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Introduction: Biology of the Canadian Arctic: A Crucible for Change in the 21st Century[1]

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Canada is a northern country. Whether defined in terms of geography, climate, culture, or political boundaries, the North is an integral part of Canadian national identity and a strategic component of the country's future (Coates, 1995). Often defined as the half of the landmass and water that lies above the line of discontinuous permafrost, extending from northern British Columbia to Labrador, this vast region is home to only 1% of the human population in Canada. However, many other species are endemic to the North and many more seasonal migrants depend on northern environments for a significant part of their life history. The Canadian North, and indeed the entire circumpolar region, is a sensitive environment, facing rapid and unprecedented social, biophysical, and environmental changes.

Several long-term, persistent, and pervasive changes are affecting northern environments simultaneously. Global climate change, ozone depletion, long-distance transport of contaminants, and rapid economic development have placed undue stress on terrestrial, freshwater and marine ecosystems. These stressors may have a wide range of ecologically significant effects on populations that will cascade upwards to affect the integrity of entire communities. World demand for energy supplies has increased interest in Canada's northern oil and gas fields with the resultant prospect of a pipeline snaking down the Mackenzie River becoming ever closer to reality. The Canadian North is also the world's third largest producer of diamonds, and mining for these precious stones now accounts for 20% of the Northwest Territories economic activity (McDonald, 2004). At the same time, new governance realities are being shaped by the settlement of aboriginal land claims and devolution of federal government responsibilities to the territories.

These stressors and changes are a great cause of concern for aboriginal peoples as their health is affected by the consumption of country foods and their culture is linked to their desire to maintain traditional livelihoods. Nevertheless, much of the Canadian North is still in a natural, relatively undisturbed state, where most wildlife species are intact in terms of population abundance, distribution, and movement, and their habitats are relatively undisturbed. Ensuring a sustainable future for northern people and wildlife requires that ecosystems remain healthy and do not become progressively fragmented and degraded by local developments or global changes. It is also evident that an understanding of the biology and ecology of northern species and ecosystems is incomplete, and that alterations to the distribution, abundance, and behavior of species and their northern habitats will profoundly change the Arctic as we now know it. The current state of knowledge will be most comprehensively reviewed in the upcoming Arctic Climate Impact Assessment, currently being prepared by the Arctic Council (http://www.arctic-council.org).

Our Symposium focused on the adaptations of northern organisms and their predicted responses to changing environmental conditions, particularly terrestrial wildlife and habitats, with particular emphasis on climate change impacts, transboundary pollutants, and ecosystem dynamics. Our premise was that northern species and environments are sensitive indicators of the thresholds of adaptation to stress in natural systems and that their survival is a crucible for understanding change in the 21st century.

BACKGROUND TO THE SYMPOSIUM

Studies of the biology of northern Canada were dominated by faunal and botanical inventories until the 1950s, when an explosion of detailed experimental research and long-term monitoring programs were initiated (Clarke, 1954; Roots, 1996). While many individual scientists have made life-long commitments to northern research, their curiosity was often sustained and facilitated by collaborative, high profile, well funded, ambitious and imaginative research programs. Some of these early efforts included Operation Hazen (1950s) on Ellesmere Island, the Icefield Ranges Research Project (1960s) in the St. Elias Mountains, and projects associated with the International Biological Programme (1964 to 1975), such as the Char Lake Project (Rigler, 1972) and studies of tundra ecology (Bliss *et al.*, 1973), among many others.

The potential effects of climate change and industrial development on northern environments were clearly recognized four decades ago (Bliss, 1970). Economic interests, such as the Mackenzie Valley Pipeline proposals in the 1970s, provided the impetus for many environmental studies and served as the basis for later efforts, such as investigations of the potential effects of climate warming and cumulative effects dur-

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ing the Mackenzie Basin Impact Study of the 1990s (Cohen, 1997).

Concerns about the management and conservation of northern wildlife have also been the focus of many studies and reports. For example, the Task Force on Northern Conservation (1984) was a joint federal-territorial effort to develop a framework for creating a conservation policy and strategy that recognized the need for balance among conflicting values and endeavors: protecting the environment; the traditional pursuits of hunting, trapping and fishing; the sustainability of communities; and the impacts of large industrial developments. Conservation and development plans in the north have consistently recognized the need for improving capacity to generate knowledge through science and research in order to provide the necessary information to implement social, economic, and environmental strategies (*e.g.*, RWED, 2000).

Biologists in Canada have met on several occasions to discuss research priorities in the north. There have been repeated calls to provide mechanisms to ensure the collection of long-term data on the ecology of northern environments, recognizing that ''there is no way to avoid laborious observations and experiments in the field'' (Hustich, 1977, p. V-3). Rather consistently however, as noted by Osburn (1977), a succinct summary of most of these conferences and meetings would likely discuss the following: an overall lack of detailed ecological and environmental information; the need to develop an effective environmental data storage and retrieval system; the harshness or fragility of the environment; the urgent need for comprehensive, systematic or holistic planning, and interdisciplinary or team research approach; the high cost of research; and a need for cooperation and integration at all levels including international efforts.

Occasionally, there has been progress towards integrated approaches to northern research in Canada. In November 1987, a conference on ''The Canadian Arctic Islands: Canada's Missing Dimension'' (Harington, 1990), provided a forum for earth scientists, biologists, anthropologists, and others to discuss research in Northern Canada. Fred Roots noted in his closing remarks, that ''research in the Arctic Islands is changing in many ways that reflects, and in some cases leads, the changes in Canadian science as a whole.'' It is increasingly true that successful research in the north must bring together scientists from many disciplines and a variety of stakeholders, including representatives from Aboriginal groups, industry, colleges and institutes, as well as municipal, territorial, provincial and federal governments. It is also true that there is a growing supply of high quality, enthusiastic young scientists ready to take up the challenge of northern research, especially in multi-disciplinary areas. But sadly, there has been little sustained support for this work in the long-term (England, 2000; Hik and Kraft Sloan, 2004). Efforts to change the existing state of affairs to allow for a sustained and revitalized approach to northern science and knowledge are underway, but have thus far been unsuccessful. Our Symposium represented an attempt to help renew the collective capacity required to sustain research interests in northern Canada.

THE SYMPOSIUM

Many papers presented at the Symposium (see abstracts in Integrative and Comparative Biology 42(6)) and in this volume reflect current priorities in northern terrestrial zoological research in Canada, focused on understanding the adaptations of organisms to changing northern environments. This understanding is timely, as parts of the western Arctic have already experienced a warming trend of 2–4°C over the past 40 years. There is evidence that this warming has lowered lake levels, thawed permafrost, increased the frequency and severity of landslides and forest fires, altered the trajectories of vegetation succession, and altered the availability of resources to support wildlife populations (Roots, 1989; Hik, 2001). However, the overall implications of climate warming and associated changes in precipitation patterns are still largely unknown for most animals (Hofgaard *et al.*, 1999).

Unique adaptations of northern species have allowed them to cope with both the severity and unpredictability of extreme northern environments. Danks reviewed the range of insect dormancy responses and modification of adverse conditions by arctic insects, particularly through seasonal adaptations. Boonstra reviewed the role of the stress axis in birds and mammals and its role in determining how species cope with changing northern conditions. Though the degree of plasticity of the hypothalamic-pituitary-adrenal axis is poorly understood, increasing evidence suggests that these physiological responses may ultimately influence population dynamics (Boonstra *et al.*, 1998). More directly measured are the impacts of climate warming on habitat suitability. Polar bears are dependent on sea ice for their survival, and may have limited options for adapting to changing conditions. In this context, Derocher *et al.* outlined a number of threats to populations of polar bears in the Arctic. Other species may have more options for adapting to climate change. This possibility was addressed by Humphries *et al.* who used a number of experimental and modeling approaches, based on bioenergetics, to predict effects of climate warming on the distribution of northern mammals. Martin and Wiebe summarized empirical data to assess and compare the coping mechanisms of alpine and arctic breeding birds to extreme weather conditions, which may increase in frequency with climate warming. Franken and Hik presented long-term results examining the influence of variation in winter and spring conditions on the timing of parturition and growth of collared pikas (*Ochotona collaris*) in the Yukon, a species living at the limit of the distribution of resident mammals in northern mountains. Berteaux *et al.* discussed the results of a long-term study of parturition dates of red squirrels to determine the balance between phenotypic plasticity, which allows an

organism to cope with short-term environmental change, and microevolution, which is essential for the persistence of populations faced with long-term directional changes.

A number of emerging areas of concern were also addressed, stressing the urgency for obtaining better and more complete information about northern species and ecosystems. Kutz *et al.* discussed emerging parasitic infections in Arctic ungulates, and showed that caribou and muskoxen may be at risk of becoming hosts for new species of parasites through population translocations, increasing population densities, and climate warming influences on larval development. Vincent demonstrated the vulnerability of high arctic freshwater systems to relatively small changes in climate, leading in some cases to sudden ecosystem collapse (Mueller *et al.*, 2003). Henry reported on the latest results of long-term research at Alexandra Fiord, Ellesmere Island (Svoboda and Freedman, 1994), focusing on experimental warming of high arctic tundra ecosystems. He showed that responses vary by species and habitat-type and that there are strong feedbacks on soil processes, herbivores and the atmosphere. Muir discussed spatial and temporal trends of contaminants in Arctic marine environments (Muir *et al.*, 2000), emphasizing the strong regional variation in different types of contaminants, and the threats they pose to wildlife populations and humans living in the Arctic. For example, whereas PCBs and total DDT decreased in female ringed seal blubber in the western Canadian Arctic between 1972 and 2001, new compounds, such as brominated diphenyl ether flame retardants, have increased dramatically. Hebert discussed the genetic structure of freshwater and marine species in the north and the opportunities to use new technologies to document their genetic diversity and vulnerability to changing climate regimes (Hebert *et al.*, 2003).

Several studies focused on ecosystem-level responses to disturbance and change, and focused on assessments of trophic dynamics using long-term studies. Gauthier *et al.* presented a detailed assessment of trophic interactions in a colony of greater snow geese on Bylot Island, emphasizing the role of predation in a multi-prey system. Jefferies *et al.* provided an overview of the influence of agricultural practices in the southern U.S. on large-scale disturbances to intertidal and freshwater marshes along the Arctic coast by lesser snow geese. Events occurring thousands of miles away clearly have a profound influence on the dynamics of Arctic environments. Russell *et al.* provided a comprehensive overview of factors influencing the dynamics of all of the tundra caribou herds in North America. They related these factors to synoptic models of precipitation and temperature in the Arctic, with the objective of conducting energetic modeling to project herd-specific impacts of climate change and development (Russell *et al.*, 2000).

Finally, Hutchinson provided an overview of the progress of northern research in Canada and compared the current state of affairs to the recommendations arising from the Final Report of the Task Force on Northern Research (2000), commissioned by the two key federal granting agencies: the Natural Sciences and Engineering Research Council (NSERC) and the Social Sciences and Humanities Research Council (SSHRC). The conclusion of the taskforce report was that Canadian northern research was indeed in crisis, and that urgent action was needed to meet Canada's domestic and international science and research obligations in order to contribute to issues of global importance. As noted above, this was not the first time such observations have been made. The specific recommendations of the taskforce called for the creation of northern research chairs, increased support for graduate and postdoctoral students, dedicated funding for northern research projects, including equipment, infrastructure and logistics, and funding for building partnerships between researchers and northern communities.

At the time of our Symposium, the backbone of Canadian Arctic logistic operations provided by the Canadian government, the Polar Continental Shelf Project (PCSP), was under threat of closure. Over forty scientists in attendance signed a letter to the Prime Minister, calling for the government to recognize a renewed commitment to northern research and development (see Spurgeon, 2003). In response, in the February 2003 budget new funding was provided for PCSP and for NSERC and SSHRC to enhance northern research. However, as of April 2004, many of the challenges facing the northern research community in Canada remain—federal spending on northern research has increased marginally, but remains at similar levels to the 1970s, and decaying research infrastructure is in desperate need of upgrading; the absence of a national northern research policy or strategy reduces opportunities for collaboration and results in fragmentation of research efforts; northern communities are unable to adequately address issues that are of great importance to their future; and finally, Canada's voice on the world stage is diminished, in a place where the country should play a leading role. This last point was especially apparent in the difficulty of organizing a coordinated Canadian effort for participating in and leading research themes for the International Polar Year in 2007–08 (see Albert, 2004).

Despite these challenges, the papers in this Symposium provided evidence that there is a strong Canadian contingent of northern biologists who care passionately for this part of the country and its future. Recent funding announcements for a new Network of Centres of Excellence focused on the Canadian Arctic coast (ArcticNet—http://www.arcticnet.ulaval.ca), a variety of new funding opportunities from the national granting councils, and a renewed focus by the federal government on a range of northern issues, will help to address some of the problems we have identified. Most importantly, everyone at the Symposium agreed that these meetings must occur more regularly! We would like to thank all of the speakers and audience members

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