The Beijer Institute of Ecological Economics

DISCUSSION PAPER

Beijer Discussion Paper Series No. 191

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Building Resilience and Adaptation to Manage Arctic Change

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As the Earth undergoes unprecedented changes resulting directly or indirectly from human actions (*1-3*), those fragments that remain relatively intact become increasingly influenced by their more human-modified surroundings and gradually lose the internal feedbacks and interactions that are important to sustaining their integrity. The Arctic may be one of the last remaining opportunities to plan for change in a spatially extensive region where many of the ancestral ecological and social processes and feedbacks are still intact. We argue that this requires proactive management of the dynamics of change to sustain those attributes that are important to society (resilience) and to develop new social-ecological configurations that function effectively under new conditions (adaptation). If the feasibility of this strategy can be demonstrated in the Arctic, our improved understanding of the dynamics of change can be applied to regions with greater human modification. We describe the major drivers of arctic change and present a framework for designing and implementing policies that enhance both resilience and adaptation in the Arctic.

Rapid warming has substantial human impacts in the Arctic (*4*), in contrast to other regions where land-cover change is the major driver of change in human wellbeing (*5*). Climate warming in the southern Arctic and northern boreal forest thaws permafrost (which destabilizes infrastructure and alters hydrology), increases fire frequency and insect outbreaks (which alters land-cover), decreases glacial and sea ice extents (which amplify warming trends), and increases coastal erosion (as sea level rises and reduced sea ice increases the energy of storm surges) (*4*, *6*, *7*).

Projected arctic warming will lead to many ecological and societal surprises due to interactions with other high-latitude changes, including nitrogen and mercury deposition from pollution, accumulation of persistent organic pollutants from agricultural pesticides, increased UV-B radiation caused by industrial production of chlorofluorocarbons, and globalization of economic controls over extractive industries (mining, petroleum, and hydropower) that are the mainstay of arctic economies (*8*, *9*). Most of these arctic changes result from altered human activities outside the Arctic, making it difficult for arctic peoples to influence these trajectories. Political uncertainty in Russia is an additional source of potential arctic surprises. We assert that policies should be designed to address expected changes within a resilience framework that facilitates coping with surprises (*10, 11*).

Many dominant arctic plant and animal taxa (e.g., willows, mosquitoes, and caribou) are continental or pan-arctic in distribution and span broad environmental gradients, so their persistence may be robust, if gene flow is more rapid than environmental change. The long-lived (clonal) nature of many widespread plant species has facilitated their survival of previous climatic changes (*8, 12*). Dominant species determine many of the properties and services provided by ecosystems, so, if the current dominant species remain abundant, arctic ecosystems might be relatively resilient to climatic change. High frequency of wind pollination and self-compatible breeding systems also provide a flexible genetic framework for rapid evolutionary adaptation to change. Many widespread arctic animals exhibit synchronous outbreak or cyclic behavior. These species might evolve quickly if rapid changes occur during population bottlenecks.

The very characteristics that make arctic organisms resilient to *environmental* change could make them vulnerable to *biotic* changes, such as the potential for rapid spread of non-arctic predators and diseases among widespread abundant organisms. Synchronous population cyclicity among animals increases the likelihood of local extinctions and therefore perhaps the successful establishment of more southerly taxa, as climate warms. Slow growth and low fecundity of arctic plants similarly constrain their ability to compete with aggressive southern species (*8*). Indigenous hunters and western scientists have already observed non-arctic species of fish, birds, insects and diseases in the Arctic (*13*). Abrupt changes, such as the thawing of permafrost, melting of sea ice, or the relaxation of thermal thresholds that previously prevented migration of southern species, place the Arctic on the cusp of potentially irreversible changes that could lead to fundamentally new ecosystem states. Changes in state are particularly likely to occur at ecological boundaries such as sea ice margins, coastal margins, latitudinal treeline, and the zone of discontinuous permafrost, where complex habitat mosaics are common and strongly influenced by disturbance and management. These are the locations where resilience management is most critical.

Near-continuous ice cover has protected the Arctic Ocean from the human over-exploitation that has occurred in all other oceans. Informed planning could develop a flexible zoning of the Arctic Ocean to accommodate needs for shipping lanes, co-managed fishing areas for local residents, and networks of fully protected marine reserves to maintain biodiversity, provide nursery stocks for adjacent fished areas, and serve as insurance against mismanagement outside the reserves. As ice cover declines in a warming climate, with associated ecological, social, and economic shifts, the optimal zoning will change, requiring adaptive governance based on both current and expected future states of the Arctic Ocean (*14*). Potential future risks to the Arctic Ocean include disruption of marine ecosystems through oil pollution, trawling, introduction of exotic species from ballast water discharge, over-exploitation of fisheries, and development of sensitive coastal habitats. These social and ecological causes and consequences have been observed so consistently in every other ocean that policy implementation in the Arctic is more a question of finding innovative institutional solutions than of scientific uncertainty about whether these changes might occur.

A unique feature of the Arctic is the diversity of indigenous cultures that are still largely intact, despite transition to a mixed cash-subsistence economy (*15*). Traditionally, arctic Indigenous Peoples were quite flexible in the resources harvested because of large seasonal and interannual fluctuations in food abundance. Most arctic communities, regardless of ethnic background, still acquire a large proportion of their food from natural ecosystems (*5*). Sharing through kinship networks that link office workers with subsistence hunters adds to this societal resilience in a fluctuating environment. Even within the cash sector of the economy, many people change jobs frequently or have several part-time jobs rather than specializing in a single profession. Strong cultural ties to terrestrial and marine ecosystem services, combined with diversity and flexibility in ways of earning a living are often viewed as maladaptive in a highly specialized western society, but these arctic characteristics may provide a source of resilience to sustain societally important attributes at times of change. There are, however, limits to this resilience. In the past, people migrated in response to climatic fluctuations, but these options are now constrained by costly infrastructure, land tenure status, and national citizenship. Education and learning about new ecological, social, and economic environments will be essential to successful adaptation.

Given that some arctic warming is inevitable due to inertia in the climate system, what can and should policy makers do in response? Some changes are unavoidable and will occur no matter what action is taken. For unavoidable ecological changes, adaptation is the only possible policy response. One potential response is to design policies in a manner that supports income levels of people in arctic regions and eliminates or at least slows migration into and out of the Arctic. Unlike other countries in marginal environments, all arctic nations (except Russia during the past decade) have the wealth to provide substantial subsidies to guide arctic development.

The manner in which economic support is provided to arctic regions is important. Subsidies to production in traditional sectors that have been adversely affected by climate change or other non-arctic changes reduce incentives for those living in the Arctic to adapt to these changes and to diversify their economic activities. A better alternative is to give economic support in a way that explicitly encourages diversity and entrepreneurship. Policies fostering economic diversification in the Arctic would enhance resilience because it is unlikely that all economic activities would be equally sensitive to any given change in the natural environment or in economic and political conditions. An example of such a policy would be financial support for economic activities that are new in the Arctic. There is good economic justification for giving such support: The knowledge gained by the entrepreneurs in such activities will typically be advantageous not only to themselves, but also to others who are considering investing in such areas. Such knowledge spillovers are typically most important in early phases of new economic activities, suggesting a well-defined time limit for such support. Strict time limits facilitate continued adaptation as the types of activities supported change over time. Careful attention should be paid to possible ecological impacts before a novel economic activity is supported in the Arctic.

Government actions at the local-to-regional scale can also be important. Investment in arctic education and infrastructure increases the capacity of arctic peoples to diversify their economy and explore other options that enhance resilience. Local stakeholders should participate in these decisions, so options selected are consistent with local goals and norms. Policies that retain some of the rents (taxes, royalties, etc.) of arctic industries at the local level provide additional resilience, if these rents are designated for long-term capacity-building rather than short-term goals.

In contrast to unavoidable ecological changes, some potential ecological changes can be avoided, or at least postponed or mitigated. Most obviously, the type and magnitude of ecological changes associated with climate warming depend on the rate of climate change, which is strongly affected by future trajectories of greenhouse gas emissions. Arctic nations account for about 40% of global CO_2 emissions, so national policies regarding carbon emissions, particularly by the largest emitters, such as the U.S., significantly affect future climate development. The large potential impacts of climate warming on arctic regions should be considered when arctic countries set their goals for greenhouse gas emissions. Reducing the rate of arctic warming is also globally beneficial because of the positive feedbacks of arctic processes to global climate warming (*4*).

Coordinated policies among the arctic countries could influence economic activities in the Arctic in ways that avoid or mitigate some potential ecological changes. For example, we recommend that now, while the Arctic Ocean is still ice-covered and relatively inaccessible, it be designated as a Marine Protected Area (MPA) to be managed for conservation and other goals. This arctic MPA should be zoned for specific uses, and a sizeable fraction of its area should be in fully protected reserves. In order to plan for both resilience and adaptation, we further propose that the Arctic Council, which has representation from all arctic nations, including Indigenous Peoples, address the following tasks:

1. Survey and identify the most important irreversible changes expected in ecosystems due to regional and global changes.
2. Find out whether it is possible to prevent or mitigate these changes if society acts now before the changes occur.
3. Make an economic cost-benefit analysis of whether it is worth preventing or mitigating these changes.
4. Propose coordinated policies for arctic countries to prevent, postpone or mitigate ecological changes, whenever it is worth it.
5. Facilitate adaptation to change where prevention, postponement, and mitigation are not economically viable.

Considerable progress has already been made in addressing these tasks. Many of the institutions required to enhance arctic resilience and adaptation (e.g., the Arctic Council) are in place. The Arctic Climate Impact Assessment and the Arctic Human Development Report have just completed thorough assessments of climatic, ecological, social, and economic changes in the Arctic (*4, 15*). The next step is to determine which of the undesirable changes can be prevented by prompt action and to proceed with cost-benefit analyses. For those changes that are unavoidable, such as thaw of permafrost and melting of sea ice, policies should be formulated now that will promote adaptive change to the new conditions.

The global community has a vested interest in enhancing arctic resilience. The Arctic is biologically connected to the rest of the world through annual migrations of whales, fish, and birds and human demographic responses to economic booms and crashes. Arctic petroleum and minerals are economically and strategically important to arctic nations. Polar regions are also the cooling system for planet Earth and the major store of non-marine water frozen in ice caps and glaciers. As the climate and environment of the Arctic change, so will the climate and ocean systems that influence people throughout the globe. Development of sound policies that influence arctic change is therefore required. Perhaps more importantly, if policies can be designed to enhance arctic resilience, this will provide a framework for addressing the resilience of other regions that are more directly impacted by human actions.

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