necessarily affect arctic residents, and research can have a role in how they address stressors; preference should be given to their research concerns, needs, and priorities.

global changes in economic and environmental conditions. Factors governing these institutional structures are therefore critical to understanding the role of humans in the arctic system.

Maturity: A large literature is developing on formal and informal resource-management and -development institutions that provide important background for these questions.

5. What effects will global changes have on education, training, and employment opportunities for arctic residents?

Relevance: Education, training, and employment opportunities will strongly influence the strength and nature of connections between humans and the rest of the arctic system. These are major vectors through which policy changes might alter the role of humans in the arctic system.

Maturity: The literature in this area needs to be developed. The effects of education are typically not fully understood until approximately 15 years after a particular practice is in place. Thus, relevant studies require large time scales.

What factors have contributed to the resilience of arctic communities in the past? Which of these can be reinforced or enlisted to promote resilience of arctic communities today and in the future?

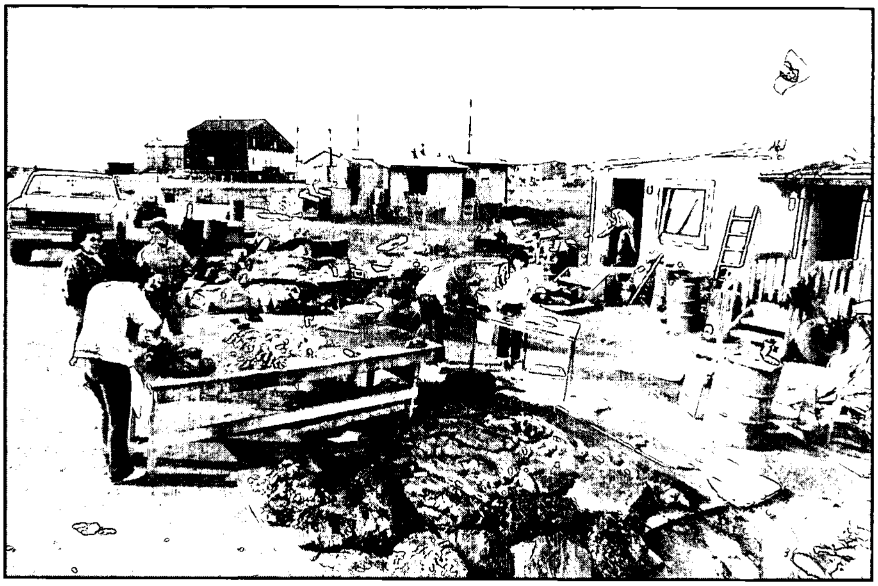
6. How will global changes affect health and access to health care in northern communities? Will these changes alter the impact of arctic residents on their environment? How will environmental change affect the health of arctic communities? For example, what is the link between global climate change and changing incidence and patterns of disease including mental health? What are the cultural impacts of environmental change that lead to increased alcoholism and drug use? What are the likelihoods that emergent diseases and novel vectors will arise? Will changing patterns of wildlife distribution introduce new parasites into subsistence species?

Relevance: Changes in health in response to global changes in environment, contaminant levels, and social conditions is a major concern to arctic residents. The sensitivity of health to these global changes and the excellent record of impact on humans (relative to any other species) suggests that changes in human health could be a sensitive indicator of major changes in the arctic system—changes that are likely to affect the role that humans play in this system.

Maturity: Much medical research in the North has emphasized curing diseases (*e.g.*, tuberculosis). The kinds of questions that need to be answered require human environmental health screening as well as more epidemiological and public health studies. These types of studies are only now coming to the fore, particularly in Alaska and Russia. HARC research will build on these studies and on recent research carried out with support from the NSF Arctic Social Science program (*e.g.*, McNabb *et al.* Forthcoming).

Elvina Turner, a nurse, visits Lucy Link in Bethel, Alaska (© James H. Barker).

7. What other socioeconomic changes (e.g., out- or in-migration, family formation, birth rates, social problems, cultural continuity) are likely to accompany large-scale environmental change? Do these changes create new anthropogenic influences on the arctic system? What sociocultural, policy, or other conditions make successful or unsuccessful adaptations most likely?



The butchering of a whale taken in September 1992 has been completed in Kaktovik, Alaska. Shown here is the captain's share and the much larger portions that will be distributed throughout the entire community during the year. Some of this whale will also end up in Anaktuvuk Pass, miles inland, where they catch no whales (© Bill Hess, Running Dog Publications).

Relevance: The socioeconomic changes that occur within families in response to changes in economic and environmental conditions strongly influence the nature of the human role in the arctic system. Only if the respective internal village dynamics are understood can we begin to predict the future role of people in the arctic system.

Maturity: The study of these issues within the context of the arctic system will strengthen linkages between social and natural scientists.

The socioeconomic changes that occur within families in response to changes in economic and environmental conditions strongly influence the nature of the human role in the arctic system.

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High school and junior high students in Point Hope, Alaska dance the Bunny Hop. Point Hope students schedule their prom in the middle of whaling season and invite the entire community. Poor weather conditions closed the lead in 1991; consequently nearly the entire community attended the prom. It is noteworthy that the young women pictured made their gowns themselves (© Bill Hess, Running Dog Publications).

D. What Are the Alternatives to Current Practices?

Human systems are open and unpredictable, in part because we can learn from the past and try to redirect our future. Human methods may be new and untried. To provide a basis for prediction, HARC must consider the alternatives. What policies or institutional arrangements might arise that do not yet exist? How might a society achieve sustainability within the constraints and changes of northern environments? How will these changes in human systems alter the role of humans in the arctic system? Weighing the alternatives will help understand the range of possible human responses. There are alternative structures and processes in arctic communities, with implications for adaptability to large-scale environmental changes, that present researchable questions.

Unresolved Scientific Issues

1. Economic: What economic alternatives are available to arctic communities, and what are the implications of such economic alternatives for the arctic system? For example, what markets exist and what potential markets may be developed for sustainable resource-based enterprises at the local level? What are the implications for domestication and commercial resource development as alternatives to subsistence resource use? What are the constraints on domestication at the northern fringes of its occurrence. How economically sustainable are alternative livelihoods as responses to environmental change? What variables affect sustainability in arctic communities? Is a sustainable state possible in the North without outside support? What are the potential, sustainability, and impacts of tourism in the Arctic? To what extent will advances in communication technology make it practical to participate in worldwide economic activity from arctic locations?

Relevance: Economic forces are a major factor governing the future of arctic communities and their influence on the arctic system.

Maturity: Although the economic future of arctic communities is uncertain, there is adequate information to develop reasonable scenarios and to model the consequences in terms of human sustainability and the changing role of people in the arctic system.

2. Social: What kinds of institutions can be designed to promote sustainability, guide sustainable use of resources, and mediate resource conflicts?

Relevance: This may be a good integrated measure of all questions in this section. Institutions to promote and manage sustainability have not yet been created in the modern world. To develop them would a major innovation (Libecap 1994).

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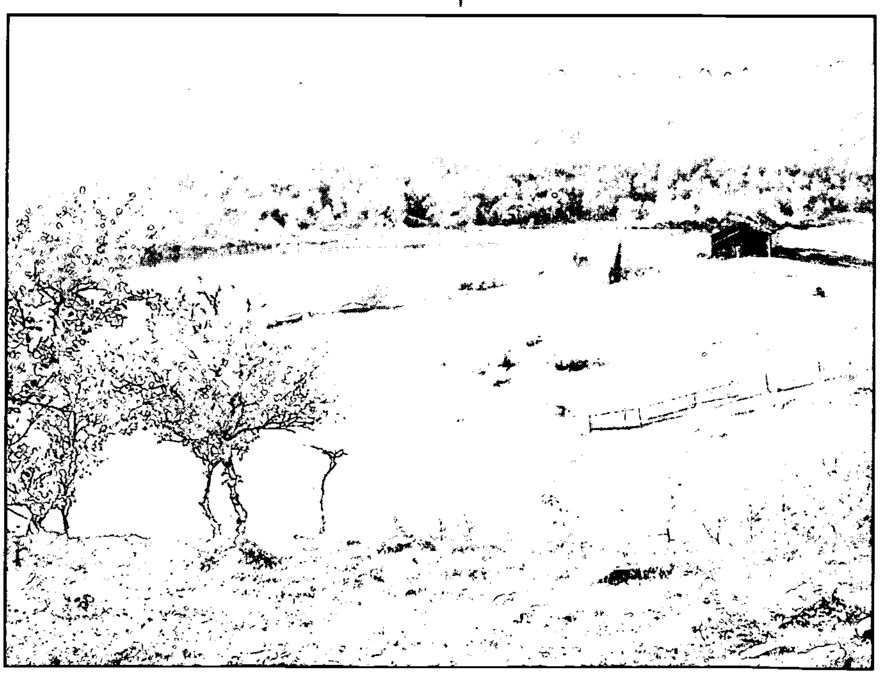


Agriculture is practiced at the subsistence level in the Arctic of northern Finland (photograph by David R. Klein).

Domestication and Land Use

Domestication has been present in the Arctic since approximately 1700 BC. Since the late 18th century, mixed agricultural economies have been introduced to various parts of the North as attempts to broaden the local subsistence base or to further commercial interests. While some of these ventures failed rapidly, others such as sheep herding in southern Greenland continue to provide multigenerational subsistence and cash employment to substantial numbers of northern residents. With the objective of halting the centuries-old trend toward deforestation, vegetation decline, and erosion, modern resource managers in Iceland have drastically reduced stocking levels for sheep to "free" land from grazing (Amorosi *et al.* 1997). The disagreements over the objectives of such efforts, and the perceived need for (or a return to) more intensive, yet viable, use of terrestrial resources, are strongly influenced by the present crisis in North Atlantic fisheries and by the impact that marine-mammal conservationists have had on the small-scale fishermen and hunters.

By critically comparing northern land-management regimes across time and space, social science in conjunction with natural science can contribute to informed environmental policy, supporting productive links among various entities that are involved directly in resource utilization and management or are operating indirectly through international domains of exchange and influence. Effective social science would explain and predict the environmental consequences of the disparate economic, social, and cultural options to use natural resources (*e.g.*, animal husbandry, fodder production, forestry, soil conservation, land reclamation, recreation). The diversity of past and present economies and social organizations in mixed farming cultures of the North provides useful case examples and insights into the range of adaptive strategies possible in the circumpolar zone (Eggertsson 1992). The long-term successes and failures of complex, socially stratified, northern cultures may be particularly relevant to attempts to widen the range of current and future responses to environmental and social change in the North (Ostrom 1990).

indeer herder in the Taimyr region of Russia (photograph by David R. Klein).

Maturity: A large literature exists on this issue, including studies in the Arctic (Young 1992, Young and Osherenko 1993). No specific effort has been made, however, to design specific institutions and model their consequences.

3. Ideological: What are the impacts of shifting ideologies, within and outside the Arctic, on resource use and the arctic environment? What are the impacts of individual environmental attitudes on the arctic environment? How do traditional and contemporary knowledge affect responses to global environmental change in the Arctic, and the resilience and adaptability of communities to such change? How does education influence response (*e.g.*, through increased mobility or in decision-making about resources)? Will residents of the circumpolar Arctic use new communication technologies to advance common interests?

Relevance: These questions address the possible effectiveness of learning and education in altering the future effects of global changes in the Arctic. Education will be a key strategy for any effort to consciously alter or adapt to environmental or societal change.

Maturity: A large literature exists, although it is mostly non-arctic (Thomas 1983).

4. Political and legal: How effective are current political systems and policies for responding to large-scale environmental change? What are the potential implications for local control over resources, and for alternative structures for resource and environmental management at the local and regional levels? What is the role of traditional structures, tenure regimes, and institutions in the management of resources? Is a sustainable state something that requires definition from outside, or is it something that northern communities will find on their own, given local control? What new institutions might help communities adapt to environmental change and mediate resource conflicts? How do the dynamics and interactions of institutions in hierarchies impact resource use? To what extent do institutions at the same and different levels have conflicting impacts? What external political and economic forces contribute to the vulnerability of arctic communities; what variables promote viability?

Relevance: Political forces are a major factor governing the future of arctic communities and their influence on the arctic system.

Maturity: Modeling of political scenarios could illustrate consequences in terms of human sustainability and the changing role of people in the arctic system.

5. Health: What are alternative approaches to improving the health of people in the Arctic? How might these approaches affect the development and spread of diseases and, thus, the effect of disease on arctic and global systems?

Relevance: Health is one of the major areas in which people's lives may be affected; circumscribing alternatives to health-improvement approaches will be important. The various standards of health care in the Arctic may be fostering new drug-resistant strains of disease.

Maturity: Alternative approaches to understanding health are being developed, but are not themselves mature. The Arctic, with its sparse population, presents special challenges to health delivery and disease prevention. Research must first consider the range of possible approaches.

6. Historical: Can we identify successful sociocultural adaptations to past change that have relevance for adapting to global change, including climate change as indicated by ARCSS research? What factors have contributed to the resilience of arctic communities in the past? Which of these can be reinforced or enlisted to promote resilience of arctic communities today and in the future?

Relevance: The research would add to the repertoire of alternatives and processes ilable for arctic communities.

One Approach to Studying Resource Variability

A key question in determining the human dimensions of the arctic system concerns the human/environment interface. Key species characterize much of this interface. Throughout much of the Arctic, some subspecies of *Rangifer tarandus* (caribou and reindeer) play a role in the economy. For coastal peoples, seals are important. Universally, some species of fish constitute part of the diet. Finally, berries provide a needed source of carbohydrates. What happens when these species decline or increase? How do societies adjust? How do cultures that depend upon specific species respond? Do they put pressure on other species? What are the differences between subsistence and commercial reactions? How does domestication affect the interface? What constraints prevent diversification, which ones encourage it? Are human responses different in the short and long term? What are the institutional constraints? Do rules exist that govern the interplay among these species when one or more is in relatively short supply?

Answering these questions could lead to the development of a geographically broad comparative study. The research group could develop a template of species analogous to that employed by the International Tundra Experiment (ITEX). Within the last 20 years, extensive research on subsistence has been conducted; much data already exists. Setting subsistence species within a circumpolar template will provide a synthesis of this research. The research could illuminate key links between the natural environment and important institutions of the societies that use them. This will provide a background for institutional analyses and environmental change response studies. Research results could also anticipate the consequences of other sorts of actions that have similar affects comparable to species decline, such as laws restricting the take of specific species.

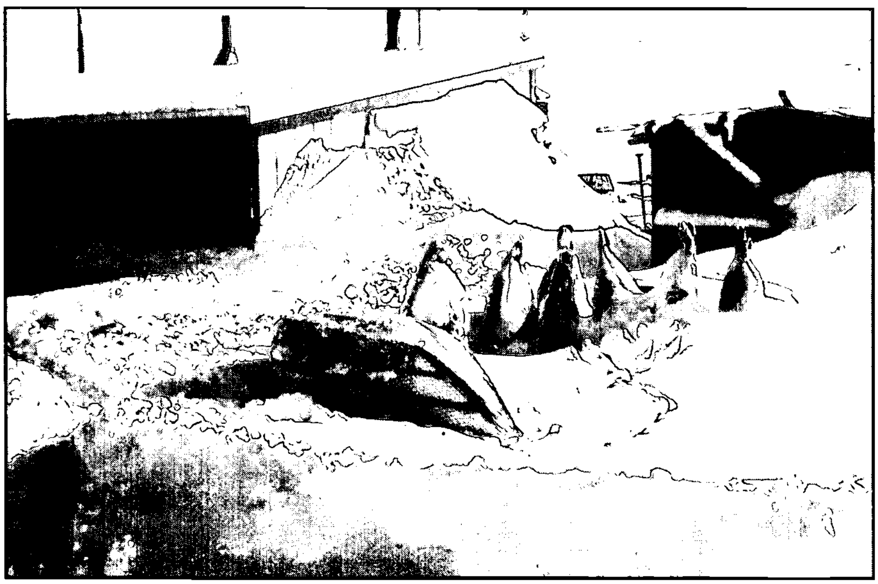
A small group of muskoxen in northeastern Greenland. The muskox is highly adapted to life in the Arctic and is indigenous to northeasten Greenland, Canada, and Alaska. Muskoxen disappeared from Alaska during the 1800's and were reintroduced with stock from Greenland in 1930 (photograph by Henning Thing).

Foxes and Bird Bones

On Amchitka Island, located in the Aleutian Islands of the Bering Sea, early Aleut hunters utilized a rich resource of seabirds, sea mammals, fish and sea urchins. Detailed analysis of the abundance and types of zoo-archeological material left behind after thousands of years of meals has revealed that cormorants were an important food resource during winter when most other seabirds had migrated away.

The arrival of Russian adventurers in the 18th century was coincidental with a sudden decline in the numbers of bones of seabirds that nest on flat ground and in burrows. At the same time, bones of the arctic fox, brought there to breed for the Russian fur trade, began to show up in the archaeological layers. Soon after, the vegetation on many of these islands began to change, as detected by the pollen, seeds, and plant remains found in the former habitation sites.

The implication is that arctic foxes introduced by humans ravaged the seabirds that were not protected by nesting on cliffs or off-shore rocks. Decreased amounts of guano, which acted as fertilized for the poor soils of the Aleutian Islands, affected the plant communities and nearshore waters (Siegel-Causey *et al.* 1991).



Ringed seals stored outside a house in Point Hope, Alaska. The small boat in the foreground is used to retrieve seals from the broken ice in front of the village (photograph by Lori Quakenbush).

Maturity: The rapidly advancing research in this area would benefit from cross-fertilization with work in community and economic development. HARC research would focus on the use of history and archaeology in developing alternatives.

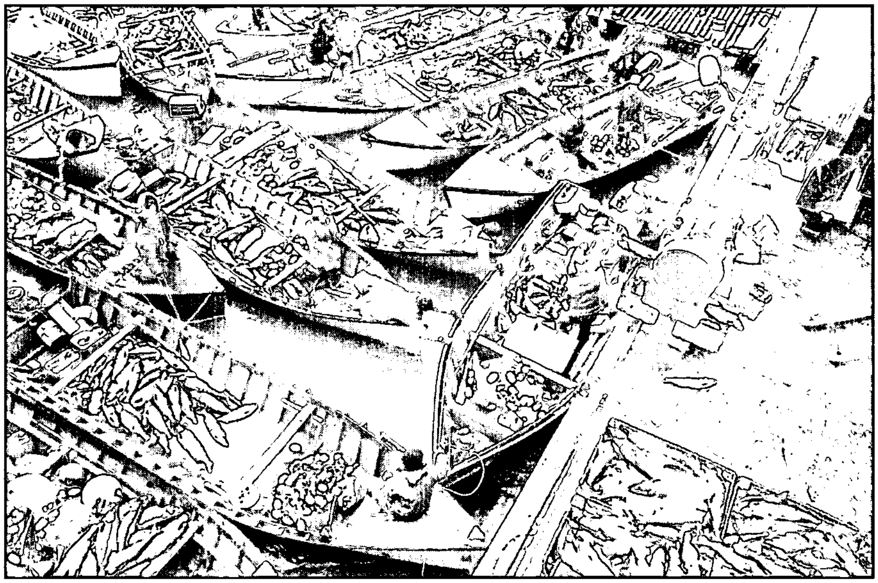
7. Ecological: What factors might predict the resilience or adaptability of individuals and communities facing ecological change (and the regulatory changes that often accompany sudden ecological declines)? Futhermore, what factors influence the maintenance of resilience, once achieved? Possible examples include demographic variables, social cohesion, human and social capital, geographic advantages, history, and cultural variations (Lubchenco *et al.* 1991).

Relevance: Resilience is an important characteristic for survival of communities and individuals.

Maturity: Much research is available, but a common definition of resilience is needed as a basis for addressing the questions above.

E. What Are the Effects of Changes in the Arctic System on People Living Outside the Arctic?

This question differs from prior question B—"What are the types and sources of global change in the Arctic?" (page 34)— in that B considers the importance of global change on the arctic system, while E investigates arctic feedbacks into the global system. Question E addresses effects outside the Arctic, such as increasing freshwater anomalies in the North Atlantic, that are connected to what happens in the Arctic Ocean and its freshwater sources. This question ties arctic physical processes directly to people's lives in the South. It includes such issues as local sovereignty, increasing transfer payments from central governments to their northern peripheries, and the burdens that such payments place upon national treasuries.



Commercial fishermen wait to sell salmon in Bethel, Alaska (© James H. Barker).

Unresolved Scientific Issues

1. How does human harvesting in the Arctic affect resource availability in the mid-latitudes? Heavy harvesting of species in the Arctic may affect species, such as salmon, that migrate to other areas. Such harvesting may be in response to shifts in species availability caused by changes in physical conditions or in response to world-market demands. It may create significant economic impacts, such as when high-seas fisheries motivate expensive efforts to enhance or restore Atlantic salmon in the eastern United States.

Heavy harvesting of species in the Arctic may affect species, such as salmon, that migrate to other areas.

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Relevance: Answers to this question would have direct implications for understanding the origins of resource problems in mid-latitudes. It would link natural resource policy in high- and mid-latitudes within and among nations.

Maturity: Given the available body of literature, synthesis studies are likely to be highly productive.

2. How do changes in North Atlantic deep-water formation, as influenced by the hydrology of the Arctic Basin, affect climate and fisheries outside the Arctic? Changes in rates of deep-water formation in the North Atlantic have been implicated in the sudden shifts in global climate that have occurred in the past.

Relevance: This research could create a direct link between OAII and GISP2 studies and impacts in the mid-latitudes.

Maturity: Current research in OAII explores ways in which changes in the output of ice and water from the arctic basin may influence these large-scale oceanographic changes. HARC can contribute to this research effort by demonstrating the consequences for non-arctic people. OAII could benefit from developing relationships similar to those between GISP2 and social scientists.

Many birds and fish migrate to southern regions where they either become inputs to other ecosystems or are harvested and become a health risk for humans.

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3. Under what circumstances would changes in surface-energy budgets or in trace-gas fluxes within the Arctic be large enough to affect climate beyond the Arctic? Other programs of ARCSS are studying the factors governing trace-gas (CO_2 and CH_4) fluxes and changes in surface-energy budgets due to changes in sea-ice extent, thawing of permafrost, or vegetation change. In some circumstances, the resulting climatic changes may be large enough to affect climate well beyond the Arctic. HARC may be able to contribute to this research effort by highlighting the consequences of these changes within the arctic system for people outside the Arctic. The research discussed in question A—"What are the impacts of human activity on arctic and global systems?" (page 29)—will add an understanding of how activities in the North exacerbate such conditions.

Relevance: This research could create a direct link between LAII flux studies and impacts in the mid-latitudes.

Maturity: Discussions between social scientists in mid-latitudes and those knowledgeable about the possible effects of changes in trace-gas fluxes and surface-energy budgets could lead to effective research plans.

Boys at Nightmute, Alaska with sandhill cranes and ducks. With the help of the U.S. Fish and Wildlife Service, village representatives from the Yukon-Kuskokwim Delta worked with the Alaska and California Departments of Fish and Game to plan for the protection of species that are threatened. This became the 1985 Yukon-Kuskokwim Delta Goose Management Plan (© James H. Barker).

4. What are the impacts on people outside the Arctic of migratory birds and fish that accumulate arctic contaminants? As discussed on page 30, there is substantial accumulation of contaminants such as radionucleides, organochlorines, and pesticides by organisms feeding in the Arctic. Many birds and fish migrate to southern regions where they either become inputs to other ecosystems or are harvested and become a health risk for humans. The magnitudes of this contaminant transport, its system consequences, and the resulting health risks to humans are largely unknown, however.

Relevance: This research would address the extent to which other areas of the world need to be concerned about the contaminants now found in the Arctic.

Maturity: The substantial research effort in the Arctic needs to be expanded to include the mid-latitudes.

Chapter 7. Methods, Data, and Infrastructure

Many different social science approaches may contribute to HARC research. These approaches must be adapted outside of their usual discipline-specific contexts, so that the approaches and the data they generate can be linked with other social and biophysical science findings to address arctic system problems and concerns. This section reviews some appropriate methods, giving examples of relevant data or applications they might generate.

Archaeological Records

The science of archaeology examines artifacts, sites, and landscapes of the past and reconstructs the long-term interaction of humans with natural resources, changing environments, and other human cultures. In the past two decades, northern archaeology has greatly expanded its fundamental database through excavation and survey, and has substantially improved its capabilities through the integration of zooarchaeology, paleobotany, human paleobiology, and new methods of relative and chronometric dating. Archaeology can provide a long perspective on human, resource, and climate interactions in periods and areas for which no other evidence exists. It can also be effectively integrated with historical documents and ethnographic research in more recent periods.

Historical Records

Historical and related documentary materials can provide important information on many topics, ranging from climatic and environmental change to analysis of the social, political, cultural, economic, scientific, and technological factors which influenced the growth, development, and dispersion of human communities (Broms 1996). While historical materials are less readily accessible to social and natural scientists than other forms of data, professional historians are able to interpret past records and locate relevant information from obscure and otherwise unavailable sources. Historical studies of past settlements in arctic regions (Levere 1993, Seaver 1996) provide useful comparative insights, as do historical studies of settlements in the Bering Sea region (Hunt 1975, Bockstoce 1986). In writing such studies, historians consult a wide variety of sources, including medieval annals and chronicles, diaries, travel accounts, newspapers, meteorological observations, government and state records, expedition records, and commercial vessel logs. Much work has been done to reconstruct past climate

Fossil Insects and Climate Change

Research on the collapse and extinction of the Norse Western Settlement in Greenland ca. AD 1350 (Skidmore 1995, Buckland *et al.* 1996) has used fossil insects in conjunction with vertebrate zooarcheology, paleobotany, historical documents organized and translated under the PALE program, and several high-resolution data sets drawn from the GISP2 core.

Researchers have demonstrated that different species of flies normally inhabited different rooms of Norse farm sites; incidentally imported warm-climate species clustered in the heated human living areas, while other more cold-tolerant species lived in the larder on scraps of rotting meat.

The terminal floor layers, however, show a very different pattern of fly distribution. The warmth-loving species had become nearly extinct, the cold-tolerant carrion feeders had spread from the larder to the whole house, and additional carrion-feeding species from the outside had moved in. Something rather sudden and final had happened at this Norse farm site. The butchered bones of what appear to be most of the farm's cattle, the disjointed skeleton of a large hunting dog, and clusters of dog bones and unrecovered artifacts on the terminal floor layers of other sites in the Western Settlement suggest that the whole settlement may have been abandoned at once.

Radiocarbon and documentary dating combined with the proxy climate record of the GISP2 core indicate that abandonment of this settlement followed a long series of cold summers in the first half of the 14th century and one or more extremely cold winters. Computer models indicate that this combination of reduced summer growing season for pasture plant communities and extended winter feeding period for imported European domestic animals may have placed the Norse economy under extreme stress. At the same time, Norse leadership appears to have been resisting all innovation available from the Thule Inuit, including ice-hunting equipment that could have expanded Norse subsistence resources during periods of cold climate.

Martina Phillip skins her husband Joe's seal in Alakanuk, Alaska (© James H. Barker).

using such historical records (Pfister 1981, Lamb 1982, Ogilvie 1992). Historical and scientific policy studies also provide pathways for interpreting the significance of climate change within appropriately broad social contexts, including human discovery of global climate change (Bowler 1993, Weart 1997).

Symbolic recordings such as carvings, and stone or whalebone monuments are also valuable resources, as are oral or narrative accounts (Grele *et al.* 1985). In the latter case, the accounts are not written, but are narrated by elder citizens of towns or villages, who have clear memories of changes that have occurred since their childhood, or of stories related to them by an earlier generation. Oral narratives can offer information on events occurring many generations before that of the narrator (Harris In press). In addition, oral histories of long-term residents of far-north and arctic regions, including members of local scientific communities, can be especially helpful in illuminating important social, political, economic, and technological factors (such as the significance of Cold War developments and the impact of changes in jet-fuel cost) that must be evaluated simultaneously to better understand the actual effect of global change phenomena. Much has been recorded already, but little has been catalogued or logged to facilitate access.

Ethnographic Studies

In-depth studies of a single or limited number of communities, including communities within urban areas, characterize ethnographic research. The tools of such research are varied and draw upon the methods of other disciplines. Surveys and historical research are standard, but so are the more specialized methods of participant observation, key informant interviews and genealogies. Ethnography can validate and provide insights into patterns observed in data obtained by other methods. It can be used strategically to understand pivotal aspects of communities or to follow one community over time. In-depth studies typically take more than one year. Shorter periods are possible where the questions are limited, or where the researcher already has some familiarity with the situation.

The accounts are not written, but are narrated by elder citizens of towns or villages, who have good memories of changes that have occurred since their childhood, or of stories related to them by an earlier generation.

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Surveys

Survey questionnaires can provide quantitative and qualitative information from large numbers of individual respondents. The strengths of surveys include the possibility of generalizing (given a solid sampling design and good response rate), and the ability to evaluate competing hypotheses or explanations through multivariate analysis. Surveys also provide a basis for comparisons by community, age, ethnicity, education, gender, and other characteristics, which may in turn illuminate policy options and future trends. Surveys have been employed as a tool to examine the social impacts of new resource-extraction industries in Alaska. Cross-cultural values and differences in language usage must be very carefully considered when translating or designing surveys for arctic residents.

Archival Community-Level and Time-Series Data

For aggregate levels of analysis such as communities, counties, or states, archival data from many existing sources could be assembled and brought to bear on HARC topics (*e.g.*, demographics and vital statistics [age/sex/ethnicity composition and change in population; births, deaths, marriages and migration], economics [household and individual income by sources, household size, employment by sector, unemployment rates], social indicators [marriage, divorce and crime rates; education], and health [mortality and morbidity rates by cause and population sector]). Such aggregate analyses may provide our best estimates of the overall scale of phenomena observed at other levels of analysis, answer questions about timing and trends, and help assess the populations at risk due to anticipated environmental change.

Interdisciplinary and Integrative Methods

The HARC program calls for investigating the human dimensions of global change in a comprehensive, interdisciplinary way. Furthermore, it seeks to enhance understanding of the arctic system as a whole. The program will, therefore, support the development of innovative research that:

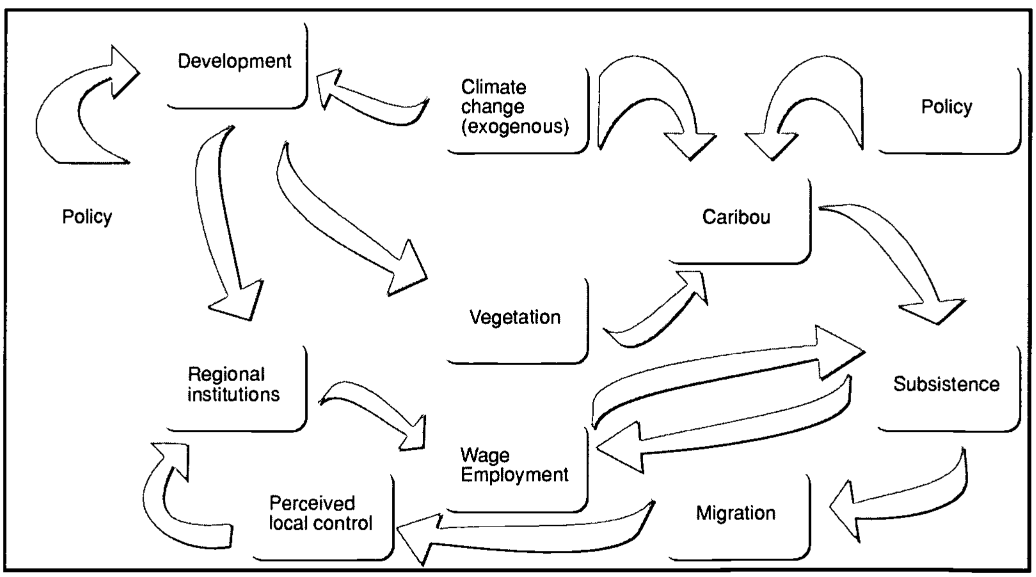
- cuts across traditional social, natural, and physical science disciplines;
- employs varied scientific methodologies chosen for their appropriateness to the problem under study;
- collects data at different levels of analysis, or across a broad range of time and spatial scales; and
- involves local people and communities in research design and implementation.

Such work requires that a consortium of local residents and researchers from a variety of disciplines collaborate to achieve the understanding desired by all.

Modeling

Most ARCSS projects include the development of models of system components. Introduction of human dimensions to arctic system models entails a substantial increase in complexity. The challenge to modelers is to combine the interactions between the different subsystems (*e.g.*, vegetation ecology, caribou ecology, human economics, human population) over a regional scale in a way that effectively addresses policy questions.

The approaches of both system modeling and spatial modeling are relevant. The challenge of effectively modeling transient dynamics (changes over a period of decades) at a regional scale, however, is still largely unresolved. A tension exists in any modeling effort of this kind between simplicity and detail. Most system models take a bottom-up approach—that is, start with the finest level of detail in the hierarchy and build the model upward. An alternative approach is to start with a simple model that reflects gross dynamic changes and successively refine it down to the level of detail appropriate to address the policy questions that have been posed.



Model from Sustainability of Arctic Communities Project (courtesy of Jack Kruse).

Both qualitative and quantitative models are likely to provide HARC researchers with excellent means of contributing to the overall understanding of arctic systems. These models offer what may be the most convenient method for integrating HARC research with the observations and results generated by other ARCSS research.

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Geographic Information Systems

Geographic Information Systems can play an important role in broad, interdisciplinary research plans.

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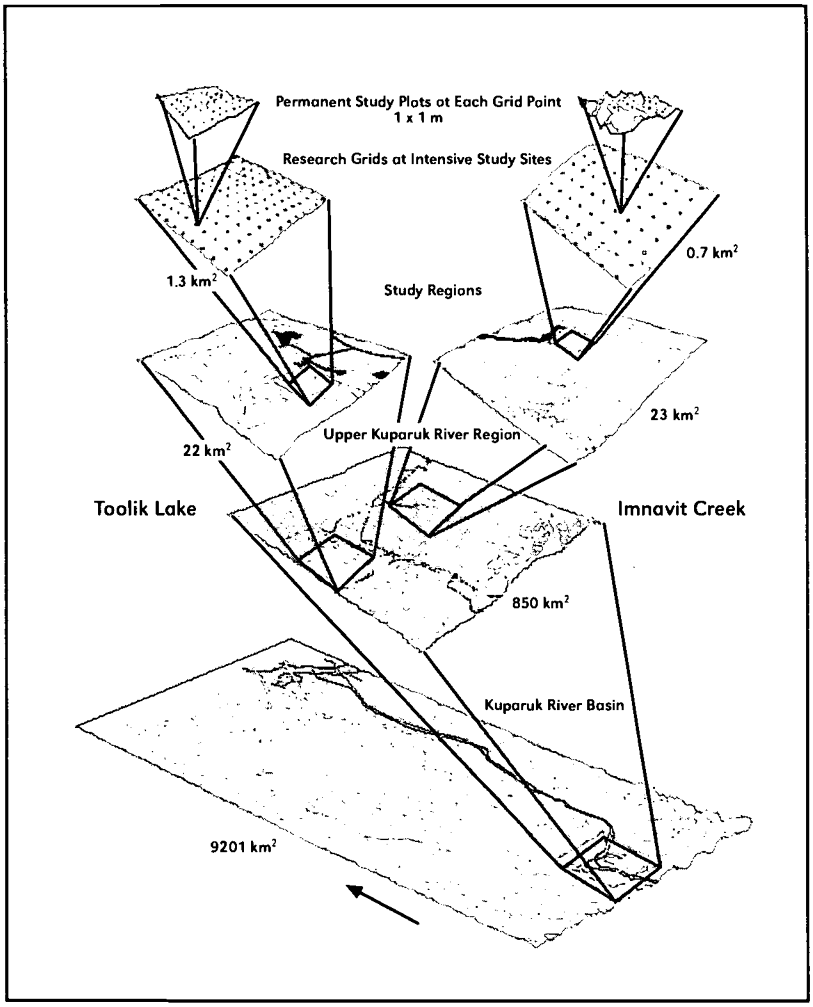
All data, whether they pertain to the Arctic as a whole or to an individual organism, have some kind of spatial component. The data-development and -management problems generated by a myriad of projects with diverse research goals and various scales require tools that will facilitate multiscalar and interdisciplinary research. Geographic Information Systems (GIS) can play an important role in broad, interdisciplinary research plans. The ability of GIS to manage, store, retrieve, and analyze massive quantities of spatial data make this technology useful in a variety of projects. The implementation of a National Data Standard now makes the use of GIS a fundamental means for data management, data sharing, and data redistribution. There is a growing literature spanning a range of disciplines including environment and land management, cartographic modeling, anthropology, social sciences, archaeology, geography, deforestation, and agricultural development.

The use of GIS for studies of northern landscapes is in its infancy. While the Arctic was the testing ground for many remote-sensing applications, and continues to have a strong emphasis on remotely sensed data, the explicit use of GIS is not yet common. Given the links among northern human communities, changes in land and sea use, and the spatial variation in the effects of global change on the Arctic, GIS may have an important role to play in synthesis and integration. Consideration of how HARC data can be incorporated into GIS should be an essential part of all research design, project evaluation, and data management.



One of the most important elements for databases at all scales is terrain topographic information in the form of digital elevation models (DEMs). The hierarchy of digital elevation models shown here demonstrates how such models can be used for studies of northern landscapes. This hierarchy of DEMs was specially made for the LAII Flux Study (page 16) (figured provided by Skip Walker).

The Special Concerns of Human-Dimensions Data

All components of the ARCSS program are expected to cooperate with the ARCSS Data Coordination Center at the National Snow and Ice Data Center (NSIDC) for long-term archiving of ARCSS data. Because ARCSS is a broad-based program aimed at synthesis of arctic system science, access to data is important. The goal to archive ARCSS data includes all HARC data; there are specific concerns, however, when dealing with human subjects. Collaboration among other ARCSS programs and HARC has the potential to raise the standards guiding all ARCSS researchers and archivists.

The Interagency Arctic Research Policy Committee has promulgated *Principles for the Conduct of Research in the Arctic* that focus particularly on human participants (see page 24). All arctic researchers are urged to follow these principles closely, as well as those associated specifically with social sciences research. Principal issues in the archiving of research data concern whether:

- informed consent has been granted,
- communities have been informed about ongoing research,
- results are being returned in an understandable form, and
- anonymity and credit have been provided as is appropriate.

Each investigator who conducts human-subject research must conform with specific governmental guidelines for the protection of human subjects (including those of other nations, when research takes place within their borders). Researchers must gain prior approval of the research plan from their home institution. A researcher must gain informed consent, address right-to-privacy issues, and state the intended use of the results. In many cases, confidentiality must be strictly maintained. Complete documentation of how these regulations are implemented must accompany all data archived at the ARCSS Data Coordination Center. Furthermore, the Data Coordination Center must adhere to the same rigorous guidelines as are required of the original investigator.

Though the *Principles* do not explicitly require it, the same guidelines should apply to future uses of the data. The community should be informed about applications of the data not part of the original informed-consent agreement. The community should also be provided with the research findings, given credit, and granted anonymity where these terms were part of the original research relationship. The latter requirement is specifically mentioned in the *Principles*. Documentation of the informed-consent process will help future researchers fulfill these commitments. In many cases, data sets were collected for specific purposes that are compatible with HARC research (*e.g.*, harvest reports). Researchers and data managers should document their efforts to obtain informed consent for the use of these data.

Researchers should seek informed consent from community organizations even when working with individuals. This need is especially strong in the North, where communities are closely knit, where the sharing of information about other people is part of the social fabric, and where the community may feel that certain types of information belong to groups rather than individuals.

The subject of informed consent and other issues relating to the responsible conduct of research activities in the Arctic are addressed in the Principles for the Conduct of Research in the Arctic.

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In order to incorporate traditional wisdom and knowledge, researchers must actively involve the Native residents of the region, as traditional wisdom and knowledge is dynamic and lives within them.

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HARC research would benefit from a means to extract human-health data for arctic residents from census tracts and the records of regional health-care delivery systems. Efforts to use health-care data may highlight the difficulties in obtaining permission after the fact.

People providing oral histories make assumptions about what the listener knows. If these assumptions are not accurate, the information may be misinterpreted. For instance, a researcher might interpret the fact that "20% of the people in northwest Alaskan communities harvest 80% of the caribou" to mean that a few people are harvesting too many animals, while many other residents are no longer involved in the subsistence economy. In fact, the harvest is widely distributed; a few people provide most of the village with food. The ARCSS Data Management Group is working to include meta-data (*i.e.*, methodology, date, conditions, qualitative assessments) with each data set. Additional efforts to gather such contextual data from social scientists may be warranted.

Finally, the *Principles* do not cover the issue of intellectual property rights. These rights have been brought to light by concerns in tropical areas where companies have benefited from information given by local people about the medical qualities of plants. The issue of intellectual property rights is appearing in the North. Use of data archived under HARC is limited to scientific purposes. For any other use, it must be considered proprietary, subject to any intellectual property rights that the original research participants may claim.

*Flensing a narwhal in Disko Bay (*Qertarsuup Tunua*), Greenland. Narwhal, beluga, and other marine mammals are an integral part of mixed subsisrence-cash economies in many Arctic communities (photograph by Richard A. Caulfield).*

Indigenous residents of the Arctic have concerns about the insistence that traditional knowledge and wisdom (TKW) be made readily available to researchers and the public. Their cultural framework has enabled them to survive in the Arctic; the relevance, utilization, and stewardship of their information must be determined by them. To date, a consistent recommendation has been that in order to incorporate TKW, researchers must actively involve the Native residents of the region, as TKW is dynamic and lives within them.

Other possibilities for the use of data should be explored. For instance, it may be possible to provide data in a way that protects anonymity. Formulae, rather than data sets, could be archived. Independent peer review could provide quality control, that is, let someone outside the project assess the protocol and results of the research.

Given the special requirements of human-dimensions data collection and management, the HARC Science Steering Committee has recommended that the ARCSS Program convene a special review group to provide ongoing oversight of human-dimensions data archiving.

Chapter 9. Important HARC Relationships

HARC Connections with Other National and International Initiatives

The HARC initiative has the potential to benefit from and, in due course, to contribute to other organized science initiatives. Among the most important of these are the Science Agenda of the International Arctic Science Committee (IASC) and the core and related projects of the International Geosphere-Biosphere Programme (IGBP) and the Human Dimensions Programme (HDP).

The hallmarks of these programs, shared by HARC, include:

- an effort to mobilize human, organizational, and financial resources around a set of carefully constructed science plans that provide strategic guidance without straight-jacketing the efforts of individual scientists, and
- a commitment to endogenizing the role of human actions in complex systems (that is, treating human actions as an integral part of the research rather than something that is added on).

The current IASC Science Agenda contains a set of priority topics clustered under the heading of the impacts of global change on the Arctic and its peoples and a second group of priorities organized under the heading of Sustainable development in the Arctic. In the first area, IASC has launched the Bering Sea Impact Study (BESIS) and the Barents Sea Impact Study (BASIS), both of which are committed to including the role of human actors in their efforts to understand the dynamics of these large coupled systems. Particular attention, in this connection, will fall on studies of the vulnerability of human communities to changes in their biophysical environments and the responses of humans to these changes, treated as feedback mechanisms in the overall systems. The IASC work on sustainable development directs attention to studies of the social and environmental impacts of industrialization on arctic systems and to research on past, present, and future social institutions governing the use of living resources of high value to arctic residents. Circumpolar in scope, this initiative is designed to encourage comparative studies of the impacts of industrialization and resource regimes operative throughout the Arctic (Skolnikoff 1993).

The links between the HARC initiative and the scientific concerns of IGBP and HDP are equally clear and significant. The importance of endogenizing human actions in connection with the IGBP core projects on Land/Ocean Interactions in the Coastal Zone (LOICZ) and Global Change and Terrestrial Ecosystems (GCTE) is now generally accepted. The core project on Land Use/Cover Change (LUCC) is itself a joint venture of IGBP and HDP which places a primary emphasis on the social drivers that account for changing patterns in human uses of land and associated natural resources. Among the projects now being developed under HDP auspices are one on the perceptions and behavior of individuals and another on the role of social

Knowledge of the dimensions, scale, and trends of past impacts of human activity in the Arctic will contribute to our ability to model their potential future contributions to arctic and global systems and to develop the basis for evaluating policy recommendations that could alter the timing or direction of such changes.

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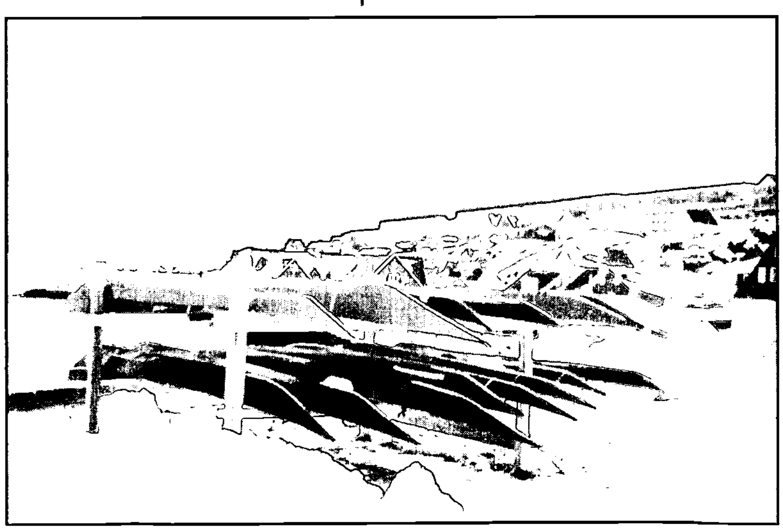

Kayaks on a rack near the national museum in Nuuk, Greenland in March 1997. The kayaks are made of seal skin with ivory toggles (photograph by Gail Fondahl).

The Arctic Council

In September 1996, the eight arctic nations established an Arctic Council, a high-level policy forum for discussion of environmental and other non-military issues of common concern in the circumpolar arctic region.

The members of the Arctic Council are Canada, Denmark (which administers Greenland), Finland, Iceland, Norway, the Russian Federation, Sweden, and the United States. In addition, the Council allows for the full consultation and involvement of the region's indigenous inhabitants. To date, three indigenous groups are named as Permanent Participants of the Council, with provisions to allow for additional groups in the future. These are:

- the Inuit Circumpolar Conference;
- the Saami Council; and
- the indigenous minorities of the Russian North, Far East, and Siberia.

The Council carries forward the science-based programs of the Arctic Environmental Protection Strategy (AEPS), which are designed to address the state of the arctic environment (Scrivener 1996). The Council intends to combine this environmental mandate with attention to broader issues related to sustainable development, including economic and social development, improved health, and cultural wellbeing. For these reasons, the U.S. State Department views the Arctic Council as an important vehicle for pursuing the objectives of the U.S. Arctic Policy Statement of 1994.

institutions in global change. The project on individuals will direct attention to how people perceive and react to environmental changes; it will benefit from a sustained effort to work with people from non-Western cultures like those of the Circumpolar North. For its part, the project on institutions will emphasize the interplay among resource regimes operating at different social scales ranging from informal arrangements at the local level to international regimes. This, too, is an area where arctic experience is of obvious relevance.

Finally, links with the several programs of the Arctic Council—formerly the Arctic Environmental Protection Strategy—(*e.g.*, Conservation of Arctic Flora and Fauna, and the Arctic Monitoring and Assessment Programme which includes monitoring of humans for environmental contaminants and considers the effects of anthropogenic contaminants) may help to identify the international policy implications of HARC projects.

The benefits to be derived from nesting the HARC initiative into these other circumpolar and international science programs are substantial. Those involved in HARC stand to gain both in intellectual terms as they connect with larger research efforts and in material terms as they demonstrate the relevance of their efforts to broader funding sources. Conversely, those involved in IASC and IGBP/HDP stand to benefit from the opportunity HARC offers to strengthen the links between natural and social scientists and to extend the range of applications of their findings.

The benefits derived from nesting the HARC initiative into other circumpolar and international science programs are substantial.

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Education and Community Collaboration

The HARC initiative demonstrates a commitment to developing strong and broad educational components that link scientists and research in ARCSS projects with students and other members of the arctic community. The scope of the HARC educational element itself also must be broad. Reasons for a HARC emphasis on education include:

- The foci of this plan will require working with the communities of the Arctic.
- HARC will provide the opportunity to inform these communities about the results of research carried out under the other components of ARCSS.
- Formal science education is often weak in the smaller communities of the North. HARC research (*i.e.*, the human/environment interface) will provide a unique opportunity to link aspects of the natural sciences into the direct interests of northern peoples.
- HARC will provide a powerful avenue to connect arctic research with human interests outside the Arctic. Thus, it could serve as the foundation for a broad educational program about the arctic environment.
- While not formulating policy, HARC research will have policy relevance. An educational element will help to make those relevant aspects explicit and understandable and will address both decisionmakers and the general public.

Communication at the local level, between the investigator and the local community, is of the utmost importance. There is a need, however, to bring science to broader communities, as well (*e.g.*, *via* regional and national TV, Internet, traveling exhibits, popular publications). HARC investigators should be encouraged to reach the largest possible audience for their work and, where possible, to include local community scholars in the dissemination of these results. If supported by the community, a system that makes scientific results accessible at the local level through the Internet might be economical and effective. The development of this type of communications and educational infrastructure (*e.g.*, community-based electronics networks, Web sites, compressed video, *etc.*) will help investigators reach these important audiences.

In the past, many science programs have neglected to educate local communities about research plans, possible impacts, or results; neverthless science itself is perceived by northern residents and communities as important for their future. For local peoples the issues of greatest concern are:

- how science is conducted in local contexts;
- the return of information and research results from scientific studies; and
- science training for local youth.

The emphasis placed on education within HARC and the methods recommended to ensure this strong educational component will support these general goals.

HARC research will provide a unique opportunity to link aspects of the natural sciences into the direct interests of northern peoples.

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Education must be adequately funded and should be made a responsibility of individual research projects. The latter requirement does not mean, however, that the solutions need to be individual. Individual projects might join together in a larger educational effort, and individual researchers could seek the aid of consultants or organizations with expertise. Where research is related to the lives of northern communities, those communities should have a primary role in development of educational components.

Certain requirements could be placed on proposals submitted to HARC announcements of opportunity to ensure that these education efforts are adequately planned for and funded. Care must be taken so that these educational requirements add to, rather than diminish, the scientific elements of proposals. Recommendations include the following:

- At least 2% should be added on to the total direct costs of a proposal for education.
- In a proposal supplement—not to be included in the 15-page limit for project descriptions specified in NSF grant guidelines—the principal investigator (PI) would describe plans for the 2% dedicated to education.

Wildlife biologist Todd O'Hara, of the Alaska North Slope Borough Department of Wildlife Management, and Susan Hope, an Iñupiat chaperone, butcher a caribou at Teshekpuk Lake in July 1995. Eliza Simmonds of Atqasuk, on the right, is trying to shoo away mosquitos. O'Hara, Hope, and Simmonds are participating in a camp established for high school students to learn more about caribou, from both scientific and traditional perspectives (© Bill Hess, Running Dog Publications).

Where the educational part of the proposal would affect arctic communities, memoranda of understanding with those communities should accompany the proposal. Researchers embarking on new work would submit a general statement, followed by a more detailed plan after the first year of the project.

First day of school for children in Qeqertarsuaq, West Greenland. The children are wearing their kalaallisuut, *the Greenlandic national costume made of sealskins (photograph by Richard Caulfield).*

- Reviewers and the panel would include the education plans in their evaluations and ranking. Should a proposal fail to address the issue of education, yet be of high scientific merit, the program officer should work with the PI before granting final approval.
- Investigators would document their educational efforts in both annual and final reports. When submitting new applications, they should include descriptions of previous efforts.

To implement educational goals of the HARC program, each proposal submitted should contain an educational plan that presents a program description and budget explicitly related to the research proposed. This plan should be prepared by the principal investigator in collaboration with relevant local groups; letters of support from participating groups should be included in the proposal. At the close of the project, the PI report to NSF, or other relevant agencies, should include a report on the educational program with suggestions for addressing future needs.

The HARC initiative and its significant focus on education provide an important opportunity to support the goal of integrating research and science education.

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Examples of Research-Based Educational Programs

Principal Investigators are urged to develop educational programs that best suit the research project and take advantage of local project collaborators. Following is a list of some types of educational activities have been used successfully in conjunction with research projects:

- Advance planning visits to project communities.
- Presentations about the research project to general audiences.
- Community meetings at the close of the field programs to provide a summary of activities.
- Local media presentations (*e.g.*, TV, radio).
- Engagement of local schools in projects, including presentations to local science classes.
- Video recording of projects for use in local media, community gatherings, and schools.
- Curricula-development projects based on the project science.
- Establishment of local science field-training programs with schools and educational authorities.
- Access programs designed to host local science trainees, Elders, or others at the investigator's institution.
- Collection-sharing programs that help build science data sets in local schools or return information from PI institutions to local communities.

- Exhibits illustrating the project's science.
- Publication of science reports in local and popular science journals or other media.
- Co-authorship opportunities for local collaborators, which may include the incorporation of traditional and local contemporary knowledge.
- Student-exchange programs between the research institutions and local communities.
- Engagement of a local person as the educational coordinator to develop programs that serve the interests of all parties.

Summary

HARC goals—and the long-term interests of scientists and northern communities—require that investigators and local groups work out collaborative programs supporting the conduct of specific science programs in the planning, research, and dissemination stages. These projects should address both local concerns and ARCSS scientific priorities, seeking to make a direct link between findings and policy.

The crucial need for the various forms of science education described here has been recognized at all levels of organization, from villages hosting research programs to Congress. The HARC initiative and its significant focus on education provide an important opportunity to support these goals.

Victor Ganyugin with the students in his Evenki culture class in Kholodnaya, Russia in August 1994. Ganyugin, a teacher in the village of Kholodnaya, runs an after-school and summer program in Evenki culture, mainly for boys. Students spend a fortnight learning to craft skis and backboards, herd reindeer, and track, hunt, and seal. Both Evenki and non-Evenki children take part in this class. The Evenki feel it is important for others to understand their culture, as non-natives often assume leadership postions that affect the Evenki (photograph by Gail Fondahl).

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Carl Hild, *M.S. Sci.Mgmt.*
Chair, HARC Science Steering Committee

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