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REPORT IN BRIEF

Frontiers in Understanding Climate Change and Polar Ecosystems

Climate change is already causing observable impacts on many polar ecosystems, but the complexity of the systems and the fact that they are subject to multiple stressors makes the prediction of future environmental changes a challenge. Scientists at a National Research Council workshop identified five questions that could help researchers better understand the impacts of climate change on polar ecosystems.

Credit: Sean Bonnette/National Science Foundation

In recent years, scientists have found that the Earth's polar regions are particularly vulnerable to climate change. Observational data and climate models show that the poles have warmed at substantially higher rates than the global average. Growing evidence reveals that recent climate warming has already significantly changed terrestrial, freshwater, and marine ecosystems in polar regions, and as climate continues to warm, scientists expect these impacts to increase. However, the inherent complexity of ecosystems makes predicting future environmental impacts a challenge. Understanding future ecosystem change will require a multi-faceted approach to determine the links between different components of the system.

An ecosystem is a system of living organisms (plants, animals, and microorganisms) interacting with each other and their physical environment, for example the air, soil, water, rocks, and sunlight.*

* IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

To investigate the steps needed to gain a better understanding of effects of climate change on polar ecosystems, the Polar Research Board of the National Research Council organized an August 2010 workshop that brought together scientists with expertise in Arctic, Antarctic, marine, and terrestrial environments. Workshop participants considered accomplishments in the field to date and identified gaps in knowledge and emerging research questions. These discussions allowed participants to identify opportunities for progress toward a greater understanding of changing polar ecosystems. The participants identified five questions that will lead to new frontiers of knowledge about climate change and polar ecosystem response.

The Frontier Questions

1. ***Will a rapidly shrinking cryosphere (the frozen portion of Earth's surface) tip polar ecosystems into new states?***

Although it is already known that polar regions are warming faster than any other area of the globe, workshop participants emphasized the need to understand what happens as the amount of frozen ground, snow pack, glacial ice, and

sea-ice at both poles begins to shrink in response to warming. For example, as ice, glaciers, and permafrost melts, populations of some polar species may decline, thus reducing biodiversity and leading to the potential extinction of important keystone species.

Workshop participants also stressed the importance of studying links between climate change and impacts on Earth's processes in order to identify "tipping points"—critical thresholds where a small perturbation in climate could push the ecosystem from one state to another. If potential tipping points are known or can be anticipated, scientists may be able to develop strategies to minimize the impacts of climate change on ecosystem properties.

2. *What are the key polar ecosystem processes that will be the "first responders" to climate forcing?*

The many components of polar ecosystems are inextricably linked, and a disturbance to any part is likely to cause cascading effects throughout the entire system. Workshop participants discussed the importance of recognizing and quantifying the interactions between living organisms and their environments at all scales, rather than simply studying isolated ecosystem components, in order to accurately predict how ecosystems will change as polar regions warm (or in some cases, cool). For example, the melting of sea ice will significantly affect large mammals that utilize polar marine ecosystems as habitats (for example, walruses).

3. *What are the bi-directional gateways and feedbacks between the poles and the global climate system?*

Polar ecosystems have the potential to influence climate and ecosystems at lower latitudes. For example, the melting of polar snow and ice will decrease the amount of sunlight and heat reflected back into the atmosphere, which in turn will alter global circulation of the atmosphere and ocean. Workshop participants identified a number of processes and phenomena that may have such feedbacks to the global system, shown in Box 1.

4. *How is climate change altering biodiversity in polar regions and what will be the regional and global impacts?*

Because polar species have evolved in cold temperatures, the rapid warming of the Arctic and Antarctic has the potential to affect biodiversity. Warming could cause shifts in habitats and the availability of food, and if species are unable to cope with these conditions, their populations will decline and biodiversity could decrease.

For example, as climate warms the boreal forest of North America, species that were previously restricted to southern regions may move north, thus increasing species competition in the northern area for food and other essential resources, causing major ecosystem reorganization, and potentially leading to the extinction of certain species. Warmer climates could also increase the likelihood of forest fires or insect infestations, further threatening biodiversity.

In the Southern Ocean, which has been a cold and relatively stable marine habitat for at least 8 million years, many species may not be able to tolerate warming oceans. For example, Antarctic notothenoid fishes die at temperatures above 4 degrees Celsius. Consequently, even small changes in ocean temperatures will produce drastic effects on marine population dynamics at both poles.

Box 1. Feedbacks Between the Poles and the Global System

Sea Level Rise

The melting of the Greenland and Antarctic ice sheets would produce about seven and 61 meters of sea-level rise, respectively, with potentially catastrophic global impacts.

Ocean Circulation

The increase in freshwater input to the sea caused by melting ice could influence ocean circulation, which in turn affects global climate.

Biome Shifts and Migration Patterns

Species that migrate between high and low latitudes may be affected by changing polar ecosystem dynamics. For example, the rapid climate warming occurring in Alaska has increased the occurrence of forest fires and insect infestations, leading to drastic changes in forest ecosystems. This could change bird and mammal migration patterns with impacts on biodiversity.

The Albedo Effect

Albedo is a measure of the reflectivity of a surface. The albedo effect—changes in reflectivity due to variations in sea-ice and glacial-ice coverage, snow cover, and, in the Arctic, forest cover— is one of the reasons climate change is most keenly felt at the poles. Usually, the bright white snow-and-ice-covered landscape reflects most sunlight back into space before the sun's heat can be absorbed. But as climate warms, the snow and ice begin to melt, exposing the sea or land beneath. The darker-colored sea and land readily absorb sunlight, warming the landscape and causing even more snow and ice to melt.

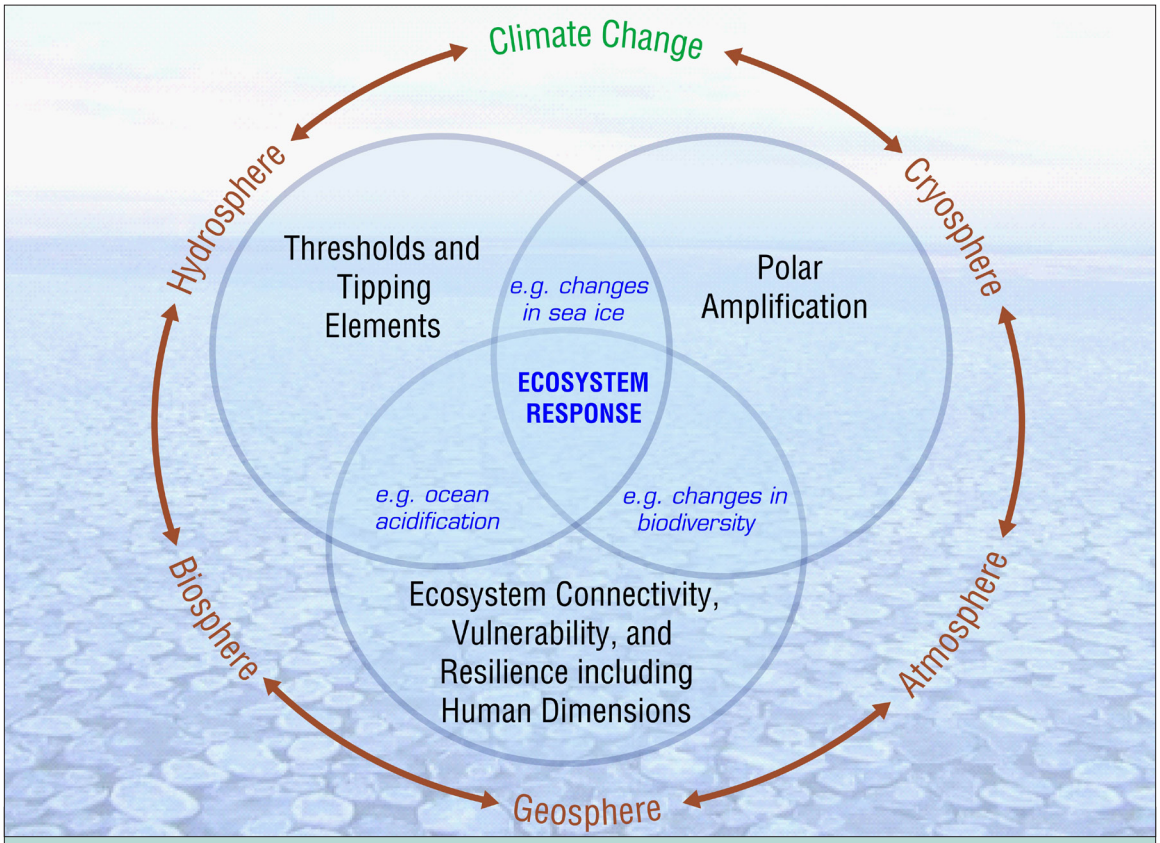
Case Study 1: Arctic Sea-ice Retreat and Walrus Relocation

Over the summer, female walruses migrate with their young to the Chukchi Sea between the United States and the Russian Far East. There, they forage for clams and worms that live in ocean sediments, using floating chunks of sea ice as resting platforms between dives. However, evidence from the United States Geological Survey and from Russian scientists indicates that sea ice coverage in the Chukchi Sea is shrinking, forcing tens of thousands of walruses to come ashore in Alaska and Russia. Because walruses must now travel further from land to reach prey fields, they are using more energy, leaving less energy available for growth. The evidence also suggests walruses will have a progressively harder time finding sea ice platforms, which is expected to have a negative impact on walrus populations.

Credit: K. Frey

5. How will increases in human activities intensify ecosystem impacts in the polar regions?

Access to polar regions has grown in recent years resulting in significant increases in human activity. For example, as the number of ice-free days in the Arctic climbs, shipping across northern routes is on the rise, industrial activity is increasing, and ecotourism cruises to both the Arctic and Antarctic are growing in popularity. The potential impacts of such human activities in polar regions include disturbances to wildlife, increased potential for oil spills, discharge of water and sewage from cruise



This figure illustrates the connectivity among the earth system components and climate change, including examples of changes that could drive an ecosystem response.

Case Study 2: Climate Variability in the McMurdo Dry Valleys

The McMurdo Dry Valleys region of Antarctica is a cold, arid polar desert. Since 1993, data on the region's plants, animals, soils, glaciers, streams and lakes have been collected as part of the National Science Foundation's Long-Term Ecological Research network.

Credit: J. C. Priscu

Meteorological data gathered over the course of the project have shown that climate in the McMurdo Dry Valleys is highly variable and is tightly linked to the Southern Annular Mode, a change in the flow of polar air currents liked due to the depletion of the ozone layer.

Summer temperatures that approach the freezing point are important for the McMurdo Dry Valleys ecosystem. As glacier ice melts, it provides liquid water to surrounding soil, streams, and lakes. However, from 1986 to 2000, summer temperatures in the McMurdo Dry Valleys cooled by about 0.7 degrees Celsius per decade. The cooler summer temperatures caused layers of permanent lake ice to thicken, reducing the amount to light available for the growth of photosynthetic plankton that serve as food for other species. In addition, cooler temperatures also reduced the flow of glacial melt streams, reducing water and nutrient input to the lakes.

ships, as well as the potential for introducing invasive species and diseases into remote polar regions.

Looking to the Future

The rapid pace of change in high latitude systems makes polar ecosystems a fundamental concern for science and society. To begin to address these frontier questions, workshop participants discussed the need for a systems science approach to understanding the complexities of ecosystem responses to climate change. In addition, participants brainstormed ways to advance understanding of polar ecosystems and promote the next generation of polar research topics. These include developing new and emerging technologies, sustaining long-term observations, upgrading data synthesis and management, and fostering collaboration through data dissemination and outreach.

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Committee on the Frontiers in Understanding Climate Change and Polar Ecosystems: A Workshop: Jacqueline M. Grebmeier (*Co-chair*), University of Maryland, Solomons; **John C. Priscu** (*Co-chair*), Montana State University, Bozeman; **Rosanne D'Arrigo**, Lamont-Doherty Earth Observatory, Palisades, New York; **Hugh W. Ducklow**, Marine Biological Laboratory, Woods Hole, Massachusetts; **Craig Fleener**, Alaska Department of Fish and Game, Anchorage; **Karen E. Frey**, Clark University, Worcester, Massachusetts; **Cheryl Rosa**, U.S. Arctic Research Commission, Anchorage; **Martha McConnell** (*Study Director*), **Laurie Geller** (*Senior Program Officer*), **Lauren Brown** (*Research Associate*), **Amanda Purcell** (*Senior Program Assistant*), **National Research Council**.

The National Academies appointed the above committee of experts to address the specific task requested by the National Science Foundation, National Oceanic and Atmospheric Administration, and National Aeronautics and Space Administration. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.

For more information, contact the Polar Research Board at (202) 334-3479 or visit http://dels.nas.edu/prb. Copies of *Frontiers in Understanding Climate Change and Polar Ecosystems* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.