Mem. Natl Inst. Polar Res., Spec. Issue, **51**, 7–24, 1996

Review

ENVIRONMENTAL RESEARCH IN ARCTIC CANADA: BRINGING GLOBAL AND LOCAL SCIENCE TOGETHER

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Abstract: Science in arctic regions is changing. Increased knowledge about the arctic environment and resources is not only valuable to arctic regions but is important for understanding of global changes and for international relations. People resident in the arctic increasingly have influences or control over research priorities. There in new emphasis in arctic research on climate change, environmental protection, the spread and effects of contaminants in ecosystems, management of living resources, northern health, indigenous cultures and rights. Arctic research increasingly draws on both disciplinary scientific knowledge, and the accumulated knowledge of indigenous societies; and is bringing together global, circumpolar, national and local interests.

Environmental research in arctic Canada is a dramatic example of these changes. Fundamental research in a wide variety of subjects is essential, and Canadians participate in many international research programmes in the arctic, but increasingly these are related to important social needs, and to policies for environmental protection or sustained economic development. An illustration of how multi-discipline researches, from basic to applied, can contribute to a common theme is the Mackenzie Basin Impact Study.

Support for science in arctic Canada comes from an increasing variety of sources. Progress is being made in co-ordinating research planning and facilities.

1. The New Importance of Arctic Regions in World Science

As the twentieth century draws to a close, the arctic regions are taking on a new importance in the world spectrum of scientific activities. Along with the increased importance, there has been a significant change in the scope, character and purpose of environment-related studies in the Arctic.

The distinctive environmental and geophysical characteristics and processes of the arctic regions, which until recently have been of scientific interest mainly in connection with the lure of commercial resources, the expression of the political or national goals of non-arctic governments, or the challenge of intellectual curiosity to understand natural phenomena and to learn about societies who have adapted to arctic environment, are now seen increasingly to be important, sometimes critical components in the knowledge that is urgently needed to address some of the most serious and pressing problems of humankind and the future of the Planet.

The critical role that arctic regions play in our understanding of the accelerated disturbances of physical and biological systems that we refer to as "Global Change" is described by Professor Weller in an accompanying paper in this symposium (Eddy *et al.*, 1988; Weller and Magnusson, 1994; Weller, 1995). The combination of natural and human-triggered influences, such as present and current changes in concentrations of greenhouse gases, alteration of land surfaces and changes in hydrological systems and erosion on a planetary scale, appear to have the possibility of altering regional heat balances and ocean circulation on both short-term and longer-term time scales. Climate models indicate that there may be a significant amplification of "greenhouse warming" in arctic regions within the next century (Canadian Climate Program Board, 1992; Ferguson, 1995); and coupled climate/ocean models suggest the possibility of significant changes in the thermal and chemical stability of the North Atlantic Ocean, triggered by events in the Arctic in the near future but with longer-term and eventually world-wide consequences (Aagaard and Carmack 1989; IPCC, 1990).

Although it cannot be stated with confidence that recent warming already observed in the Arctic is due to human-caused changes in greenhouse gases, the past decade has in many parts of arctic North America seen the highest mean annual temperatures and the highest average winter temperatures since meteorological observations began (Etkin and Agnew, 1992; Hengeveld, 1993).

If to these indications of possible impending environmental change we add the present evidence that:

- a large portion of the long-lasting industrial pollutants and toxic materials released to the environment from almost anywhere in the northern hemisphere or the tropics will eventually be carried to and deposited in the arctic regions (Rey, 1982);
- changes in biological diversity have a greater relative and absolute impact on the low-energy and comparatively simple arctic ecosystems than they do in the biologically richer lower latitudes;
- almost any modern human industrial activity in the Arctic requires more applied energy and thus is more of an "un-natural" disturbance of the environment and living systems than is the case for comparable activities in temperate regions;

--- it becomes apparent that what is happening in the arctic regions is very much a part of the environmental stresses and changes occurring in the world as a whole. To understand what may be happening to our planet, it is necessary to have knowledge of the changes taking place in arctic regions.

There is a further dimension to the world-wide importance of scientific research in the Arctic. Because of the low natural energy flux, in high latitudes physiographic and biochemical changes take place relatively slowly and, compared to most other regions, often in a simplified fashion, with cause and effect more apparent and accessible to study than they usually are in lower latitude regions (Woo and Gregor, 1992).

Arctic ecosystems are comparatively simple; food chains are short and uncluttered, so that the processes of nutrient and energy transfer and the mechanisms or constraints of ecological stability and response to change can be more easily observed or experimentally tested than is usually the case in the more complex environments of lower latitudes. The arctic regions are therefore of special value in providing opportunity to study the behaviour of the natural world under changing environmental conditions. Such studies provide information that is important to understanding the processes of environmental and ecological change in other parts of the world.

In a similar way, studies of the indigenous human societies of the North, which over many generations have evolved life styles, technologies and cultures that are closely tried to and adapted to the harsh and often changing conditions typical of a low-energy environment, can not only provide information necessary for understanding the effects of modern changes on northern peoples and their communities, but also can provide valuable lessons about social organizations, adaptation, and relationships to the natural environment that are applicable to all societies everywhere. These lessons are particularly pertinent at the present time, as humankind copes with the severe environmental changes and constraints on available natural resources that appear to be in store for all of us (BIRKES, 1992; PETERSON and JOHNSON, 1995). However, essential to the knowledge of northern societies and its application to problems and societies elsewhere is the active scientific participation of and research undertaken directly by indigenous people themselves (BROOKE, 1993; INGLIS, 1993).

It is for these reasons, plus the simple fact that in several fields of science some of the greatest areas of ignorance and some of the most important scientific intellectual challenges are found in the polar regions, that many countries, even during the present conditions of financial constraint and the need to confine their scientific endeavours to subjects of highest national priority, have maintained or increased their arctic research activities. Nearly every scientifically sophisticated country in the northern hemisphere, regardless of whether or not it has arctic national territories or a past tradition of arctic research, today is engaged in or is planning research in the Arctic (COMMISSION FOR SCIENTIFIC RESEARCH IN GREENLAND, 1992; IASC, 1995). The new research in the Arctic is increasingly multi-disciplinary, and increasingly focused on environmental issues or questions of the social and economic effects (STAGER, 1994). These reasons, and these changes in research priorities and research support, lie behind our meeting here at this symposium, and the many nations represented.

2. A Changing Perspective—Different Ways of Looking at Arctic Research

Most of the reasons for the recent increased importance of environmental research in the Arctic are because knowledge of the arctic environment is valuable to people who do not themselves live in the Arctic but whose livelihood, economies, or policies in non-arctic areas will be influenced by what happens in, or by what can be learned from, the arctic regions (ROOTS, 1993a). However, at the same time that the study of the Arctic is recognized to be of increasing importance to the issues and problems of the world as a whole, scientific knowledge of the arctic environment has assumed a new importance for the people who live in the Arctic itself. (Dr. WELLER and Dr. BREKKE are, I believe, the only persons at this conference who are year-round residents in the Arctic or sub-arctic, presenting scientific studies from institutions or programmes that are based in arctic or sub-arctic latitudes). Arctic residents are the people most affected by changes in the arctic environment. Whether arctic residents today follow a traditional subsistence way of life or one that is immersed in the commerce of a wage-dependent and professional society, —or if, as is increasingly the case, they manage to live a mixture of both—, their economic prosperity, living conditions, ability to express their cultures and pass on their spiritual values and social institutions to following generations are likely to be affected by environmental change, to a greater extent than the same changes will effect people living in lower latitudes (KASSI, 1993; ROOTS, 1993b).

Rapid changes in regional climate, physical changes in terrestrial or aquatic or marine habitats including land disturbance and changes in permafrost and drainage, changes in the availability of nutrients, widespread distribution of toxic materials, over-harvesting of wild species, and many other phenomena found in various combinations throughout the circumpolar North directly affect northern residents in ways that call for careful research and new environment-related knowledge. The kind of inter-related knowledge needed, by and large, has not been available from the mainly discipline-oriented arctic scientific investigations of the past.

In all countries surrounding the Arctic Ocean, indigenous peoples have achieved new political power in the last two decades, and have won the right to influence or in some instances to control arctic research. This change has put a new perspective on the need for, and priorities of, arctic environmental research.

A new arctic scientific community is emerging. It is one that is international or non-national, but also strongly focused on *local* arctic or northern issues and effects. At the same time, this new scientific community is involved in and dependent upon the research on world-wide issues such as global change, biological diversity, long-range transport of pollutants, etc., which have been and continue to be important subjects of the "classical" sciences in the Arctic. The current front-line research programmes in Global Change, ocean energy flux, and changes in high-latitude stratospheric chemistry are relevant both to global issues and local issues. How this emerging new scientific community and its interests will relate to the interests and activities of the established international arctic scientific community and its institutions will have much to do with the balance that can be achieved between three distinct ways of looking at arctic environmental research. These ways are:

(i) scientific activities carried out to increase knowledge or information *of* or *about* the arctic regions for economic, policy, or environmental objectives which are important to the country or region as a whole, or as an addition to basic world knowledge;

(ii) scientific activities carried out *within* the Arctic, but on subjects of broad or global interest, addressing subjects or problems important to the rest of the world or to the world as a whole. These may be considered to be the arctic component of global studies.

(iii) scientific activities that view the Arctic in its own right, and which are carried out *for*, or in *the interests of* the local or regional Arctic economy and the people who live in the Arctic, on subjects and priorities expressed by the peoples themselves.

These three approaches to arctic sciences, and the motivations behind them, lead to profound differences in the way that science and research is undertaken and supported. They result in differences in the way that the scientific problems are formulated, in who carries out the research, and in the use that is made of the new knowledge obtained through research. The relationship between these approaches has changed considerably in the past, as the motivation for arctic research has shifted from politically-supported exploration of unknown lands, best expressed in the seventeenth to nineteenth centuries, to the discovery and exploitation of commercial resources, (whales, gold, petroleum) to military rivalry and arctic geopolitics, and to environmental protection. The relationships are changing rapidly and profoundly at the present time, as scientific activities in the Arctic become on the one hand more closely integrated with world science, global processes and human issues everywhere, and on the other hand more directly connected to local arctic issues and problems (ROOTS *et al.*, 1987).

3. Environmental Research in Arctic Canada: Marriage or Dichotomy of Global and Local Issues?

From the first flowering of natural sciences on a global scale in the nineteenth century, the Canadian arctic has played an important part in world science. The researches of SABINE, ROSS and LEFROY in the early part of that century on gravity gradients, regional magnetism, aurora and the North Magnetic Pole established the Canadian Arctic as an important locale in the evolving science of the physics of the Earth (LEVERE, 1993), while prodigious biological collections and interpretations by RICHARDSON, DRUMMOND, HOOKER and others in arctic Canada played an essential role in the establishment of systematic science in botany, ornithology and taxonomy (RICHARDSON, 1829–37; HOOKER, 1840). Knowledge of the geology, land forms and physiographic processes in the arctic regions in general and of planetary structures and tectonics grew importantly from the scientific explorations in arctic Canada by SABINE, BELCHER, RICHARDSON, ROSS, and later nineteenth-century geologists (SUESS, 1904–24; CHRISTIE and KERR, 1981; WEBER and ROOTS, 1990).

By the time of the International Polar Year, 1881–82, which included three major and seven smaller expeditions to northern Canada (HEATHCOTE and ARMITAGE, 1959), natural science in all the major "classical" fields of investigation had been established in the Canadian Arctic, mainly by European scientific institutions. The International Polar Year, although devoted to the natural physical sciences, also was the occasion for the beginnings of systematic studies of the characteristics and cultures of arctic indigenous societies, by the German anthropologist Franz BOAS. BOAS' pioneering study of the Inuit of Baffin Island (BOAS, 1884) had an important influence in overturning the then prevailing Victorian assumptions that studies of different societies would prove the superiority of one society over another. His work advanced anthropology as an impartial and scholarly science throughout the world.

The scientific study of native people and their life styles in the Canadian Arctic continued to receive attention through the publicity and controversy surrounding the quasi-scientific work of STEFANSSON and the careful ethnographic studies of JENNESS in the first third of the twentieth century (JENNESS, 1926). Up until this time, all of the priorities for scientific studies in the Arctic were the priorities of institutions, governments and scientists in temperate latitudes. Although John ROSS in 1828–32 and Franz BOAS in 1882–84 had shown insight and sympathy with indigenous peoples, JENNESS was perhaps the first scientist in the Canadian arctic to consider that scientific research should also be undertaken to meet the expressed problems of northern peoples themselves, and to be publicly concerned with the need for conservation of the resources upon which northern people depend.

In the modern era, until quite recently, the needs and scientific priorities of non-arctic institutions and scientists have continued to dominate programmes and expenditures for arctic research in Canada.

The High Arctic Weather Stations, which evolved from a joint US–Canada response to the need for meteorological data for military and transpolar aviation and thus to become part of the world meteorological network, became sites for geophysical observations and bases for geological and biological studies. The Polar Continental Shelf Project, started in 1958 as a means to facilitate and co-ordinate logistics support to a wide range of researches in the Canadian Arctic Islands and Arctic Ocean, remained for its first twenty years exclusively devoted to national—that is, southern Canada—scientific priorities (Hobson and Voyce, 1983). However, increasing political recognition that scientific research in the arctic also had a responsibility to arctic residents, especially in the environmental field, and increasing demands by arctic indigenous organizations that their people should have influence in scientific studies of their own region, began to change the nature of Canadian arctic science. In the late 1970's, the Northern Science Training Programme, a government fund to help support university research in the arctic, began publicly to give increasing emphasis to social, human, and environmental sciences, in particular research involving northern indigenous people (Savoie, 1985).

An important step in this direction was a symposium in 1981 supported jointly by the Association of Canadian Universities for Northern Studies, and the UNESCO Man and the Biosphere Programme on "Renewable Resources and the Economy of the North" (Freeman, 1981). In this symposium, spokespersons for northern people examined jointly with researchers from established institutions from all circumpolar countries the adequacy of scientific knowledge and the role and priorities of new research needed to address problems of the economy and well-being of societies and communities in the Arctic which were dependent on living resources which in turn were seen to be subject to human-caused environmental stresses.

Arctic science in Canada in the environmental field has continued to develop in a disjointed fashion. Important research contributes to global scientific issues and international programmes, and is part of the programmes and priorities of southern Canada and its scientific institutions, aimed at obtaining better knowledge of arctic phenomena, biology, people and resources. These studies are undertaken for the most part as an activity of science in general, and supported for academic, policy, and economic purposes. The listing of research projects supported by the Polar Continental Shelf Project for 1994, for example, shows 210 separate projects, undertaken by 170 principal researchers in the Canadian Arctic Archipelago, along the Arctic Ocean coast, and adjacent areas (Polar Continental Shelf Project, 1994). The studies can be listed in the following subject areas, which probably give a representative breakdown of the current proportionate divisions of research in Arctic Canada as a whole:—anthropology, 3; archaeology and history, 12; general biology, 27; botany, 14; marine biology, 6; zoology, 31; climatology and meteorology, 9; geological sciences, 46; geophysics, 8; glaciology, 3; hydrology, 8; limnology, 8; oceanography, 2; hydrography, 1; sea ice studies, 2; multidisciplinary studies, 12; general studies (including pollution, land use, new technologies), 18. The main objectives of these researches can be seen to support the first two categories of arctic science mentioned above, namely, studies to increase knowledge about the arctic regions for reasons or purposes that important to science in general or the country as a whole. A comparatively smaller, but important and growing, body of environmental and social research responds to the expressed needs of northern residents: the third category.

Fundamental research in a wide range of disciplines is very important in the Canadian arctic. Some of the best-known Canadian arctic research includes studies of the chemistry of the high-latitude stratosphere and ionosphere at the Upper Air Chemistry Laboratory at Alert, NWT, (Lat. 84°N), the most northerly research laboratory in the world and one of the best equipped anywhere for studies in this subject. There is a sophisticated new mountain-top observatory at Eureka, NWT (Lat. 80°N) dedicated to studies of stratospheric ozone; and special experiments of arctic seasonal phenomena such as the "Polar Sunrise Experiment" that investigates changes in the polar atmosphere consequent upon the return of sunlight in the spring after prolonged winter darkness. Other studies relate to the palaeohistoric record of climate and atmospheric deposition in ice cores, peat, stream deltas and lake or sea-bottom sediments. Researches such as these provide information necessary for understanding of the processes of climate change, far-travelled pollution, etc., and their effects on the environment. Such basic research is valuable on a global basis as well as important to the Arctic. Still other researches, such as those of genetic DNA differentiation in different populations of circumpolar arctic fishes and their likely palaeohistory start with a need to understand fundamental processes of biological evolution, but have led to information that is important for fisheries management (TAYLOR and DODSON, 1994). Some unique data-gathering projects, such as the migration of radio-tagged arctic whales, caribou, or polar bears, are providing new information on the ranges and behaviour of familiar yet scientifically poorly known species and their vulnerability or response to environmental changes and human-caused disturbances (PCSP 1994). Several other typical studies in the Canadian Arctic of environmental problems of interest to non-arctic scientists are described in papers and posters at this conference. Virtually all of these researches are of the first two types of arctic research noted earlier. They are studies about the arctic regions undertaken to add to world scientific knowledge, or studies carried out in the arctic regions as the arctic component of a world-wide scientific issue. Such studies are for the most part perceived and formulated by scientists whose intellectual background is that of the temperate regions, and often who do not themselves live in the Arctic.

The increasing emphasis on a "local benefit" component in Canadian arctic research can be seen in the incorporation of social or human studies in the Canadian contribution to several international programmes in which, in the programmes of other countries, the biophysical and human or social science studies tend to be carried out independently. Canada was among the first countries to include studies of social responses to environmental change in the International Geosphere-Biosphere Programme from the beginning (SUTTER, 1990), and to urge the development or inclusion of the Human Dimensions of Global Change as component of, rather than a supplement to, the biophysical Global Change Programme (ROYAL SOCIETY OF CANADA, 1994). This recognition of the need to combine human and biophysical sciences to produce an integrated understanding of changes in the geosphere and biosphere and their human dimensions, resources, and feedbacks was the theme of the first major publication of the Canadian Global Change programme, "Planet Under Stress", which gave due attention to the polar regions (MUNGALL and MCLAREN, 1990).

The Canadian Global Change Programme has integrated human and social research with research in the natural sciences (CGCP, 1994). Each of the IGBP core programmes in the Canadian Arctic—the studies of Global Change in Terrestrial Ecosystems (GCTE), Past Global Changes (PAGES), Land-Ocean Interactions in the Coastal zone (LOICZ), and Biological Aspects of the Hydrological Cycle (BAHC)—has a specific "human" component as justification for its support and relevance. The central mission of the Canadian Global Change Programme is to generate new scientific knowledge not only for its own sake but for "**Promoting informed action through sound advice on global change**" (Royal Society of Canada, 1994; Roots and Stenbaek, 1994).

In addition to the Global Change studies, several other international environment-related researches in arctic Canada have begun to involve northern people in problem formulation as well as the execution of the research, and are endeavouring to obtain local northern support by showing how the results of the research will affect the ability to recognize and understand the implications that possible changes in the northern environment may have on the future economies and life styles of northern residents. An example is the International Tundra Experiment (ITEX) of the UNESCO Man and the Biosphere (MAB) programme, in which ten countries are participating in a comparative study of selected widely distributed arctic plants to slightly elevated ambient temperatures or CO_2 levels to assess their likely response to possible future warming of the arctic climate (Molau, 1992–95). A change in the composition of the plant community, or the timing, duration or vigour of the vegetative cover will have profound effects on all living resources in the arctic, and thus on humans. (Professor Svoboda, a leader of the Canadian component of ITEX, is at this symposium). Another example of an international collaborative environmental research with direct relevance to the future well-being of arctic communities is the Boreal Ecosystem and Atmosphere Study (BOREAS) where a combination of local-based, airborne and satellite sensors and surveillance are investigating the balance of trace gas exchange between the atmosphere, wetlands and vegetation across the border zone between boreal forest and tundra to determine not only the response of these critical areas to environmental change, but also the role that such regions may play in initiating and determining the course of climate change and the future productivity of boreal vegetation and ecosystems (Sayn-Wittgenstein, 1993; Stewart, 1994; Sellers, *et al.*, 1995).

The changes in the natural environment of northern regions that may occur in the next few decades could have a profound effect on biological productivity and on northern ecosystems (Roots, 1982; Riewe and Oakes, 1994; Hom, 1995; Gunn, 1995; Ono, 1995). These changes will have the most direct consequences for northern residents and especially indigenous people who depend for their livelihood and cultural values on a close relationship with the present natural systems (Kassi, 1990; Roots, 1993a), but who, in addition to having to cope with natural environmental changes, are beset with social, economic and imported "environmental value" changes (Wenzel, 1995). Thus there is good incentive for northern people to take part directly in these researches, and they bring to the science a knowledge base and depth of observation that can be provided in no other way.

Studies of the direct effect of far-travelled pollutants from non-arctic areas on arctic human residents and in wildlife are among the best-known and from a policy perspective among the most important of current environmental researches in Arctic Canada. Toxic organochlorides and other persistent chemicals released to the environment from industrial processes or agriculture in the mid-latitudes or the tropics get carried by atmospheric currents to the Canadian Arctic (Barrie *et al.*, 1992) where, being soluble in animal fat, they become incorporated in the arctic food chain (Lockhart *et al.*, 1992; Muir *et al.*, 1992; Thomas *et al.*, 1992). At each link in the food chain, the concentration of contaminants may increase by several orders of magnitude. Humans and mammal predators at the top of the food chains, whose diet includes large quantities of fat from animals in the local ecosystem, thus may accumulate in their bodies serious amounts of toxics released to the environment half a world away. Though their mothers' milk, arctic humans, bears, wolves and whales pass the contamination in even more concentrated form to their offspring (Kinloch *et al.*, 1992). Here is a global environmental problem that is of intense local concern in the Canadian Arctic (Roots, 1993a).

These kinds of problems integrate social, health and policy sciences in arctic environmental research (Roots, 1990b). The study of these problems requires full participation of social scientists and researchers in policy and management fields as well as those in the natural sciences and medical sciences. It has, however, been very difficult to establish high-quality front-line research in the Arctic involving social scientists. The funds available for support of human and social science research on Global Change themes are less than those for the natural sciences, and the programmes and peer review procedures remain dominated by natural scientists.

4. The Mackenzie Basin Impact Study:- An Example of Integrated Research

An interesting and important example in Canada of multi-disciplinary arctic research and of the evolution of the difficult art of bringing together biophysical research, social, human and medial sciences, economic and applied operational studies together to address a common problem of potential environmental change in the Arctic is the Mackenzie Basin Impact Study (Cohen, 1994, 1995a).

The Mackenzie Basin Impact Study (MBIS) is a comprehensive, multi-subject research project launched in 1991 to assess the potential impacts of postulated global warming and associated environmental changes on a large Arctic watershed and all its inhabitants. Existing climatic, hydrological, biological and resources data are being applied to three widely-used international global circulation models to prepare slightly different scenarios of future environmental conditions based on the same information; these scenarios in turn are used in field studies to examine processes of environmental change and explore possible impacts on hydrology, land stability and land uses, vegetation, wildlife, living resources, the economics of exploiting non-renewable resources, stresses on the social structure and needs for community planning and infrastructure affecting a variety of cultures in a large region that includes boreal forest, tundra, extensive wetlands and freshwater lakes, arctic deltas and coastlines.

The study has required the planning and coordination of more than 50 separate projects in the physical, biological, social, economic and managerial sciences; and it involves the scientific perceptions and participation of indigenous people and their communities.

The MBIS is still under way, and is moving from the scenario formulation and initial data collection phase to an assessment of preliminary findings and identification of linkages between environmental changes and their ecological or socio-economic impacts. Innovative techniques for cross-disciplinary environmental resource accounting and assessment of change are being developed and tested. It is hoped that knowledge of the likely linkages between specific changes in the physical environment and biosystems and their plausible socio-economic consequences in sub-arctic and arctic areas, as identified through scientific study and perceived by the northern residents themselves, will help to determine the kinds of data and the understanding of natural and social processes that will be needed if useful policies, incentives or opportunities to change social practices, and investments are to be made to enable the region cope successfully with environmental changes that appear to be in store.

Some of the major areas of research in the MBIS include:-

- the inter-relationships, in policy-related terms, of the impacts of different model-driven scenarios of the hypothetical global warming in the real-life Mackenzie Basin on
  --- water management;
  --- the sustainability and resilience of boreal and arctic ecosystems;
  --- locally based economic activities, and economic development based on export of resources or services to non-arctic economies.

Other studies or groups of studies involve:-

- researches into options for planning, adaptation, or financing of the social and institutional infrastructures to accommodate the changed environment and resources (town planning, transportation networks, schools);
- the sustainability of indigenous life-styles and cultures under conditions of rapid environmental change, and the options for residents under rapidly changing conditions.

Individual studies within MBIS have investigated the likely impacts of climate change in selected environmental categories, which then can be combined to explore their social and economic consequences. For example, studies of the effect of global circulation model climate predictions on the regional hydrology includes predictions of changes in river flow, on the stability of permafrost, wetlands, and the storage and turnover in large lakes. It has been found for example that under some plausible conditions the higher winter temperatures and increased precipitation predicted with climate warming will lead to a decrease, not an increase of run-off, because of a longer snow-free period and greater evapotranspiration. These kinds of potential changes are then "followed" to investigate possible practical consequences for river transportation, water supply, etc. For example, the operation of hydroelectric facilities in major north-flowing river systems subject to ice conditions may be affected in complex ways.

Studies of land areas underlain by permafrost suggest that the response to climate change may be very sensitive to topography. Steep slopes may respond immediately to climate variations, while peat lands may lag far behind and be relics of past climates. River deltas may have erratic responses. Almost all scenarios predict increases of coastal erosion (SOLOMON *et al.*, 1993; SOLOMON, 1994).

Studies of sub-arctic and arctic vegetation show that the boreal forest of today is the result of interplay between the direct response of plants to temperature, moisture, and sunlight conditions, the stresses caused by insects and parasites, and the conditions that lead to fires. Changes in climate will not only lead to changes in the growth and species mix of the plant communities but to changes in the distribution, life cycle timing and effectiveness of insects and parasites, and of the conditions favouring forest fires. These three major determinants of the condition of the boreal forest and the forest-tundra ecotone will be effected in different ways, and at different rates, by a given pattern of climate change, and thus the net effect on the forest may be complex (JOHNSON, 1992; LANDÄHUSER and WEIN, 1993; SPITTLEHOUSE and SIEBEN, 1994). Similarly, the effect of the timing of the development of insect larvae, changes in soil microbiota in the thaw layer on permafrost, variations in the onset of growth of tundra vegetation, or of aquatic invertebrates may have a controlling influence on the ability of migratory birds to cope with climate change (GRATTO-TREVOR, 1994).

The indicated or postulated environmental impacts in turn are applied to models of resource and environmental accounting, transportation, etc., in order to estimate the possible future economic impact of climate change on the Mackenzie drainage basin. Such estimates must take into consideration the peoples' perceptions of past environmental events and their concern over future changes. The response by an individual resident or family, by the community, or the policy response by the authorities to changes in natural conditions is in many cases more of a social or cultural reaction to extreme events such as a flood or drought than to the physical and biological effects of changes in climatic averages or trends in weather or water conditions. Studies to date have shown that different small communities in the Mackenzie Basin have had quite different collective responses to environmental stresses in the past, such as floods, forest fires, landslides, winters without snow, or delayed ice break-up. Different communities have shown different degrees of self-sufficiency or of dependency on government policies or outside assistance. The reasons for these differences are being investigated.

Interim reports of each of these studies, with voluminous references, are presented in COHEN (1994). It is apparent that the integration of the goals and results of such a wide variety of researches on a common problem, and the development of effective management and communications techniques between researchers of diverse backgrounds, are research problems in themselves (COHEN, 1995b).

The Mackenzie Basin Impact Study, and other studies of a similar nature under way or being planned in northern Canada, (RUSSELL, 1993; USHER, 1995) represent a new style of environmental research in the Canadian North. With its different components rooted firmly in rigorous sciences of the classical disciplines, making use of new technologies of remote sensing, mathematical simulation modelling and genetics, but dependent also on traditional ecological knowledge accumulated by those who have lived in the area for generations, these new studies are moving openly from the arms-length so-called objective approach of science to incorporate issues of social behaviour, economics and policy. They are exploring new ground in bringing together the environmental and human sciences in an attempt to apply scientific research to major environmental problems facing the arctic region. They are also bringing global science and local science together.

5. The Capacity for Undertaking Arctic Science

Scientific studies in arctic Canada or on arctic or polar subjects are undertaken in 26 Canadian universities, eight federal government departments, agencies of two territorial and five provincial governments, and a wide range of resource, service, transport and communications and technology development industries. Some indigenous, environmental and professional organizations also carry out selected, but important, research in northern Canada (Roots *et al.*, 1987; Roots, 1994a). Support for these activities comes from a wide variety of sources. There is no dominant Canadian funding source for arctic research. Important co-ordination in a practical sense is provided by two arctic-wide science logistic support systems:- the Polar Continental Shelf Project, which supplies field support but not funding to a variety of studies by a wide range of researchers and institutions in arctic areas including the Arctic Ocean, that are distant from northern settlements, and the High Arctic Weather Stations, which in addition to their primary function of obtaining meteorological information can provide modest but vital support to field studies from fixed bases in the Arctic Archipelago. With the increasingly difficult financial restrictions faced by all government scientific bodes, these sources of support and the few research laboratories situated in the Canadian arctic are facing serious difficulties (Stager, 1994).

Co-ordination in planning of research and communication in discussion of research priorities, especially in assessing needs and possibilities for bringing together social and physical sciences, and involving northern residents and their special areas of knowledge, as well as for addressing issues of global-importance and local importance in arctic research, is not as well developed in Canada as most would like. However, co-ordination and science planning is facilitated by a number of Canadian institutions that are important to arctic research. These include the Canadian Polar Commission, an agency established under authority of the Canadian Parliament, to "monitor and assess the state of polar scientific knowledge in Canada and circumpolar regions and to foster development of knowledge about the polar regions in Canada" (Canadian Polar Commission, 1994); the Association of Canadian Universities for Northern Studies (Northline, 1995); the Northern Sciences Training Programmes sponsored by the Department of Indian Affairs and Northern Development to facilitate northern research in Canadian universities; and the Arctic Institute of North America, now attached to the University of Calgary. The Canadian Polar Commission, in particular, has a responsibility to facilitate and encourage the involvement of indigenous people and their knowledge in arctic research (Canadian Polar Commission, 1993).

As is happening in many countries, the facilities and support structures for arctic research are changing in Canada. Not only are the scientific priorities changing, with the progress of science itself and the growth of a more direct connection between the findings of research and the use made of new scientific knowledge in social, economic. and policy decisions in arctic and northern Canada, but the number of agencies and authorities interested in some aspects of arctic science is widening. The importance and need for arctic research is increasing as an arctic component in high-priority world-wide or planetary studies. Basic research, comprehensive data gathering and interpretation, and development of new environmental monitoring technologies are increasingly seen as necessary to provide the information and knowledge needed to address regional issues of environmental protection (AEPS, 1993), or to meet urgent social and economic development in the light of environmental, social, economic and political change (SAMSTAG, 1993). Because in many areas relevant to arctic issues and study, the sciences have developed to the point where highly sophisticated research and technical monitoring is needed, as well as because of the escalating logistics costs, arctic science is becoming increasingly expensive, in comparison with research in lower latitudes. At the same time, Canada, in common with many other countries, is faced with severe financial constraints and has at least in part responded by curtailing its budget for fundamental science and long-term environmental monitoring, especially in those areas, such as the Arctic, in which the activities are most expensive.

Environmental research in arctic Canada is thus facing a dilemma not unusual in science in the 1990's, but one that is especially serious in the Arctic and the polar regions. This dilemma may have long-term effects not only for Canada but for the world. At a time when arctic environmental research is recognized to be of great importance not only for the future well-being of arctic regions themselves but for the world as a whole—for understanding the likelihood and effects of climate change, alteration of chemistry of the stratosphere, effects of stressed and disrupted ecosystems, controls and consequences of long-travelled pollutants, responses of societies and human value systems to changes in environment and resources, and many other environmental issues that are critically apparent or most clearly studied in arctic regions—, the capacity to undertake scientific studies is arctic regions is declining or threatened. In such a situation, international co-operation is more vital than ever. Such co-operation is being addressed through various mechanisms, such as the Arctic Environmental Protection Strategy (AEPS, 1993), the UNESCO MAB Northern Sciences Network (ROOTS, 1994b), the International Arctic Sciences Committee (IASC, 1995) and others. But progress is these areas still depends, fundamentally, on the willingness and ability of each nation to recognize the importance of, and to support, research and long-term environmental monitoring in arctic regions.

6. The Influence of Arctic Research on Policies and Expectations

There is one aspect of the new and broader importance of arctic environmental research that has become apparent during the Mackenzie Basin Impact Study and other recent arctic studies, such as the Global Change researches, that should be borne in mind by researchers from all countries who are working in the Arctic today. This is the fact that the scientific researches themselves may have a strong influence on the public and policy expectations of what science can do. Nearly all scientists, and scientific institutions have been accustomed to explaining to the authorities that their studies are relevant to some recognized national need or problem. They have had to do this, to obtain support for their work. But when the research itself, especially in the environmental field, directly involves a wide range of local people, and when it addresses practical or perceived future problems that the people themselves have helped to describe, those people naturally expect the research to lead to positive and practical results. As the environmental research in the Arctic directly involves social, economic and cultural issues as well as the physical and biological sciences, it is more than ever essential that the results of the research, and follow-up action, be available to, and in a form that can be understood by, those who took part. The researchers, wherever their home institution may be, have an obligation not only to produce new information that is scientifically sound, but also realistic and useful, in social, economic or cultural terms. The Mackenzie Basin Impact Study has shown the importance of broad participation by all communities and cultures in environmental studies of the affected region. But it also has shown that the research community has a responsibility to develop the communication and two-way education that can spread awareness of the seriousness of the changes that may occur in the future, without raising false hopes that science will somehow have a magic cure for the problems. Other studies of the arctic environment and its changes will, to an increasing extent, be expected to respond in the same way (Peterson and Johnson, 1995b).

The days when a scientist could go unobtrusively to the Arctic, study it, and return without affecting it, are gone. If there ever was a scientific "ivory tower" in the Arctic regions, that tower has turned out be a common iceberg, mostly below the water, and has drifted away, overturned, or melted.

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(Received October 30, 1995; Accepted May 10, 1996)