RACER

RAPID ASSESSMENT OF CIRCUM-ARCTIC ECOSYSTEM RESILIENCE

A TOOL FOR IDENTIFYING AND MAPPING LAND AND SEA FEATURES THAT SUPPORT ECOSYSTEM FUNCTIONING IN A CLIMATE-CHANGED ARCTIC

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Written and edited by Peter Christie and Martin Sommerkorn

Concept and Design by Daniel Lohnes (DOCUMENT)

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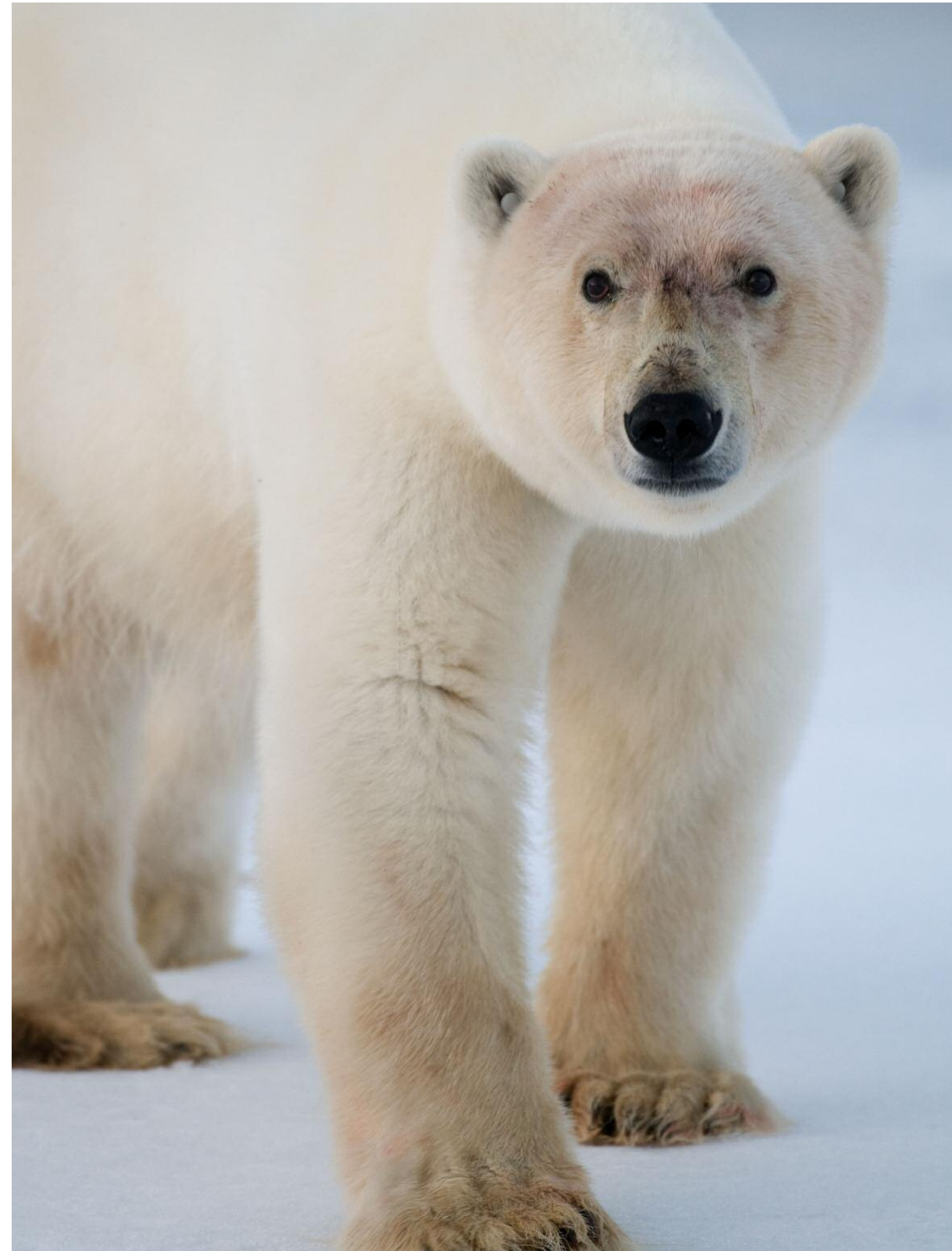

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EXECUTIVE SUMMARY

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RACER PRESENTS A NEW VIEW OF ARCTIC CONSERVATION THAT, PERHAPS FOR THE FIRST TIME, LOOKS AHEAD TO ANTICIPATE THE IMPACT OF CHANGE.

RECOGNIZING THAT CONSERVATION EFFORTS TARGETING THE VULNERABILITY OF ARCTIC HABITATS AND SPECIES ARE NOT KEEPING PACE WITH ACCELERATING CLIMATE CHANGE, RACER INSTEAD LOCATES SOURCES OF ECOLOGICAL STRENGTH.

WWF'S RAPID ASSESSMENT OF CIRCUM-ARCTIC ECOSYSTEM RESILIENCE (RACER) presents a new tool for identifying and mapping places of conservation importance throughout the Arctic.

Recognizing that conservation efforts targeting the *vulnerability* of arctic habitats and species are not keeping pace with accelerating climate change, RACER instead locates sources of ecological *strength*. RACER finds places that generate what scientists call ecosystem resilience to fortify the wider ecological regions in which these places are found. RACER then looks ahead to whether these wellsprings of resilience will persist in a climate-altered future.

The RACER method has two parts. The first part maps the *current location* of land or sea *features* (such as mountains, wetlands, polynyas, river deltas, etc.) that are home to exceptional growth of vegetation and animals (productivity) and varieties of living things and habitats (diversity). These *key features* are especially productive and diverse because the characteristics that make them up (e.g., the terrain of mountains or the outflow at river mouths) act as *drivers* of ecological vitality. The exceptional vitality of these key features–in the places where they are currently found–is what makes them local sources of resilience for the ecosystems and ecosystem services of their wider regions (*ecoregions*). The second part of RACER tests whether these key features will continue to provide region-wide resilience despite predicted climate-related changes to temperature, rain, snowfall, sea ice, and other environmental factors important to living systems. Changes to these climate variables affect the drivers of ecological vitality (which depend on these variables) at key features. RACER uses forecast changes to these climate variables to predict the future vitality of key features and the likely persistence of ecosystem resilience for arctic ecoregions through the remainder of this century.

RACER presents a new view of arctic conservation that, perhaps for the first time, looks ahead to anticipate the impact of change. The approach emphasizes the need to support ecosystems and ecosystem services important to people by addressing the *future capacity of these ecosystems to adapt* (in the face of rapid warming) rather than by responding only to what's *vulnerable now*.

This introductory handbook is intended as a general roadmap to the RACER method. It describes the RACER approach and its use of *the best available data as rapidly as possible* to create maps of arctic key features as targets for future conservation efforts. Two pilot case studies–representing early assessments of both a marine and a terrestrial arctic ecoregion–illustrate how RACER can be used to inform arctic planning and management decisions.

RACER's new method focuses conservation and management attention on the importance of minimizing environmental disturbance to places that are–and will be for the remainder of this century–sources of ecosystem resilience in the Arctic. In particular, RACER's ecosystem-based approach equips resource managers and conservationists with new targets for their efforts–managing not just our impact on species and habitats but on the combinations of geographical, climatic, and ecological characteristics that drive ecosystem functioning in the Far North. Identifying the sources of resilience for region-wide arctic ecosystems and nurturing them into the future may be the best hope for the survival of the Arctic's unique identity—including its habitats, plants, animals and the ecological services that northern people and cultures depend upon.

FOREWORD BY ROBERT W. CORELL

THE ARCTIC IS NOW EXPERIENCING some of the most rapid and severe climate changes on Earth. Forty years from today, average annual surface temperatures across the region are expected to be 5 degrees Celsius warmer than before the beginning of global industrialisation. Warming across the Arctic is expected to accelerate throughout this century, contributing to major physical, ecological, social and environmental changes.

ROBERT W. CORELL IS CHAIR OF THE ARCTIC CLIMATE IMPACT ASSESSMENT AND PRINCIPAL WITH THE GLOBAL ENVIRONMENT AND TECHNOLOGY FOUNDATION.

The area covered by summer sea ice is one-tenth smaller every ten years, and it is projected to be gone within decades. More than 90 per cent of the Arctic's near-surface permafrost is forecast to disappear by 2100. These and other signs of change are affecting arctic ecosystems–sometimes slowly, such as with the northward creep of the tree line, and other times more suddenly, such as with precipitous drops in the numbers of some caribou and wild reindeer herds. In several of these recent developments, the signature of man-made climate change is clear. In others, it is suspected.

Changes in the arctic climate will also affect the rest of the world. The Arctic plays a central role in the Earth's climate system and affects many globally important ecological resources, such as fisheries and migrating birds and mammals valued in the Arctic and beyond. Thus, in the decades ahead the arctic environment will become a bellwether of climate-related impacts, and people around the world will look to our response to arctic change for guidance in learning to adapt to climate changes elsewhere.

The governments and indigenous peoples of all arctic countries have expressed their deep concern about the pace and extent of these arctic changes and their impact on the natural world and on people. The Arctic Council's Nuuk Ministerial Declaration urges all parties to the United Nations Framework Convention on Climate Change to keep global average temperatures at less than 2 degrees Celsius above preindustrial levels.

Yet, even if the world's governments and peoples urgently cut greenhouse gas emissions today, the Arctic will still experience massive climate-driven changes for decades and even centuries to come. That is how long already-released greenhouse gases will remain in the atmosphere. This world of change is therefore inevitable; it is this world of change for which we must plan if we wish to conserve arctic ecological systems, including the services they provide to people.

WWF's RACER (Rapid Assessment of Circum-Arctic Ecosystem Resilience) project–described in the following pages–looks ahead to this climate-altered world. RACER provides a planning and conservation tool that recognizes and accommodates the inevitability of arctic change. In this way, RACER sets the stage for renewed discussions about where conservation efforts should focus and what these efforts should be. It anticipates the future to ensure the strength of ecosystems as they cope with climate change and to support arctic people for whom these ecosystems are integral to their identity.

RACER is designed to identify and provide measures of key ecological characteristics, such as productivity and diversity, that act as the fundamental "engines" of functioning ecosystems. Focusing conservation efforts on these engines should provide the means by which ecosystems and the people who depend on them can better adapt to changing conditions. It is an approach that looks to the future and accepts that we cannot and should not seek ways to maintain ecosystems in the form they are found now. Rather, RACER is designed to provide better means and ways to understand and forecast the change that is to come and to steer the fundamental engines of ecosystem functioning in ways that best serve the social and ecological systems that will thrive in those changed conditions. Thus, the RACER approach is designed to enhance our understanding of the resilience of ecological systems (and the services they provide to people) by identifying how climate change affects the drivers of these ecosystems. In this way, RACER seeks to understand the means by which arctic ecological systems can resist damage, recover, and/or evolve into new but viable states.

WWF is not the only organization to emphasize the importance of ecosystem strength rather than vulnerability in the face of change. The 2011 Arctic Council's Nuuk Ministerial Declaration commits the Council to further investigate how managing ecosystems (rather than single resources) can support the long-term viability of resources during change. The Declaration promotes and establishes programs and activities that focus on resilience and on an assessment of how integrating different drivers of arctic change can inform adaptation and mitigation. The RACER framework found in this document is designed to be a significant contribution to the Declaration's objectives and to the Council's developing approach.

Planning for resilience is a relatively new discipline, but in preparing this report, WWF has gathered together many of the foremost experts in resilience and arctic system science to advise the development of the methodology. WWF intends to continue to convene such experts from science and policy backgrounds and to draw on the experience and expertise of arctic indigenous peoples. In this way, RACER can apply and adapt its methodology to specific regional or local conditions in an effort to ensure that the change coming to the Arctic can be best managed for the benefit of both people and ecosystems. R.W.C.

INTRODUCTION

JAMES POKIAK'S VISIONS OF ARCTIC change have been subtle glimpses so far. The 57-year-old Inuvialuit hunter and guide says decades of rising global temperatures have brought warmer winters and windier summers to his Beaufort Sea coastal community of Tuktoyaktuk in Canada's Northwest Territories.

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But the fish, whales, caribou, bear, and other animals that Pokiak and his family depend upon for more than 90 per cent of their food and for many other goods do not appear to Pokiak to have been affected much–yet. "The animals are still out there," he says. Pokiak, who spent much of his adult life trapping on the land, is one of thousands of arctic residents whose intimacy with the Arctic represents not just a means of earning a livelihood and finding food but also a cultural link to generations of Inuit tradition: Pokiak was barely a teenager when he was taught to harpoon beluga whales in nearby Kugmallit Bay; his children learned the skill from him when they reached the same age.

The Mackenzie River Delta landscape around Tuktoyaktuk can be austere, but it is also flush with nutrients and rich with life. No single species is as important as the ecological vitality of the systems and biological interactions at work there. The vitality and interactions in these systems are what keep belugas and bowhead whales coming back for the ample herring and krill fed by clouds of plankton. Ashore, the same kinds of systems mark an ancient schedule for journeying caribou, moose, muskox and bear.

The changing climate is tied to these systems, too. Climate-affected shifts in temperature, rain, snow and ice can affect the ecological characteristics and processes that drive productivity and diversity. Small changes here or there can affect this ecological vitality and make ecosystems more susceptible to other environmental impacts.

The uneasy result is a world more vulnerable than Pokiak and his community are used to. Climate change may not have tipped any ecological balance yet. But Pokiak worries that other threats and continued warming may combine and accumulate: ecosystems stressed by climate are more at the mercy of the potential impact of industrial exploration and development.

"In a sense, as a people, from generation to generation, all the wildlife management and things like that have been automatic things that are done here," Pokiak explains. But the combination of environmental change and recent, growing interest in development mean "it's harder to know what's coming."

→ "IT'S HARDER TO KNOW WHAT'S COMING."

JAMES POKIAK, SUBSISTENCE HUNTER, GUIDE, AND AUTHOR, TUKTOYAKTUK, CANADA

THE IMPACTS OF THE PROJECTED ATMOSPHERIC AND OCEAN CHANGES IN THE 21ST CENTURY WILL TRANSFORM ARCTIC ENVIRONMENTS IN MANY PLACES.

INEVITABLE CHANGE

By the end of this century, the Arctic–one of the world's last and largest intact natural spaces–will be a very different place. Temperatures are warming more than twice as fast as they are for the planet as a whole. Sea ice is melting. Arctic wildlife and people are beginning to live altered lives.

These days, the question is not whether the Arctic will change; the question is whether this change will push plant, animal, and human systems beyond the brink–where gradual ecological shifts give way to sudden, unpredictable transformation, and our polar environments and communities become abruptly unrecognizable.

Many scientists now acknowledge that current approaches to conservation and natural resource management may not be enough to help important arctic regions avoid this threshold. Protecting weakened species populations or imperilled habitats remains important, but today's scale and pace of change requires safeguarding ecological strength, durability, and responsiveness to change: we need to identify ecosystems that are viable and providing services to people (e.g., harvests of mammals, fish, or other food) so we can support the characteristics and features that invigorate these systems and help them adapt in the future.

The complexity of arctic living systems makes it difficult to anticipate exactly how rapid change will affect biodiversity or any single resource. By emphasizing a more comprehensive ecosystem approach to conservation, RACER maximises the management options available for protecting the North and its unique ecological identity into the future. Given the rate at which we are racing to develop resources in the Arctic, time is also of the essence: we need scientific tools *now* that can help us to manage biodiversity and other natural resources and to support the ecosystem services important to the livelihoods and well-being of arctic people–even as we continue to deepen our comprehension of the complexity of arctic life.

A NEW WAY FORWARD

WWF's Rapid Assessment of Circum-Arctic Ecosystem Resilience (RACER) is an innovative scientific tool for answering the new conservation concerns facing the Arctic. For the first time in arctic systems, RACER combines scientific insights into ecology and climate to create a new, forward-looking, ecosystem-based approach to inform arctic management and planning.

In particular, RACER looks to the continued viability of arctic ecosystems–systems that include not just the functional interactions of organisms and their environment but also the important ecological services these systems provide to people. RACER identifies and maps landscape or sea features–such as mountains, ocean polynyas, river deltas, etc.–that are uniquely equipped to help each

FINDING IMPORTANT AREAS FOR ARCTIC CONSERVATION

Today's climate-affected Arctic poses increasing and unique challenges for conservation. The impacts of the projected atmospheric and ocean changes in the 21st century will transform arctic environments in many places. For instance, sea ice will be increasingly absent in summer, and more permanently frozen ground will thaw across the tundra. Ironically, warming is caused mainly by human activities thousands of kilometres to the south, but the impacts are most rapid and severe in polar regions; this means mitigating change is often beyond local or regional control.

A number of global organizations and initiatives have looked at ways of identifying ecologically important areas in the Arctic. Many of these highlight areas described as vulnerable or sensitive. Their focus is to respond to threats now and to restore ecosystems to the status quo. Few of these efforts consider or give priority to criteria of ecological importance that would prepare for the inevitable changes to come.

More recently, a growing frustration with the limitations of the current approaches has encouraged others to explore ways to adopt ecological resilience as a necessary concept to prepare for future change and to think ahead when considering arctic conservation. Committees of the Arctic Council, for example, have begun to turn their attention to the benefits of ecosystem-based management to better understand and manage the range

WWF RESEARCHERS IN COOPERATION WITH TEAMS OF GLOBAL EXPERTS DEVELOPED RACER AS A GUIDE FOR ARCTIC CONSERVATION THAT ANTICIPATES CHANGE THROUGH THE REMAINDER OF THIS CLIMATE-AFFECTED CENTURY.

of the 50 regional arctic ecosystems avoid the threshold where these functional interactions and services are abruptly transformed. These *key features* (as RACER describes them) help ecoregions steer clear of this unknown through their exceptional contributions to the viability of the larger regional ecosystems to which they belong–even as the climate continues to shift throughout this century.

Raising awareness of the location of key features is important not because they are in trouble but, on the contrary, because they are region-wide sources of ecological strength and durability. This fortitude comes from the exceptional local performance of two main engines responsible for ecosystem functioning. One engine, *productivity*, is the ability of local food webs to capture and pass on energy from the sun. Productivity plays a key role in supporting the vigour of ecosystems to encourage the growth of more and readily harvestable living things to furnish people with harvestable food and other ecosystem services. The other engine is biological *diversity*; larger numbers of different kinds of life and habitats help complex ecosystems respond and adapt to environmental change while remaining largely intact. RACER uses the word *vitality* to describe the overall effect of each or both of these two engines.

Features for which these engines are working especially well now–and into a climate-affected future–are critical because they help the wider ecological regions in which they occur respond to change. That's because the exceptional productivity or diversity (or both) found at these key features can be said to equip their entire surrounding region–through region-wide functional relationships between living things and their environment–with a quality that fortifies the ecosystem against risks that change will bring unexpected transformations.

Scientists call this quality *resilience*, and it means ecosystems that benefit from local sources of exceptional productivity and diversity are likely better than others at enduring environmental shocks and surprises. They can adapt to outside pressures and disturbances without radically altering their identity or the way they function–even if the kinds of plants and animals within these ecosystems may change. Resilience, in other words, means living systems can adjust to change–they can *adapt*–to bounce back from environmental shocks or to take advantage of new ecological opportunities.

Locating features that are naturally equipped to support regional ecosystem resilience–features that combine physical and ecological characteristics to drive exceptional productivity and diversity–is a critical first step toward planning for rapid change. Recognizing and encouraging what makes these key features work and remain ecologically vital guards both natural values in the Arctic and the important ecosystem contributions to the well-being of people in the Arctic and elsewhere on the planet.

FINDING IMPORTANT AREAS FOR ARCTIC CONSERVATION (CONTINUED FROM PREVIOUS PAGE)

of new pressures facing arctic life. Many environmental organizations–such as the International Union for the Conservation of Nature, the Natural Resources Defense Council, and others–are adopting a similar tactic, highlighting the benefits of an ecosystem approach to management.

WWF has been grappling to find a forward-looking approach to arctic conservation since the inception of its Global Arctic Programme (GAP) in 1992. The programme, which consolidates the earlier work of WWF organizations in seven arctic countries, recognizes that conservation in the fast-changing North is unlikely to succeed without a new way. In August 2009, the WWF Arctic Conservation Principles outlined the organization's internal blueprint for action which anticipates change and plans for the conservation of ecosystems and wildlife in ways that increase their chances for their survival.

WWF researchers in cooperation with teams of global experts developed RACER as a guide for arctic conservation that anticipates change through the remainder of this climate-affected century. RACER allows WWF in partnership with agencies and organisations to look to the future rather than to the present or past to better safeguard the identity of arctic ecosystems and circumpolar wildlife as well as northern communities and cultures.

RESILIENCE MEANS ECOSYSTEMS THAT BENEFIT FROM LOCAL SOURCES OF EXCEPTIONAL PRODUCTIVITY AND DIVERSITY ARE LIKELY BETTER THAN OTHERS AT ENDURING ENVIRONMENTAL SHOCKS AND SURPRISES.

A STRATEGIC, FUNCTIONAL APPROACH

RACER signals a new way forward for natural resource management and conservation in the Arctic. The approach highlights the conservation importance of the characteristics of key features (e.g., the terrain of mountains or the open water of polynyas) that act as *drivers* of exceptional productivity and diversity where these features are found. These drivers of local ecological vitality are at the heart of continued ecoregional resilience and provide new and essential targets for conservation.

RACER's new view encourages a functional rather than descriptive understanding of the arctic landscape and seas, and it is an important first step in management efforts that look to the ecological underpinnings of arctic life–and its benefits to people–to help ensure its continued survival into the next century. RACER relies on internationally recognized computer climate models to predict the regional impact of arctic warming through to 2100 and uses these to generate scenarios reflecting the future viability of arctic ecosystems. The approach directs conservation efforts at the basic elements that keep ecosystems functioning, supplying the hope of survival for their many arctic plants and animals during climate change.

The RACER assessment of ecosystem resilience includes consideration of ecosystem services to people. Ecosystem services are nature's contributions to the well-being of people and include such things as hunting and fishing, locally relevant cultural practices, and globally important food harvests. RACER's inclusive definition of arctic ecosystems means the RACER assessments can, in turn, be used to inform similar evaluations of arctic social-ecological resilience. By identifying the key features behind the resilience of ecosystems, including ecosystem services, RACER can help reveal the appropriate conservation targets relevant to the management of human communities and systems.

THE RACER INTRODUCTORY HANDBOOK

This introductory handbook describes RACER's new approach. It provides both an outline of the RACER method and explains RACER's science and rationale for an ecosystem approach to arctic conservation. The handbook and the related, more-detailed material provided on the Web (www.panda.org/arctic/racer) are intended as a "toolkit" that will equip future efforts to identify and map key features–wellsprings of region-wide ecosystem resilience–for ecoregions throughout the circumpolar North. Their objective is to raise awareness of the importance of resilience for maintaining natural and ecological values and benefits throughout the Arctic in the face of rapid change.

The framework of the RACER method is explained in Chapter 2. The two parts of the RACER method–mapping and identifying key features that confer resilience to ecoregions, and assessing the likelihood the key features will continue as sources of resilience despite climate change–are described in detail in Chapters 3 and 4.

A case study example of a RACER assessment at sea is described in Chapter 5 for the Beaufort Continental Coast and Shelf ecoregion in northern Canada. Chapter 6 describes a terrestrial case study example, outlining a resilience assessment for the Eastern Chukotka ecoregion in eastern Russia. These chapters are intended to illustrate the application of the RACER method. They also identify key features, and offer results that provide an early look at how the RACER approach can inform spatial planning and management in the Arctic. The maps and descriptions of the key features are intended as a new starting point for discussions about the future of planning and conservation in the Beaufort Sea and the eastern reaches of the Chukotka Peninsula– even as continuing research continues to deliver results and as management decisions affect and refine the maps that reveal places of conservation importance.

Meanwhile, efforts continue to multiply WWF RACER assessments and to raise awareness about the most appropriate targets for conservation efforts across the remainder of the Arctic. For example, RACER assessments of key features in the ecoregions of the Central Canada tundra and Russia's Laptev Sea are being completed. Further RACER work in four ecoregions in Greenland–two on land and two in the sea–are expected to be complete by mid-2012. In Norway, assessments are underway in the two marine ecoregions of Northern Norway/Finnmark and the Norwegian Sea with results expected in early 2012.

However, the purpose of this handbook (and the more detailed Web materials) is to encourage the wider use and further development of the RACER method. RACER is not intended as an exclusive WWF tool. In fact, WWF will only succeed in achieving meaningful conservation goals for arctic ecosystems and peoples if RACER is widely adopted, discussed, and improved by agencies and organizations in the North.

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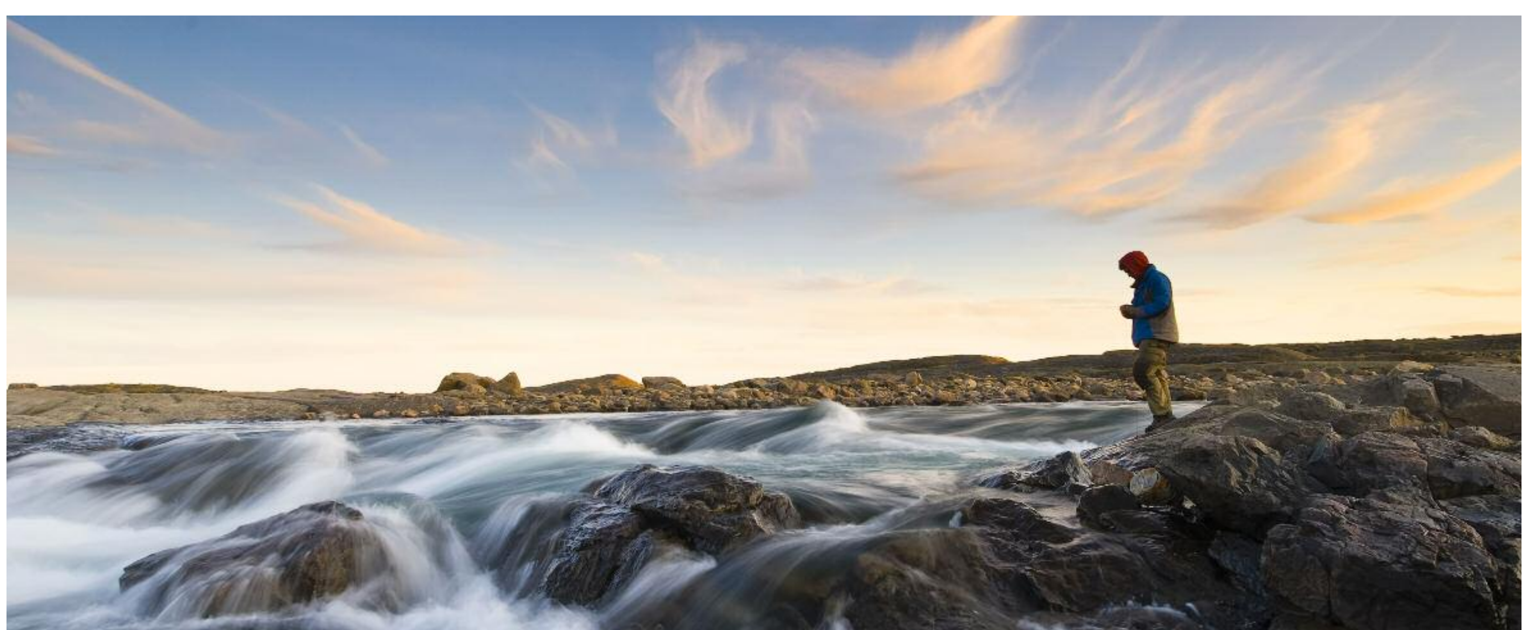

THIS INTRODUCTORY HANDBOOK PROVIDES BOTH AN OUTLINE OF THE RACER METHOD AND EXPLAINS RACER'S SCIENCE AND RATIONALE FOR AN ECOSYSTEM APPROACH TO ARCTIC CONSERVATION.

RESILIENCE AND CONSERVATION IN THE ARCTIC

THE ARCTIC IS NOT WHAT IT ONCE WAS. Change is at work in the region at a pace that rivals the life-altering climate effects of more than 10,000 years ago. Polar bears, ice-dependent whales, and scores of other arctic wildlife are witnessing their habitats transformed by a rate of warming that's already more than twice as fast as the global average.

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"RETURN TO PREVIOUS ARCTIC CONDITIONS IS UNLIKELY."

CONCLUDING STATEMENT OF THE 2010 ARCTIC REPORT CARD OF THE U.S. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION IN PARTNERSHIP WITH THE ARCTIC COUNCIL'S WORKING GROUPS CAFF AND AMAP.

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Sea ice is increasingly absent in summer. Ground that has remained frozen for millennia is thawing (Fig. 1.1 and Fig. 1.2; SWIPA 2011).

The accelerating change is also affecting hunting, fishing, ice travel, and other traditional practices by arctic peoples and cultures (IPCC 2007). So many physical, biological, and even social characteristics are being altered, it is difficult to know how, where, and when species and people may be affected. The result is a new uncertainty that is challenging how we think about managing and safeguarding the future of arctic life.

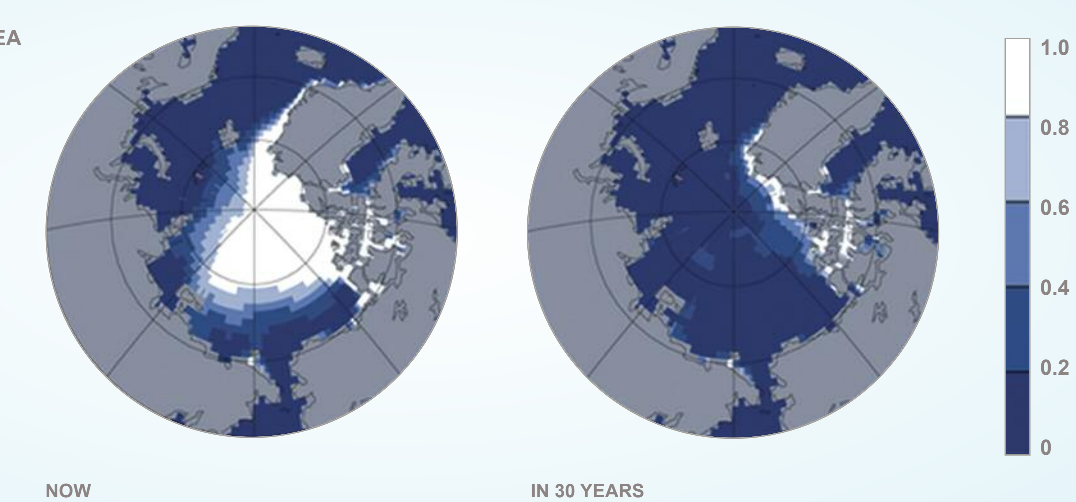
This uncertainty has global importance. The circumpolar Arctic–covering 14.8 million square kilometres of land and 13 million square kilometres of ocean (Fig. 1.3; CAFF 2007)–is among the planet's largest intact natural spaces. It is ecologically unique and has a disproportionately large role in the atmospheric and ocean systems that affect our global climate (ACIA 2004; WWF International Arctic Programme 2009; SWIPA 2011). It hosts ice sheets and glaciers and vast areas of tundra. The surrounding Arctic Ocean–the smallest of the world's five oceans–supports huge stretches of sea ice and multi-year pack ice that is unique in the world. The Arctic's extent touches eight circumpolar countries, including the United States, Canada, Russia, Norway, Sweden, Finland, Iceland, and Denmark (through Greenland).

50 DIVERSE ECOREGIONS

Fifty representative ecological regions, or ecoregions (Fig. 1.4 and 1.5; Spalding et al. 2007; CAVM Team 2003), are found within the boundaries of the circumpolar Arctic (as defined by the CAFF Working Group of the Arctic Council). These ecoregions are home to diverse biological communities and unique arrays of creatures, plants, and sea life superbly adapted to harsh conditions, dramatic seasonal shifts, and months of dark cold. With these adaptations also comes the high genetic diversity that characterizes arctic life (CAFF 2007). As many as 279 species of migratory birds–from places as far afield as New Zealand and southern Africa–travel to the Arctic to breed along with several land and marine mammals that also migrate to the food-rich North to raise young during the summer. Some arctic animals represent globally significant populations, including more than half of the world's shorebird species and 80 per cent of geese, several million reindeer and caribou (vital to human communities in the North), and 28 per cent of the world's commercial marine-fish harvest (CAFF 2007).

The cultural significance of the Arctic is also far-reaching. From as early as perhaps 45,000 years ago–long before they reached the Americas–people migrated to the top of north-eastern Asia and began settling there (Goebel et al. 2008). Rich, regionally distinctive cultures and communities became intimately connected

FIGURE 1.1
STATUS AND PROJECTION OF ARCTIC SUMMER SEA ICE AREA AND THICKNESS (in metres).
Source: Wang and Overland 2009.



THE MILDER ARCTIC AND ITS MORE ACCESSIBLE, MORE OPEN SEA ARE INCREASINGLY ATTRACTING DEVELOPMENT INTERESTS IN THE NORTH.

ECOSYSTEM RESILIENCE

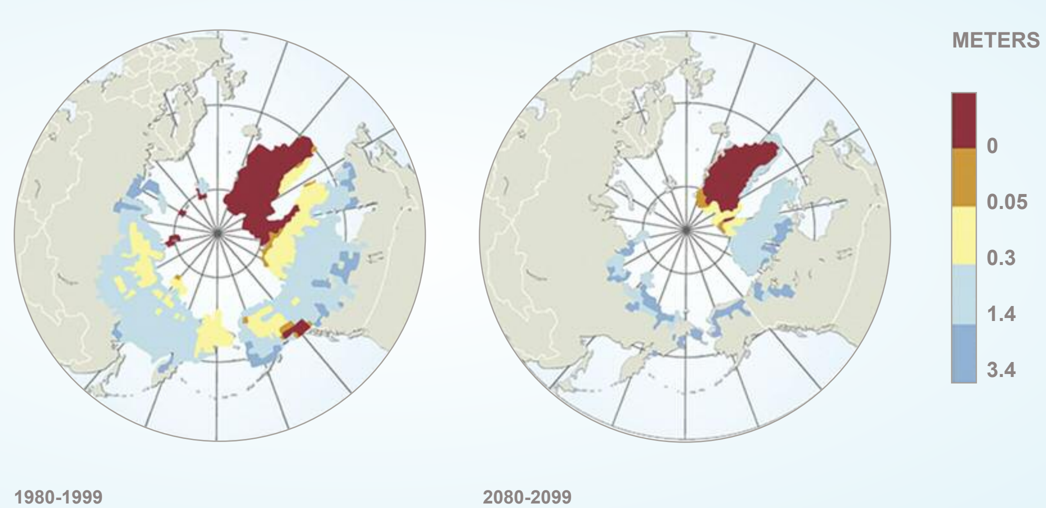
Many conservationists now acknowledge that an ecosystem approach is crucial for helping circumpolar habitats and wildlife, as well as traditional communities and cultures, adapt to their changed and changing environment (see, for example, Arctic Council 2004, 2011). This approach works to strengthen and support the functioning relationships that bind plants, animals, and other living things to their environment and to each other. It offers a functional view of conservation, on land or at sea, with a primary goal of preventing an abrupt failure of the ecosystems that the living things in these places depend upon.

In recent decades, the concept of ecological resilience has developed as an important theoretical foundation for conservation based on an ecosystem approach (Gunderson 2000). Resilience is described as the capacity of an ecosystem to absorb disturbance and reorganize while remaining functionally and structurally the same. That is, resilient ecosystems are systems that are less likely to abruptly fail when faced with outside pressures, reducing the risk of transforming into entirely different ecological regimes that no longer deliver the services we have come to expect (Scheffer et al. 2001; Andersen et al. 2009). Resilient ecosystems adjust to and recover from disturbance, respond to new ecological opportunities, and adapt to change (see Folke et al. 2005 for review). For the purposes of RACER, ecosystems are defined to include the services and resources they provide to people (e.g., food harvests) to ensure the conservation targets identified by the method are relevant to current and future human needs.

Ecosystems avoid thresholds of transformation–remain resilient–when their functioning is supported by fundamental ecological processes, such as productivity and diversity. Management and planning can support resilience by focusing on characteristics in the environment that encourage and support this ecosystem functioning. Although ecosystem resilience offers a promising conservation goal, its usefulness as a management tool in the Arctic has long been constrained by a shortage of information; intensive, local-scale surveys of arctic natural history are often limited to a very few areas where new development is proposed or where access, logistics, and costs permit. As a result, it is often difficult to link the species and habitats found in a place with an understanding of why they are there and what their presence means for ecosystems.

Recently, however, advances in analyses of satellite remote imagery and other techniques have been able to provide information about ecological productivity and diversity for areas around the world, including the circumpolar Arctic. For the first time, this data offers the promise of estimating important aspects of ecosystem function in regions throughout the remote North. Although these estimates reflect only approximations of ecological conditions on the ground, this best-available information provides a critical starting point for ecosystem-based conservation at a time when further monitoring and research are fast outpaced by change.

FIGURE 1.2
STATUS AND PROJECTION OF ARCTIC NEAR-SURFACE PERMAFROST.
Source: WWF, redrawn from Lawrence and Slater 2005.



ARCTIC CONSERVATION EFFORTS MUST BE BOTH EFFECTIVE NOW AND YET CONTINUE TO HELP THE ARCTIC ENVIRONMENT COPE WITH NEW OUTSIDE PRESSURES AND DEVELOPMENT IMPACTS INTO THE FUTURE.

OPEN FOR BUSINESS

The milder Arctic and its more accessible, more open sea are increasingly attracting development interests in the North (see review in Koivurova and Molenaar 2009). Disappearing multi-year ice is opening up opportunities for oil and gas companies–such as BP or Russia's Rosneft Oil Company. Receding glaciers and ice caps are similarly exposing land for mineral exploration and mining. Marine traffic is also increasing. The Northwest Passage through the Canadian Arctic Archipelago–which could reduce shipping times between New York and most major Chinese ports by as much as 10 days–is expected to become navigable for two to four months each year by later this century. The North-East Passage, or Northern Sea Route, across the top of Eurasia could be open to boat traffic for even longer periods.

FIGURE 1.3
THE ARCTIC AS DEFINED BY THE CONSERVATION OF ARCTIC FLORA AND FAUNA (CAFF) WORKING GROUP OF THE ARCTIC COUNCIL.
Source: UNEP/GRID-Arendal 2010.

to the land, water, and ice. They fished, hunted seals, and tracked great herds of migratory caribou. The traditions of some of these groups have survived for millennia with a remarkable heritage intact, far from the outside reach of most other cultural influences. Today, many of these practices continue alongside modern economic activities. In many parts of the Arctic, authority and stewardship of the land and its resources belongs to these northern peoples. But the fate of their traditions is tied in large part to the survival of the wildlife and ecosystems that continue to sustain them.

CONSERVATION URGENCY

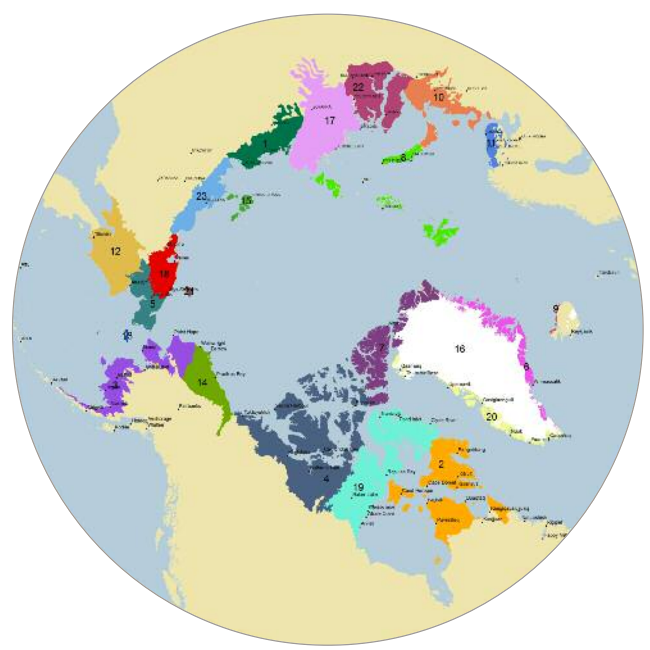
Rapid and accelerating climate change means arctic conservation has never been more pressing. The shifts occurring today present opportunities that may be gone tomorrow. While many of the ecological systems responsible for the values and varieties of circumpolar life remain intact, the pace of change means unprecedented challenges. Arctic conservation efforts must be both effective now and yet continue to help the arctic environment cope with new outside pressures and development impacts into the future. In general, the global causes of warming are beyond the reach of any local- or regional-scale management (SWIPA 2011). Instead, management and conservation must look to adaptation, helping wildlife populations and communities to be prepared for an inevitably and increasingly altered environment. The task is made more difficult when species or even habitats respond to change by moving from one area to another. In the climate-affected Arctic, conservation often faces moving targets.

MANY CONSERVATIONISTS NOW ACKNOWLEDGE THAT AN ECOSYSTEM APPROACH IS CRUCIAL FOR HELPING CIRCUMPOLAR HABITATS AND WILDLIFE, AS WELL AS TRADITIONAL COMMUNITIES AND CULTURES, ADAPT TO THEIR CHANGED AND CHANGING ENVIRONMENT.

FIGURE 1.4
TERRESTRIAL ARCTIC ECOREGIONS THAT ARE THE FOCUS OF RACER ASSESSMENTS.
Source: WWF, adapted from CAVM Team 2003.

TERRESTRIAL STUDY UNITS

1. Anabar - Lena
2. Baffin – Labrador
3. Beringian Alaska
4. Central Canada
5. Eastern Chukotka
6. Eastern Greenland
7. Ellesmere – Northern Greenland
8. Franz Josef Land – Novaya Zemlya – Severnaya Zemlya
9. Iceland – Jan Mayen Island
10. Kanin – Pechora
11. Kola Peninsula
12. Koryakia
13. North Beringian Islands
14. Northern Alaska
15. Novisiberian Islands
16. Rock and Ice
17. Taimir Peninsula
18. West Chukotka
19. West Hudsonian
20. Western Greenland
21. Wrangel Island
22. Yamal – Gydan
23. Yana – Indigirka - Kolyma

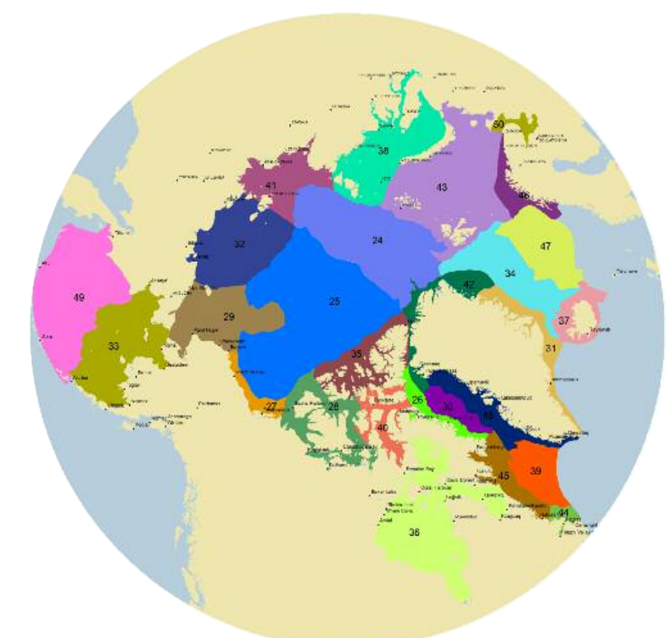


THE ARCTIC IS HOME TO 50 REPRESENTATIVE ECOREGIONS THAT REFLECT THE WIDE RANGE OF UNIQUE ECOSYSTEMS AND VARIETIES OF LIFE FOUND THROUGHOUT THE FAR NORTH.

FIGURE 1.5
MARINE ARCTIC ECOREGIONS THAT ARE THE FOCUS OF RACER ASSESSMENTS.
Source: WWF, adapted from Spalding et al. 2007.

MARINE STUDY UNITS

24. Arctic Ocean – Atlantic Basin
25. Arctic Ocean – Pacific Basin
26. Baffin Bay – Canadian Shelf
27. Beaufort Sea – continental coast & shelf
28. Beaufort – Amundsen – Viscount Melville – Queen Maud
29. Chukchi Sea
30. Baffin Bay
31. East Greenland Shelf
32. East Siberian Sea
33. Eastern Bering Sea
34. Fram Strait
35. High Arctic Archipelago
36. Hudson complex
37. Iceland Shelf
38. Kara Sea
39. Labrador Sea Basin
40. Lancaster Dound
41. Laptev Sea
42. North Greenland
43. North and East Barents Sea
44. Northern Grand Banks – Southern Labrador
45. Northern Labrador
46. Northern Norway and Finnmark
47. Norwegian Sea
48. West Greenland Shelf
49. Western Bering Sea
50. White Sea



ECOLOGICAL REGIONS OF THE ARCTIC

The Arctic is home to 50 representative ecoregions that reflect the wide range of unique ecosystems and varieties of life found throughout the Far North. These regions are distinguished and located on a map (Fig. 1.4 and 1.5) using two broad biogeographic ecological classification methods: the Circumpolar Arctic Vegetation Map (CAVM Team 2003; Walker et al. 2005) for regions on land and, at sea, the Marine Ecoregions of the World project (Spalding et al. 2007).

CAVM classifies the variation in plant species groups and communities found in clearly recognizable regions across the Arctic. Although many plants occur throughout the circumpolar North, variation in other species groups reflects the Arctic's diverse glacial histories, topography, and other factors that may have isolated plant populations and contributed to regional differences. Importantly, the CAVM classes also fall into categorical distinctions according to regional differences in the soil type, soil moisture, and temperature.

At sea, ecoregions are classified based on distinctions described by the recent Marine Ecoregions of the World (MEOW) project. The team of international researchers involved in MEOW used recognizable species groups of both plants and animals to make regional distinctions. Marine ecoregions are defined as "areas of relatively homogeneous species composition that clearly differ in this regard from adjacent systems." These identifiable species groupings are likely the consequence of characteristics in the seascape that encourage biological isolation and difference, such as seafloor mountains and canyons, temperature, ice, currents, upwelling, or coastal complexity (Spalding et al. 2007).

THE GEOGRAPHY OF ARCTIC ECOLOGICAL RESILIENCE

WWF'S RAPID ASSESSMENT OF CIRCUM-ARCTIC ECOSYSTEM RESILIENCE is a tool for finding and mapping targets for future conservation and management efforts. These targets are the sources of ecological resilience that help keep ecosystems functioning and contributing to ecosystem services throughout the Arctic.

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Sources of resilience are located where *key* land or marine features (such as ocean polynyas, mountains, and river deltas) help generate exceptional productivity and diversity and confer the benefits of this ecological vitality to the wider ecosystems to which they belong and to the people who rely on them. RACER uses *the best available data as rapidly as possible* to identify and map the key features that currently support ecosystem resilience in each of 50 ecologically distinctive regions (ecoregions) throughout the circumpolar North.

The wild card is climate change: arctic warming, shrinking ice, changes in rain and snow, shifts from wet to dry, and multiple climate impacts can disrupt the biological and physical characteristics of features that are responsible for generating productivity and diversity.

RACER locates key features *now* and determines the likelihood they will remain sources of ecological resilience given climate change forecasts for the 21st century. By identifying key features that will remain exceptionally productive and diverse into the future, managers and planners can safeguard the sources of resilience important for the continued functioning of arctic ecosystems and the ecosystem services people in the North depend on.

While RACER's objectives relate to ecosystems that include harvestable species and other resources important to northern people and their cultures, the method does not explicitly consider social and economic factors. That is, RACER is not an assessment of *social-ecological resilience*. Instead, RACER helps to understand climate impacts on northern communities and economies by testing the enduring resilience of ecosystems that support the animals and plants important to the livelihoods, culture, and traditions of arctic people and others.

CHANGING TO FACE CHANGE

The rationale for RACER began with a review of the current state of arctic conservation during a WWF workshop in Oslo, Norway in May 2009. Conference participants agreed that the scale and the speed of climate-related ecological change in the Arctic would soon outpace and frustrate efforts to conserve species and habitats where they are found today. The immensity of this challenge demanded a significantly new way of thinking about planning and management in the Arctic.

The Oslo workshop concluded that a first step must be a rapid assessment of where arctic ecosystems are functioning particularly well now and how likely they will continue to function in the climate-altered future. The assessment would take a mechanistic view and look for the features (on the landscape or at sea) whose characteristics drive exceptional productivity and diversity and lend resilience to regional ecosystems. Both the current location of

DEFINITIONS OF RACER'S MAIN TERMS

ECOSYSTEMS
The functional interaction of organisms and their environment, including the services these functions provide to people.

DRIVERS
The characteristics–such as the soil type, sea ice, currents, temperature, topography, and nutrients in an area– that drive ecosystems by helping life to flourish (productivity) and by encouraging varieties of vegetation, creatures and other living things to thrive (diversity). Drivers are not static; they respond to changes in the environment at different speeds and to different degrees (e.g., temperature and sea ice change faster than topography in response to changes in climate).

FEATURES
Any local combination or alignment of drivers (previous) within an ecoregion that can be located on a map (at any given time).

KEY FEATURES
Any feature (above) for which levels of productivity and diversity are exceptional (i.e., above RACER-defined thresholds) compared to the average productivity and diversity for the ecoregion to which the feature belongs. (SEE ALSO FIG. 2.1)

RACER LOCATES KEY FEATURES NOW AND DETERMINES THE LIKELIHOOD THEY WILL REMAIN SOURCES OF ECOLOGICAL RESILIENCE GIVEN CLIMATE CHANGE FORECASTS FOR THE 21ST CENTURY.

features and the ecological drivers at work in these places would become important targets for conservation and management efforts in the face of change.

In October 2010, WWF's arctic expert advisors met in Ottawa, Canada. Equipped with resilience science and a better understanding of the limits of arctic data, the group developed the RACER analytical framework–a model that could be both quick and effective (based on the best available information) at identifying the most important sources of ecosystem strength within arctic ecoregions.

A series of ecoregional workshops followed to further develop the on-the-ground methods and to examine the preliminary conclusions of the sample pilot studies–including those in the Beaufort Sea, the Laptev Sea, the Central Canada tundra, and the Eastern Chukotka region of Russia. The overall RACER framework also continued to develop to bridge the gaps between its ecosystem-theoretical foundations and the practicable approaches to ecological assessments identified by the case studies.

THE RACER METHOD

What emerged was an innovative ecosystem-based method that finds and evaluates the *local* sources of exceptional productivity and diversity–or ecological vitality. These local sources are behind the continued viability (i.e., continued functioning) of their larger-scale, regional ecosystems now–and into the climate affected future (Fig. 2.1). These local sources of ecological vitality are landscape or sea features that support exceptional biological productivity or diversity (or both) in discrete, readily identified places within arctic regions.

The relationship between the resilience of the large regional ecosystems–*ecoregions*–and the most productive and ecologically diverse features that support that resilience is central to the RACER method. In general, features are places that stand out on the landscape or in the sea, such as canyons, river mouths, mountains, or ocean polynyas. These features combine characteristics–such as topographic variety, currents, ice edges, and nutrient upwelling–that drive productivity or diversity or both (Fig. 2.3; see also sidebar, Driving ecosystems). Features are understood and located where these *drivers* align in unique combinations. Although some features represent locations fixed by a physical structure that is not expected to change much over the coming century (e.g., canyons), others are defined by characteristics directly or indirectly affected by climate change and can move (e.g., ocean polynyas).

RACER assessments test ecosystem resilience for entire ecoregions. This allows RACER to make conclusions that are relevant to planning in regions that represent ecological communities, biodiversity, and natural values and services across the circumpolar Arctic.

FIGURE 2.1 THE RACER ANALYTICAL FRAMEWORK

PART 1: MAPPING RESILIENCE

STEP 1. MAP PLACES OF EXCEPTIONAL PRODUCTIVITY AND DIVERSITY
Uses literature and remote sensing analysis to identify places with exceptional productivity and diversity within each ecoregion.

STEP 2. IDENTIFY KEY FEATURES
Describes the unique combinations of drivers considered responsible for the exceptional local-scale productivity and diversity (above). Identifies these driver combinations as *key features* that confer ecoregion-wide resilience and shows these features on a map.

PART 2: ASSESSING PERSISTENCE

STEP 1. ASSESS THE IMPACT OF CLIMATE CHANGE ON THE ECOREGION
Identifies the GCM variables that are relevant to the ecoregion and describes the GCM-projected change of these variables through to 2100.

STEP 2. ESTIMATE HOW DRIVERS OF EXCEPTIONAL PRODUCTIVITY AND DIVERSITY OF KEY FEATURES ARE AFFECTED BY CLIMATE CHANGE
Estimates how projected changes in GCM variables affect the ecoregion-scale drivers and interpret their impact on the drivers of the exceptional productivity and diversity at the scale of key features.

STEP 3. ASSESS THE PERSISTENCE OF THE CAPACITY OF KEY FEATURES TO CONFER RESILIENCE ON THE ECOREGION AFFECTED BY CLIMATE CHANGE
Assesses the likely persistence of a key feature's continued ability to confer resilience by interpreting whether feature-scale drivers will continue to support exceptional productivity and diversity for identified key features.

DECISION MAKERS AND MANAGERS CAN USE THE RACER PERSPECTIVE TO DISCOVER AND SAFEGUARD THE DISCRETE LOCATIONS OF KEY FEATURES THAT CONTRIBUTE TO THE ECOSYSTEM FUNCTIONING OF THE ECOREGIONS IN WHICH THESE FEATURES ARE FOUND.

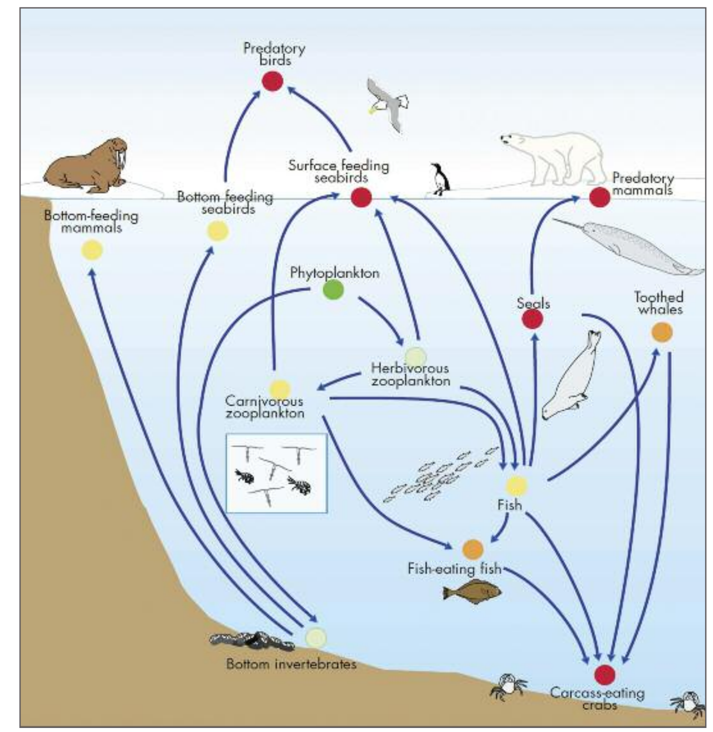


FIGURE 2.2
A SIMPLIFIED ARCTIC MARINE FOOD WEB.
Source: CAFF 2001.

- THIRD AND HIGHER LEVEL PREDATORS
- SECOND LEVEL PREDATORS
- FIRST LEVEL PREDATORS
- GRAZERS AND FILTER FEEDERS
- PRIMARY PRODUCERS

IN THE ARCTIC, THE MANY INTERACTIONS THAT COMPRISE ECOSYSTEMS ARE OFTEN VERY EFFICIENT AT PASSING ENERGY FROM PHOTOSYNTHETIC LIFE TO LARGE PREDATORS.

KEY FEATURES AND THEIR DRIVERS

From among the many features in an ecoregion, RACER identifies and maps only *key features*. Key features are found where the combined effect of the currents, soil types, sea ice, and other drivers generates exceptional ecological vitality compared to the ecoregion as a whole. The combination of drivers at key features work together better than the drivers do at other features when it comes to feeding, fertilizing, and otherwise encouraging plant and animal growth (biological productivity) and supporting large numbers of different kinds of life and habitats (diversity) or both.

RACER's spotlight on the importance of key features and their drivers marks a significant shift in thinking for natural resource management and conservation in the Arctic. Decision makers and managers can use this new perspective to discover and safeguard the discrete locations of key features that contribute to the ecosystem functioning of the ecoregions in which these features are found.

Preserving one local-scale key feature can affect ecosystem resilience at a far larger scale. Meanwhile, recognizing the importance of drivers can encourage management efforts that are strategically aimed at the functional underpinning of the ecosystems that support arctic life.

Importantly, the RACER focus on key features and their drivers also allows researchers to assess whether the ecosystem resilience of ecoregions is likely to continue despite climate change. The relationship between the climate variables used in General Circulation Model (GCM) predictions and the drivers that characterize key features offers the capacity to base current strategic planning and management decisions on the best-informed scientific scenarios of future change.

RACER DESCRIBES THE KEY FEATURES OF AN ECOREGION AS THE DRIVER COMBINATIONS RESPONSIBLE FOR GENERATING THE LOCALLY EXCEPTIONAL PRODUCTIVITY OR DIVERSITY THAT SERVE AS WELLSPRINGS OF RESILIENCE.

PRODUCTIVITY AND DIVERSITY-ECOSYSTEM ENGINES

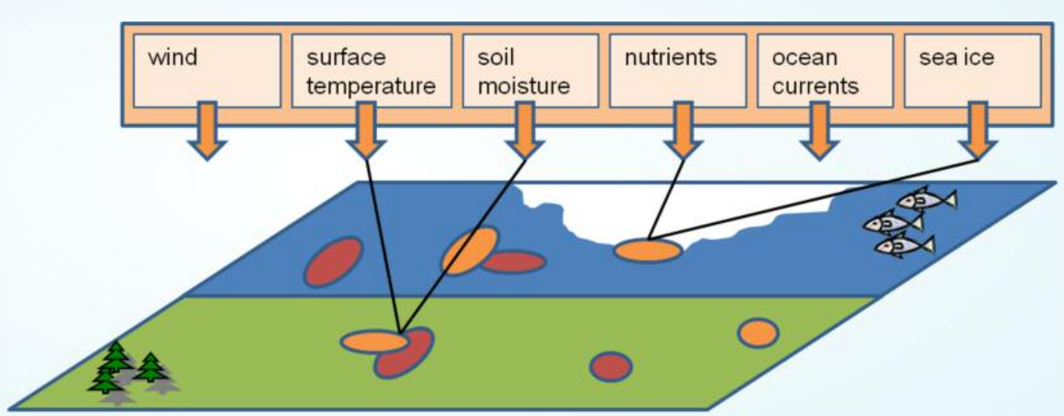
RACER uses the biological productivity and diversity of features to indicate the likely resilience of the ecosystems (including their ecosystem services) to which these features belong. This inference is based on two important concepts: the first argues that productivity and diversity are two central *engines* that keep ecosystems going and generating useful services for people, and the second suggests that features where these engines are working especially well–that is, where productivity and diversity are above the eco-region average–can confer resilience beyond the places they are located to the eco-system of the wider region.

Productivity, for example, reflects the work of plants and plankton that capture energy from the sun and carbon from the atmosphere to pass it along as energy-rich organic compounds within ecosystem food webs (Allaby 2010). The productivity of a place, therefore, is one indicator of how well the surrounding eco-systems, including the services they provide to people, are functioning (Arrigo 2005; Milutinović and Bertino 2011). The animals and other life that feed on the plants represent another level of biological production, directly linked–even if for only periods in their life cycle–to primary productivity. *Secondary productivity*, as this level is known, is often especially relevant to the livelihoods of people and communities who harvest fish, whales, and other larger animals throughout the North.

Diversity is the number and variety of kinds of life and habitats that interact to make ecosystems function (Allaby 2010). In the Arctic, the many interactions that comprise ecosystems are often very efficient at passing energy from photosynthetic life to large predators. Because conditions are harsh, the diversity of life is often relatively limited, its distribution sparse, and the numerous food chains it comprises are simple (Fig. 2.2); each link in these chains is represented by few species. That means these ecosystems are considered vulnerable because the decline or loss of a single species threatens to break a link and imperil a chain. Higher levels of diversity mean that when species and habitats disappear or move elsewhere, there is a higher chance that other animals and plants can fill in to replace the lost links, protecting the ecosystems against catastrophe (Pimm et al. 1991).

Thus, productivity and diversity work together to power arctic ecosystems and to enable these systems to better absorb environmental shocks. The work of these ecological engines generates ecological resilience, ensuring an ecosystem's capacity to work in much the same kind of way and keep the same or a similar identity while enduring stress. Productivity and diversity enable resilience by ensuring ecosystems are better equipped to recover from disturbance, to respond to new ecological opportunities, and to adapt to change.

FIGURE 2.3
THE RELATIONSHIP BETWEEN DRIVERS, KEY FEATURES, EXCEPTIONAL PRODUCTIVITY AND DIVERSITY.
Source: WWF.



THE RELATIONSHIP BETWEEN THE RESILIENCE OF THE LARGE REGIONAL ECOSYSTEMS—ECOREGIONS—AND THE MOST PRODUCTIVE AND ECOLOGICALLY DIVERSE FEATURES THAT SUPPORT THAT RESILIENCE IS CENTRAL TO THE RACER METHOD.

DRIVING ECOSYSTEMS

RACER emphasizes the conservation importance of the physical, climatic, and biological *drivers* that generate ecological vitality (i.e., exceptional productivity and/or diversity)–rather than targeting habitats and species. RACER highlights the role of these drivers as characteristics that enable ecosystem resilience. The result is a new approach to arctic conservation and resource management that depends on a functional understanding of the Arctic and its regions. It allows for more reliable forecasts of future ecological change because the relationship between drivers and the variables affected by climate change is more direct than correlations between climate shifts and changes to species and complex living systems.

Drivers include elements from geography and oceanography (the soils, currents, topography, etc.), local climate (temperature, precipitation, wind, etc.), ice and water (sea ice, snowfall, soil moisture, etc.), and the presence and interactions of species (vegetation, food webs, etc.). Drivers change as their environment changes. In response to different environmental pressures, some drivers change quickly and significantly while others respond more slowly or hardly at all. For example, climate shifts may prompt rapid changes in temperature and sea ice while topography will remain effectively the same. RACER uses an understanding of the degree of each driver's responsiveness to change in its assessment of future ecosystem resilience. RACER assesses ecosystem resilience across ecoregions. Key features are places within each ecoregion that act as sources to this region-wide resilience. That's because the ecosystem drivers relevant to these regions uniquely align at these sites to generate exceptional productivity and diversity. The combination and expression of these drivers at key features fuel local productivity and diversity that, in turn, power and strengthen the ecosystem functioning of the larger ecoregion in which these key features are found. Thus, RACER describes the key features of an ecoregion as the driver combinations responsible for generating the locally exceptional productivity or diversity that serve as wellsprings of resilience.

RACER's emphasis on the drivers behind productivity and diversity rather than on the species and habitats that result from these ecological engines is unique (Fig. 2.3) and marks a critical new approach to arctic conservation and management thinking. Most importantly, it allows for resilience-focused ecosystem management and strategic planning based on change scenarios that directly impact the way drivers work. These scenarios are often available, as in the case of climate change forecasts, and can be linked to the performance of drivers by the relationship between the climate variables used in models and the drivers (see Chapter 4).

MAPPING FEATURES THAT CONFER ECOLOGICAL RESILIENCE

THE FIRST PART OF THE RACER METHOD identifies and maps the current location of mountains, river deltas, ocean polynyas, and other land or sea features significant for the functioning of ecosystems across arctic regions. These are called key features, and they are exceptional because they help the larger ecosystems in which they are found to continue to function and to adapt to outside pressures and disturbances.

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That is, key features act as local sources of ecological strength to fortify ecosystem resilience across the entire region in which these features are found.

RACER identifies key features from their biological productivity and diversity–the two main engines of ecosystem functioning. Productivity and diversity, in turn, are driven by the ecological effects of the physical and ecological characteristics that make up features on the landscape or in the sea.

The RACER method recognizes key features from among the many features in each arctic ecoregion by looking for places where productivity or diversity (or both) are above–or well above–the region-wide average (Fig. 3.1.) Evidence of this exceptional vitality can be used to conclude which features currently play a significantly large role in the continued viability–*resilience*–of regional ecosystems. These key features act as local wellsprings for resilience across the region because their locally exceptional productivity or diversity (or both) affects ecosystem processes and species interactions beyond the specific feature location, acting to improve the likelihood that the entire region-wide ecosystem can endure and adapt to change.

To detect and map places where the ecosystem engines of productivity and diversity are working well, RACER gathers and analyses information from three general sources: remote sensing data; reviews of ecoregion relevant literature (such as scientific publications or harvest records of indigenous people); and evaluations of the information by scientific and local experts familiar with the regional ecology (Fig. 3.2).

SATELLITE REMOTE SENSING

Satellites can be used to assess productivity and diversity across continuous space on the ground or at sea. RACER uses satellite remote sensing technology to identify the location of exceptional productivity or diversity across the often-remote ecoregions throughout the Arctic (see sidebar, Detecting productivity and diversity). For example, RACER uses satellite imagery to determine where plants and plankton are especially productive (Fig. 3.5 and 3.6). The primary productivity, in turn, suggests levels of animal (secondary) productivity linked by the food chain to the plant life that sustains it.

Remote sensing evidence of diversity is less direct: biological diversity can be implied from satellite data that shows greater topographic heterogeneity because the amount of landscape variety is linked to the number of available habitats that each support different sets of species (Walker et al. 2002; Rocchini et al. 2010).

FIGURE 3.1 THE RACER ANALYTICAL FRAMEWORK

PART 1: MAPPING RESILIENCE

STEP 1.
MAP PLACES OF EXCEPTIONAL PRODUCTIVITY AND DIVERSITY
Uses literature and remote sensing analysis to identify places with exceptional productivity and diversity within each ecoregion.

STEP 2.
IDENTIFY KEY FEATURES
Describes the unique combinations of drivers considered responsible for the exceptional local-scale productivity and diversity (above). Identifies these driver combinations as "features" that confer ecoregion-wide resilience and shows these features on a map.

EVIDENCE OF EXCEPTIONAL VITALITY CAN BE USED TO CONCLUDE WHICH FEATURES CURRENTLY PLAY A SIGNIFICANT ROLE IN THE CONTINUED VIABILITY—RESILIENCE—OF REGIONAL ECOSYSTEMS.

SCIENTIFIC REVIEW

A second line of evidence to help identify areas of exceptional productivity and/or diversity comes from published (and unpublished) scientific papers and reports. These reflect available research into the biological, geographical, climatic, and sociocultural dimensions (e.g., traditional hunting areas) of ecoregions. In some cases, the research provides a basis for the RACER analysis. For example, the mapped results of the Circumpolar Arctic Vegetation Map (CAVM) project are a key resource in the terrestrial search for arctic key features (CAVM Team 2003; Walker et al. 2005). Available scientific literature is also used to understand the biological and physical characteristics–the drivers–that contribute to the ecological vitality of features (Fig. 3.3 and 3.4; see, for example, CAVM Team 2003; Walker et al. 2005; Carmack et al. 2006; Ingram et al. 2008).

Other ecological surveys and species-specific biological research are used to reveal the feeding, spawning, or calving grounds for fish, birds, or mammals (indicating secondary productivity and diversity), or sometimes the diversity of local plant life. In most cases, this literature and research material is only locally plentiful and provides a discontinuous picture of the biological activity and ecology of ecoregions. Furthermore, locations for which research exists disproportionately reflect areas of development interest or localities readily accessible to scientists and students. Nevertheless, these growing numbers of intensive and frequently field-based studies can be mapped and used to suggest or confirm evidence of important drivers as well as the productivity or diversity accompanying key features.

EVALUATION BY EXPERTS

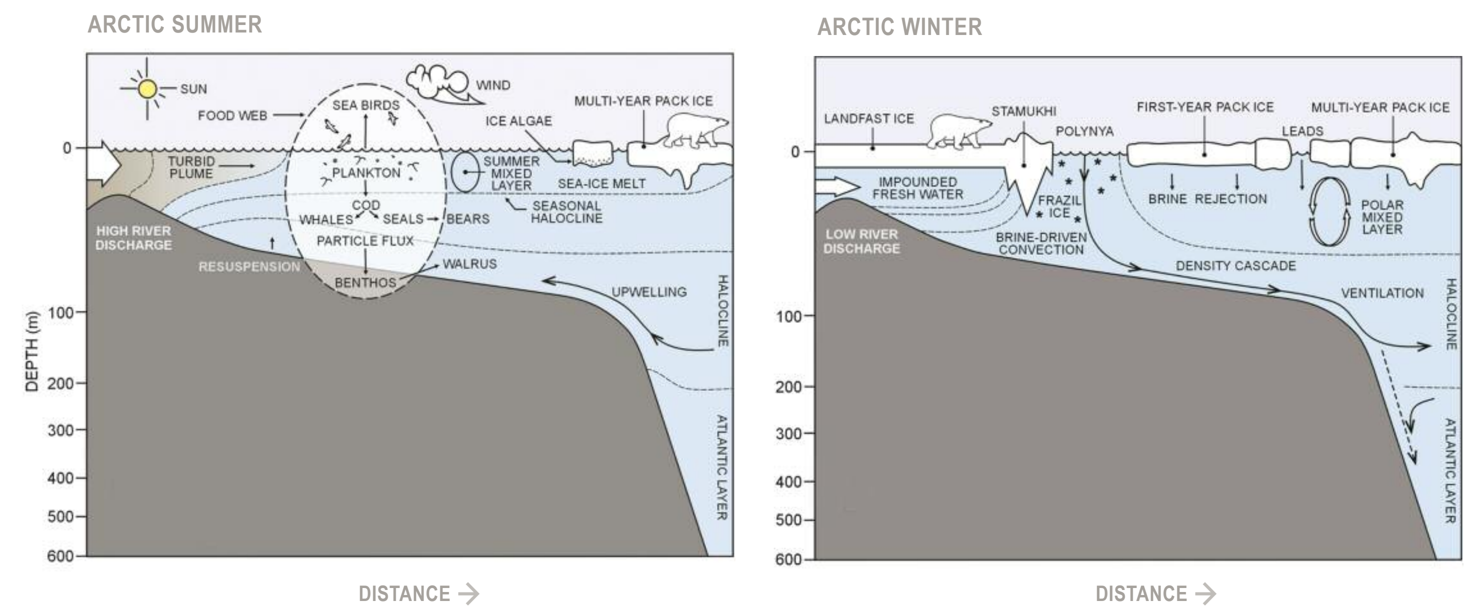
Expert consultation plays a pivotal role in RACER's work to identify key features. The direction and advice of multiple experts is used to find and sort scientific literature as corroborative evidence for the exceptional nature of suspected key features.

Expert assessments are also used to understand what combination of local-scale drivers are responsible for a key feature's exceptional ecological activity. For example, soils, ocean salinity, steep slopes, sea ice, snowfall, ground moisture, current upwelling, nutrients, and other drivers can all contribute to vigorous plant and plankton growth and thriving varieties of life. But it is the unique alignment or combination of several drivers–each with their own specific quality and influence–that powers the outstanding ecological vitality. Understanding the role of these drivers is important for making strategic management decisions because of the likely availability of driver scenarios, such as those from climate change models. Using drivers in this way is the approach used in the second part of the RACER assessment–determining whether these features will continue to contribute to region-wide ecological resilience in the face of future climate change.

FIGURE 3.2
EXAMPLES OF DATA SOURCES FOR IDENTIFYING EXCEPTIONAL PRODUCTIVITY AND DIVERSITY.
Source: WWF.

KEY FEATURES WITH EXCEPTIONAL BIOLOGICAL PRODUCTIVITY OR DIVERSITY IN MARINE ARCTIC ECOREGIONS EXIST IN THREE-DIMENSIONAL ECOLOGICAL SPACE.

FIGURE 3.3
DRIVERS OF ARCTIC MARINE SHELF SYSTEMS.
Source: Modified from Ingram et al. 2008 (© Patricia Kimber).



FINDING KEY FEATURES IN ARCTIC SEAS

RACER's search for key features that confer ecosystem resilience requires a careful understanding of the northern seas which comprise almost half the area of the circumpolar Arctic. The Arctic Ocean is fringed by the northern reaches of three continents, but its polar-capping expanse is interrupted only by Greenland, the Canadian Arctic Archipelago, and smaller island groups in Northern Europe and Russia. The abundance of islands and continental interior shelf in the otherwise deep Arctic basin contributes to a rich variety of marine life, including krill, fish, and whales and other marine mammals (ACIA 2004). The dynamic ecology of these areas is enhanced by dramatic seasonal changes in sea ice (with especially vibrant ecosystems along the ice edges) and by the effects of merging water masses from global ocean currents and polar seas.

Key features with exceptional biological productivity and/or diversity in marine arctic ecoregions exist in three-dimensional ecological space: oceans have depth as well as length and breadth. Thus, the ecological drivers at work there–such as currents, sea ice, and nutrient upwelling–are often numerous and complex and sometimes difficult to discern. For instance, key features can exist at the surface (e.g., a polynya), in the water column (e.g., a river plume), or at the sea floor (e.g., a shelf break). Some marine arctic regions, such as the sedimentary Beaufort Continental Coast and Shelf ecoregion (Fig. 3.3), have become subjects of intense study as a result of growing interest and development by oil and gas industries. However, many other undersea regions of the Arctic are much less studied, and information concerning their ecology and dynamics is limited.

RACER LOCATES KEY FEATURES ACROSS ARCTIC LAND BY DEVELOPING A CAREFUL UNDERSTANDING OF THE TERRESTRIAL CHARACTERISTICS AND PROCESSES AT WORK THERE.

FINDING KEY FEATURES ON ARCTIC LAND

RACER locates key features across the 14.8 million square kilometres of arctic land by developing a careful understanding of the terrestrial characteristics and processes at work there. The arctic landscape comprises the lowlands, tundra, mountains, and shore along the northern reaches of three continents as well as many increasingly barren islands closer to the pole. Much of the area is covered above with low vegetation and lichen-covered rock. Beneath is permafrost–permanently frozen soil, sediment, and rock that underlies most arctic land and dramatically affects top-layer moisture, surface water, and plant life. Land glaciers and ice caps characterize large tracts of some islands, and much of Greenland–the Arctic's largest landmass–lies under a vast, lasting ice sheet.

For most of the terrestrial Arctic, a short growing season with low summer temperatures supports only hardy plants, such as dwarf shrubs, grasses, herbs, lichen and mosses, which grow close to the ground. In the far south of the region, warmer temperatures encourage more varieties of vegetation as well as tall shrubs and even occasional groups of trees. At higher latitudes, many plant species grow increasingly scarce, and vegetation becomes sparse, separated by bare soil and rock.

The ecosystems of terrestrial arctic regions and the key features found there (e.g., wetlands, the terrain of mountains) differ from their marine counterparts by ecological activity that is confined (mainly) to the two dimensions of the landscape surface. Thus, the drivers of key features are limited to ambient temperature, soil quality, and soil moisture, and the important climate changes are those that substantially affect these three drivers (see Fig. 3.4).

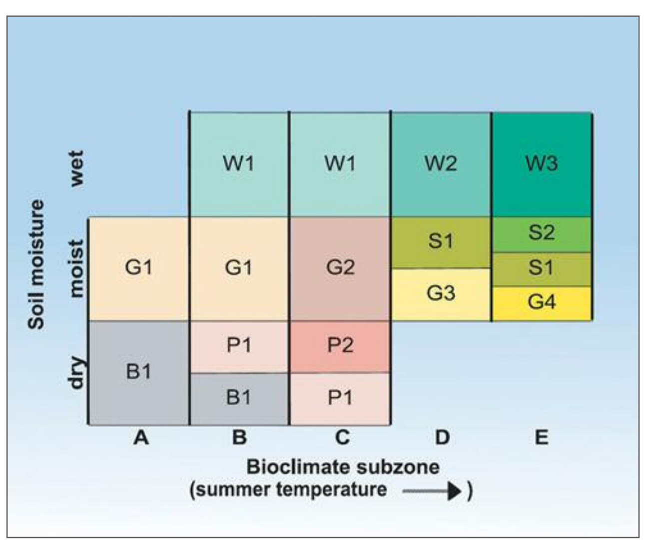


FIGURE 3.4
DRIVERS OF THE ARCTIC TERRESTRIAL SYSTEM.
Squares in the grid indicate the relationship between arctic vegetation classes and the principal environmental controls, summer temperatures and site moisture. Soil quality—the third driver—is expressed by the colours of the classes within the temperature-soil moisture grid.
Sources: CAVM Team 2003, Walker et al. 2005.

Barrens
B1. Cryptogam, herb barren
B2. Cryptogam barren complex (bedrock)
B3. Noncarbonate mountain complex
B4. Carbonate mountain complex

Graminoid Tundras
G1. Rush/grass, forb, cryptogam tundra
G2. Graminoid, prostrate dwarf-shrub, forb tundra
G3. Non-tussock sedge, dwarf-shrub, moss tundra
G4. Tussock-sedge, dwarf-shrub, moss tundra

Prostrate-shrub tundras
P1. Prostrate dwarf-shrub, herb tundra
P2. Prostrate/hemiprostrate dwarf-shrub tundra

Erect-shrub tundras
S1. Erect dwarf-shrub tundra
S2. Low-shrub tundra

Wetlands
W1. Sedge/grass, moss wetland
W2. Sedge, moss, dwarf-shrub wetland
W3. Sedge, moss, low-shrub wetland

RACER RELIES ON SATELLITE REMOTE SENSING TO HELP LOCATE AND MAP AREAS WHERE LEVELS OF PRODUCTIVITY AND DIVERSITY ARE HIGH.

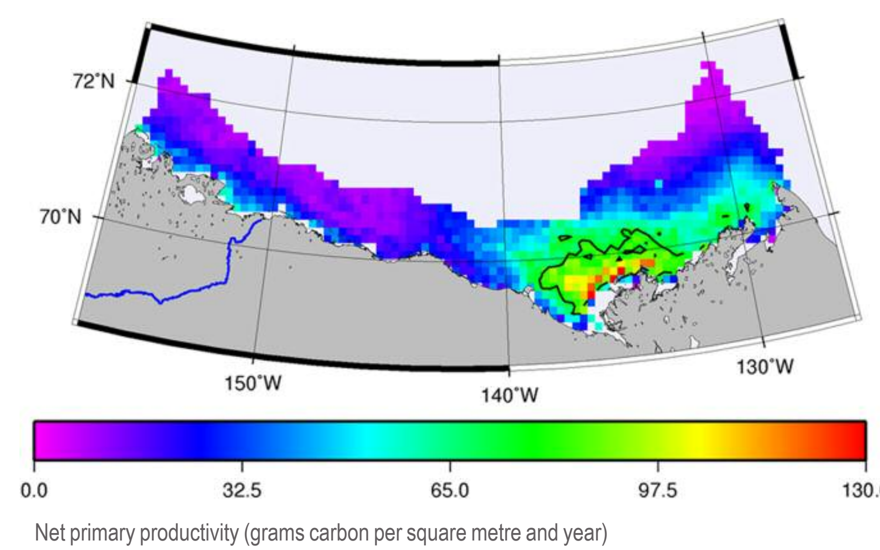
DETECTING PRODUCTIVITY AND DIVERSITY

RACER relies on satellite remote sensing to help locate and map areas where levels of productivity and diversity are high. Remote sensing relies on satellite imagery to discover what's happening on the ground, particularly in inaccessible or rarely visited places, such as most areas of the Arctic. For decades, the use of satellite detection of light or other energy waves has been steadily refined to provide remarkably detailed information about everything from landscape topography to on-the-ground environmental health (see, for review, Kerr and Ostrovsky 2003; Rocchini et al. 2010).

Satellite measures of primary productivity, for example, rely on the detection of reflected and absorbed light that reveals concentrations of the pigments involved in plant photosynthesis (chlorophyll) at the Earth's surface. On land, the annual amount of biomass produced by plants and plankton (called primary productivity) is determined through an adjusted analysis of the intensity of "greenness" reflected into space by ground vegetation (Kerr and Ostrovsky 2003). RACER identifies land areas of high primary productivity–exceptional plant growth–in each bioclimatic subzone using the Normalized Difference Vegetation Index (NDVI; Rouse et al. 1973). The NDVI data reveals areas (at a scale of two-square kilometres) where productivity levels are in the top 25 per cent of productivity for each temperature (bioclimatic) subzone in each ecoregion (Fig. 3.6; see also sidebar, Temperature subzones).

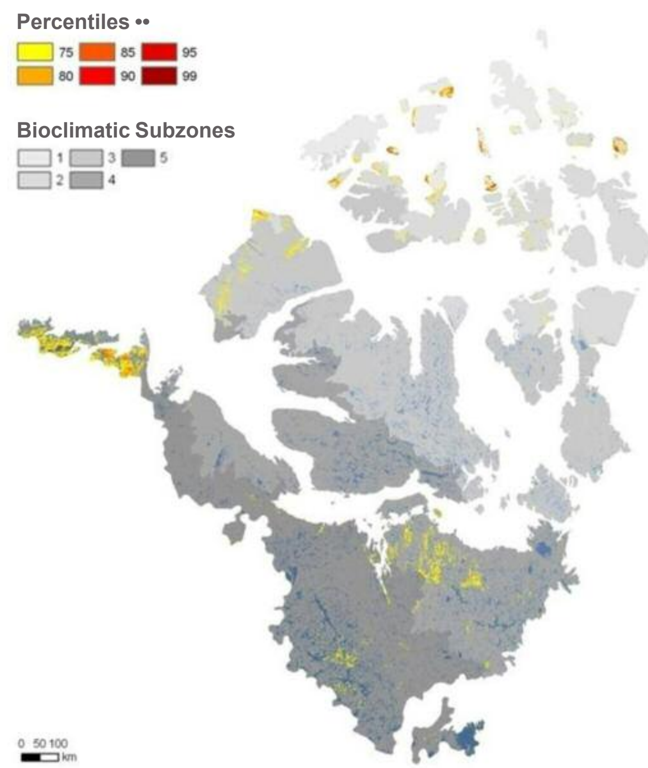
For marine ecoregions, RACER uses data from the international Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project to detect changes in ocean colour (caused by the chlorophyll a pigment) that reveal the quantities of microscopic marine plants found near the sea surface (O'Reilly et al. 1998). This information, averaged over several years, is used to reveal areas where plant and plankton productivity is in the top 20 per cent relative to levels in the rest of each ecoregion for near surface areas during periods of open water (i.e., no ice cover) (Tremblay et al. 2011; see Fig. 3.5). The primary productivity also serves as a proxy measure of levels of overall productivity involving animals (secondary productivity) because biological production in creatures is linked to the plant life that sustains them. (CONTINUED ON NEXT PAGE)

FIGURE 3.5
MARINE NET PRIMARY PRODUCTIVITY IN THE BEAUFORT CONTINENTAL COAST AND SHELF ECOREGION USING 13 YEARS OF SEAWIFS OBSERVATIONS. Contour lines indicate the 10 per cent most productive pixels based on a 90th percentile analysis.
Source: Arctus Inc. and WWF 2011.



REMOTE SENSING RELIES ON SATELLITE IMAGERY TO DISCOVER WHAT'S HAPPENING ON THE GROUND, PARTICULARLY IN INACCESSIBLE OR RARELY VISITED PLACES, SUCH AS MOST AREAS OF THE ARCTIC.

FIGURE 3.6
AREAS OF EXCEPTIONALLY HIGH TERRESTRIAL NET PRIMARY PRODUCTIVITY IN THE CENTRAL CANADA ARCTIC ECOREGION.
Source: WWF.



•• PERCENTILES WERE CALCUATED FOR EACH BIOCLIMATIC SUBZONE WITHIN THE ECOREGIONAL STUDY UNIT.

Based on ten year median (2000-2010) of peak seasonal NDVI (June-August), calculated from MODIS monthly reflectance at 1000m resolution (MOD13A3).

DETECTING PRODUCTIVITY AND DIVERSITY (CONTINUED FROM PREVIOUS PAGE)

To measure biological diversity on land, RACER uses satellite-derived radar measures of landscape topography that reveal its hills, valleys, plains, etc. The richness of different landforms represents a wealth of habitats that can support a larger variety of sets of interacting species through differences in landform effects on available water, nutrients, and heat (Walker et al. 2002; CAVM Team 2003; Walker et al. 2005; Rocchini et al. 2010). Diversity of plants, even within the vegetation classes mapped by the CAVM, is also strongly affected by the richness of topographic landforms within the landscape (Walker et al. 2002). RACER uses computer-derived digital elevation models (DEMs) to picture landscape topography from satellite remote data, assessing whether places within an ecoregion show an exceptional variety of landforms packed within a single area (Fig. 3.7).

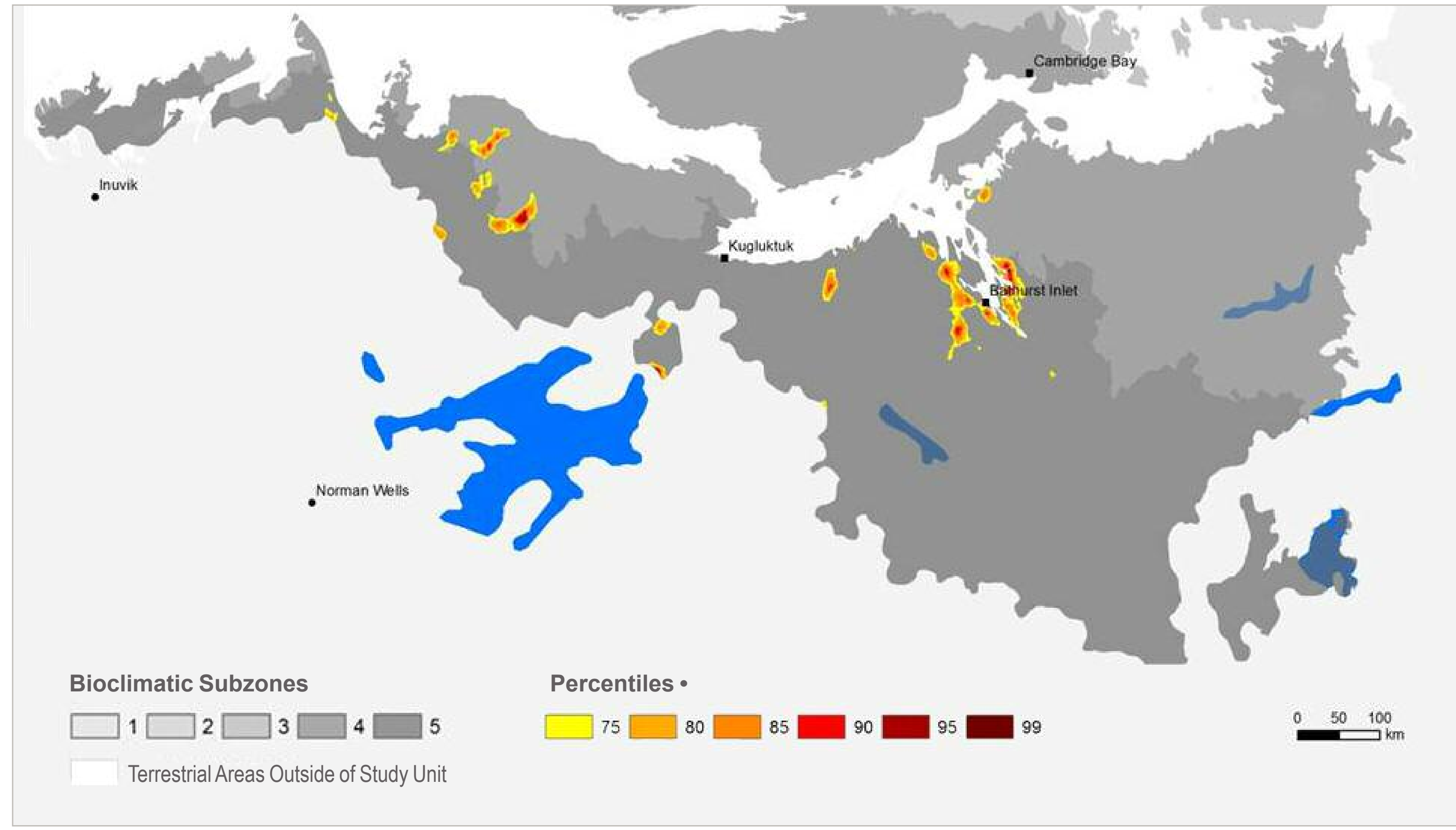
While the relationship between topographic–surface-heterogeneity and diversity may also hold true for the sea floor, arctic marine maps of seabed topography–such as information from the International Bathymetric Chart of the Arctic Ocean (IBCAO)– are available only at a relatively coarse resolution of 2 – 2.5 km and are not useful as proxy-indicators of benthic diversity. RACER continues to develop the potential for using measures of seabed variability, complexity, rugosity, etc., as proxies for biological variety of the sea bottom (benthos).

FIGURE 3.7
AREAS OF SIGNIFICANT LANDFORM HETEROGENEITY IN THE CONTINENTAL PART OF THE CENTRAL CANADA ARCTIC ECOREGION
Source: WWF.

• Significance of landform heterogeneity is defined here as the upper 75th percentile of values for the ecoregion.

Landform heterogeneity depicted here is calculated in two steps:
1. Diversity of landform features (via the Topographic Position Index**) was calculated at a 600m distance.
2. The diversity of those assemblages of landform features was assessed at the scale of 20km.

**Landform features were derived using the Topographic Position Index (TPI) calculated at 100m and 2km and based on ASTER GDEM (25km).



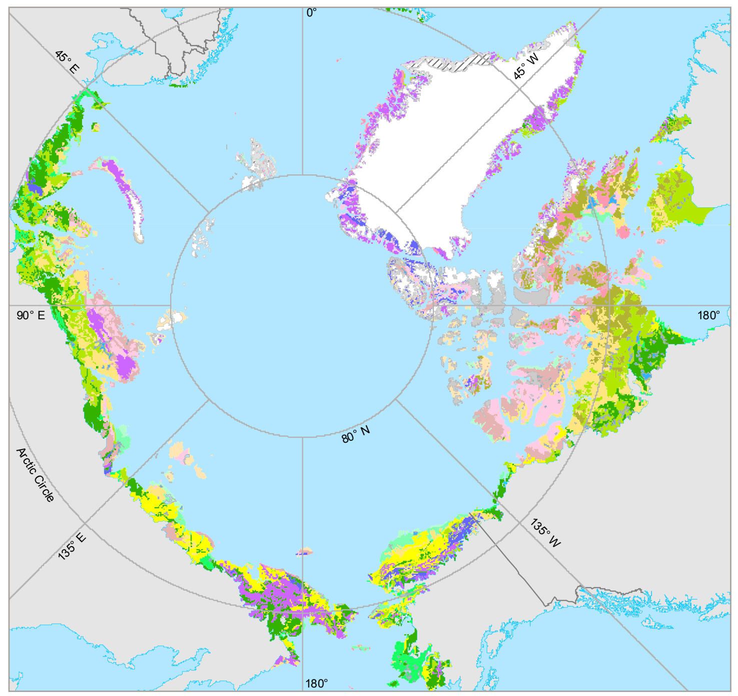
RACER RELIES ON THE VERSATILITY AND DETAIL OF THE CIRCUMPOLAR ARCTIC VEGETATION MAP (CAVM) TO LINK THE DRIVERS RESPONSIBLE FOR THE EXCEPTIONAL PRODUCTIVITY AND DIVERSITY OF TERRESTRIAL KEY FEATURES TO CLIMATE CHANGE FORECASTS.

FIGURE 3.8

ARCTIC VEGETATION CLASSES.

Sources: CAVM Team 2003, Walker et al. 2005.

- Cryptogam, herb barren
- Cryptogam barren complex (bedrock)
- Noncarbonate mountain complex
- Carbonate mountain complex
- Prostrate dwarf-shrub, herb tundra
- Prostrate/Hemiprostrate dwarf-shrub tundra
- Rush/grass, forb, cryptogam tundra
- Graminoid, prostrate dwarf-shrub, forb tundra
- Nontussock sedge, dwarf-shrub, moss tundra
- Tussock sedge, dwarf-shrub, moss tundra
- Erect dwarf-shrub tundra
- Low-shrub tundra
- Sedge/grass, moss wetland
- Sedge, moss, dwarf-shrub wetland
- Sedge, moss, low-shrub wetland
- Nunatak complex
- Glaciers
- Water
- Lagoon
- Non-Arctic Areas



Lambert Azimuthal Equal Area Projection
Longitude of or igin: -180°, Latitude of origin: 90°

0 250 500 750 1000 Kilometers

THE CIRCUMPOLAR ARCTIC VEGETATION MAP (CAVM)

RACER relies on the versatility and detail of the Circumpolar Arctic Vegetation Map (CAVM) to link the drivers responsible for the exceptional productivity and diversity of terrestrial key features to climate change forecasts. CAVM is an international project to describe and map categories of land vegetation that occur across the Arctic. The effort by a global team of arctic vegetation scientists representing the six arctic countries–Canada, Greenland, Iceland, Norway, Russia, and the United States–used high-resolution satellite images to determine hundreds of plant communities throughout the arctic landscape (CAVM Team 2003; Walker et al. 2005).

The CAVM-determined plant communities were then classified into 15 "types" based on general plant growth and form (Fig. 3.8; CAVM Team 2003, Walker et al. 2005). These include vegetation groups found in several categories of arctic barrens and mountains (e.g., low plants, mosses, and lichen), tundra (e.g., low and erect shrubs, grasses, and sedges), and wetlands (e.g., sedges, mosses, wetland shrubs). Importantly, the CAVM plant classes also reflect variation in the combined effects of three characteristics–soil moisture, soil quality, and temperature (Fig. 3.4). For instance, some landscapes at high latitudes are dry, cool (in the summer), and barren and are characterized by plant classes of very sparse, low-growing herbs, lichen and mosses. Much farther south, on the other hand, warmer wetlands host plant classes with sedges.

TERRESTRIAL ECOREGIONS IN THE ARCTIC ARE INFLUENCED BY THE SIGNIFICANT EFFECTS OF SUMMER AIR TEMPERATURE.

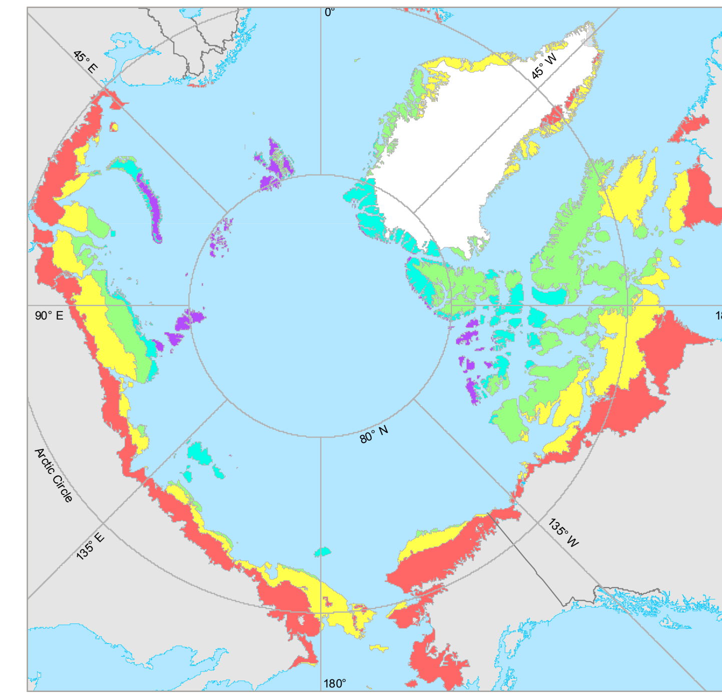
FIGURE 3.9

BIOCLIMATIC SUBZONES OF THE ARCTIC

Bioclimatic subzones of the Arctic used in the CAVM and delineated by mean July temperatures and Summer Warmth Index.

Sources: CAVM Team 2003, Walker et al. 2005.

- ZONE A, mean July temperature 0-3°C
- ZONE B, mean July temperature 3-5°C
- ZONE C, mean July temperature 5-7°C
- ZONE D, mean July temperature 7-9°C
- ZONE E, mean July temperature 9-12°C
- NON ARCTIC
- GLACIERS



Lambert Azimuthal Equal Area Projection
Longitude of or igin: -180°, Latitude of origin: 90°

0 250 500 750 1000 Kilometers

TEMPERATURE SUBZONES

Terrestrial ecoregions in the Arctic are influenced by the significant effects of summer air temperature. Landscapes–both between different ecoregions and within individual ecoregions–become dramatically cooler closer to the pole. Colder temperatures through the growing season, in turn, have a profound effect on plant growth, plant types, and reduce productivity in the more northerly reaches within a single ecoregion. In the tundra of the Central Canada arctic ecoregion, for example, the temperature driver allows shrubs to grow taller than knee height only in the southernmost portion (CAVM Team 2003, Walker et al. 2005). These within-ecoregion temperature impacts mean identifying places of exceptional productivity across entire ecoregions is not helpful.

RACER accommodates and corrects for large differences of within-ecoregion air temperature and the resulting difference in plant productivity by subdividing its analysis of productivity according to subzones based on measures of average summer warmth. To accomplish this, RACER relies on the delineation for *bioclimatic subzones* within ecoregions as characterised by the Circumpolar Arctic Vegetation Map project (Fig. 3.9; CAVM Team 2003; see also sidebar, The Circumpolar Arctic Vegetation Map). The terrestrial assessment of areas of high diversity (using landform heterogeneity analysis) was also subdivided for consistency. Therefore, the terrestrial search for areas of high productivity and diversity deliver independent results for each bioclimatic subzone within an ecoregion, adding a greater degree of precision and sensitivity to the analysis.

ECOLOGICAL RESILIENCE IN A CLIMATE-CHANGED ARCTIC

THE SECOND PART OF THE RACER METHOD LOOKS AHEAD to anticipate whether regional arctic ecosystems with a capacity for resilience today will continue to exhibit the same ecological fortitude in a future altered by climate change.

RACER assesses the likely persistence of key features as sources of ecological resilience in three steps: Step 1 describes climate impacts on the ecoregion; Step 2 estimates the effect on ecological drivers at key features; and Step 3 evaluates the likelihood key features will remain places of exceptional ecological vitality (Fig. 4.1).

RACER gauges the impacts of climate change using the drivers of productivity and diversity as measuring sticks (see sidebar, Ecosystem drivers and conservation). The drivers relevant to RACER's assessment come together in unique ways at the sites of key features to generate locally exceptional ecological vitality. These high-performing combinations of drivers are the result of the physical and ecological characteristics that make up the key features. For example, the characteristics of a key feature's mountainous terrain could affect the drivers of habitat richness or of the moisture and nutrients available for plant growth. Similarly, the nature of a shore-lead key feature could affect how sea ice conditions drive the impact of available sunlight and wind.

Although the same ecological drivers are at work across the entire ecoregion, RACER's assessment is concerned only with their performance (now and into the future) at the places where key features are found–that is, where the drivers align and combine to generate locally exceptional productivity and diversity that helps to confer regionwide resilience.

A FOCUS ON ECOLOGICAL DRIVERS

The novelty of the RACER method is the use of drivers of exceptional productivity and diversity as a quantitative link between climate change and the continued functioning of regional arctic ecosystems.

This link–missing from many other methods attempting to forecast climate-related ecological change–takes advantage of the close relationship between the ecological drivers of productivity and diversity and the climate-affected environmental variables for which forecasts are available.

In Step 1 of the persistence assessment, RACER uses the best-available forecasts of change to climate-related environmental variables provided by Global Circulation Models (GCMs)– computerized models providing 21st century global change scenarios for impacts on rain, snow, temperature, ice, and many other variables (see textbox, Global Climate Modelling). Values for these climate-affected variables are available for locations determined by a worldwide grid. RACER uses these values to calculate the corresponding, region-wide values for the ecoregions being assessed (see Fig. 4.2).

For Step 2, forecasts of change to environmental variables allow RACER to evaluate changes (in direction and degree) to related ecological drivers in the region. For example, projected changes to the extent of arctic sea ice provided by the GCMs can be used to

FIGURE 4.1 THE RACER ANALYTICAL FRAMEWORK

PART 2: ASSESSING PERSISTENCE

STEP 1.
ASSESS IMPACT OF CLIMATE CHANGE ON THE ECOREGION. Identifies the GCM variables that are relevant to the ecoregion and describes the GCM-projected change of these variables through to 2100.

STEP 2.
ESTIMATE HOW DRIVERS OF EXCEPTIONAL PRODUCTIVITY AND DIVERSITY OF KEY FEATURES ARE AFFECTED BY CLIMATE CHANGE. Estimates how projected changes in GCM variables affect the ecoregion-scale drivers and interpret their impact on the drivers of the exceptional productivity and diversity at the scale of key features.

STEP 3.
ASSESS THE PERSISTENCE OF THE CAPACITY OF KEY FEATURES TO CONFER RESILIENCE ON THE ECOREGION AFFECTED BY CLIMATE CHANGE. Assesses the likely persistence of a key feature's continued ability to confer resilience by interpreting whether feature-scale drivers will continue to support exceptional productivity and diversity for identified key features.

RACER USES FORECASTS FROM CURRENT GENERAL CIRCULATION MODELS (GCMs) TO PREDICT CLIMATE-RELATED CHANGES TO ECOLOGICALLY SIGNIFICANT VARIABLES WITHIN ECOREGIONS FOR THE REMAINDER OF THIS CENTURY.

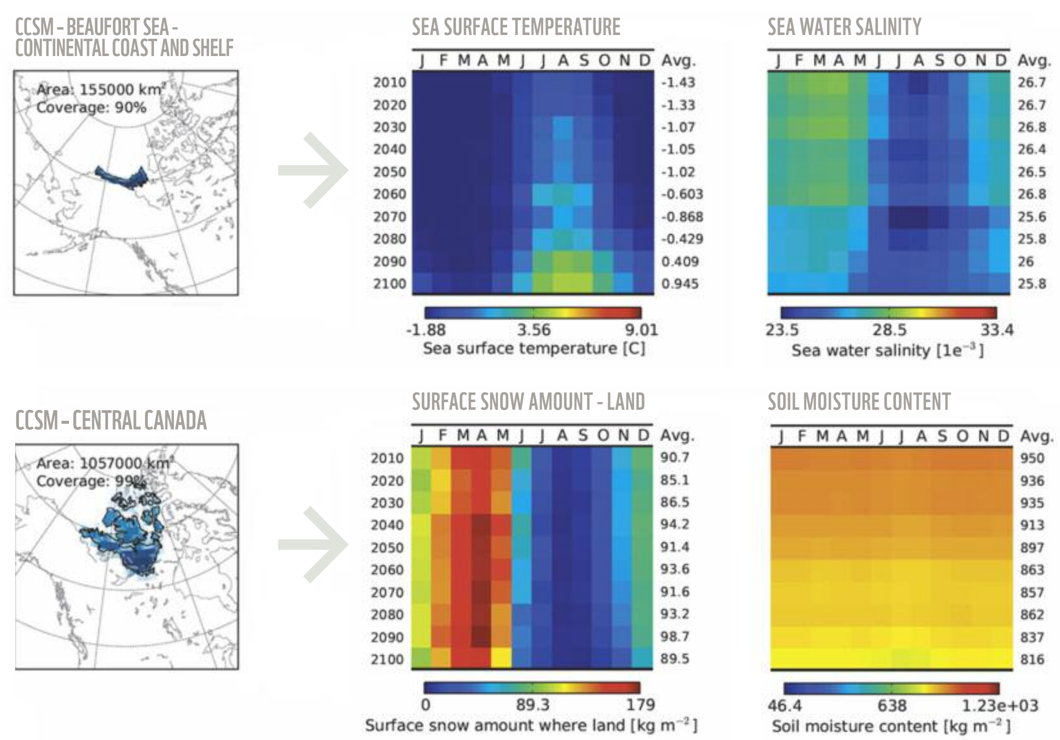


FIGURE 4.2
EXAMPLES OF CLIMATE VARIABLES PROJECTED BY ONE GENERAL CIRCULATION MODEL (GCM) FOR THE BEAUFORT SEA CONTINENTAL COAST AND SHELF ECOREGION (MARINE) AND THE CENTRAL CANADA ARCTIC ECOREGION (TERRESTRIAL).
Source: Huard 2010.

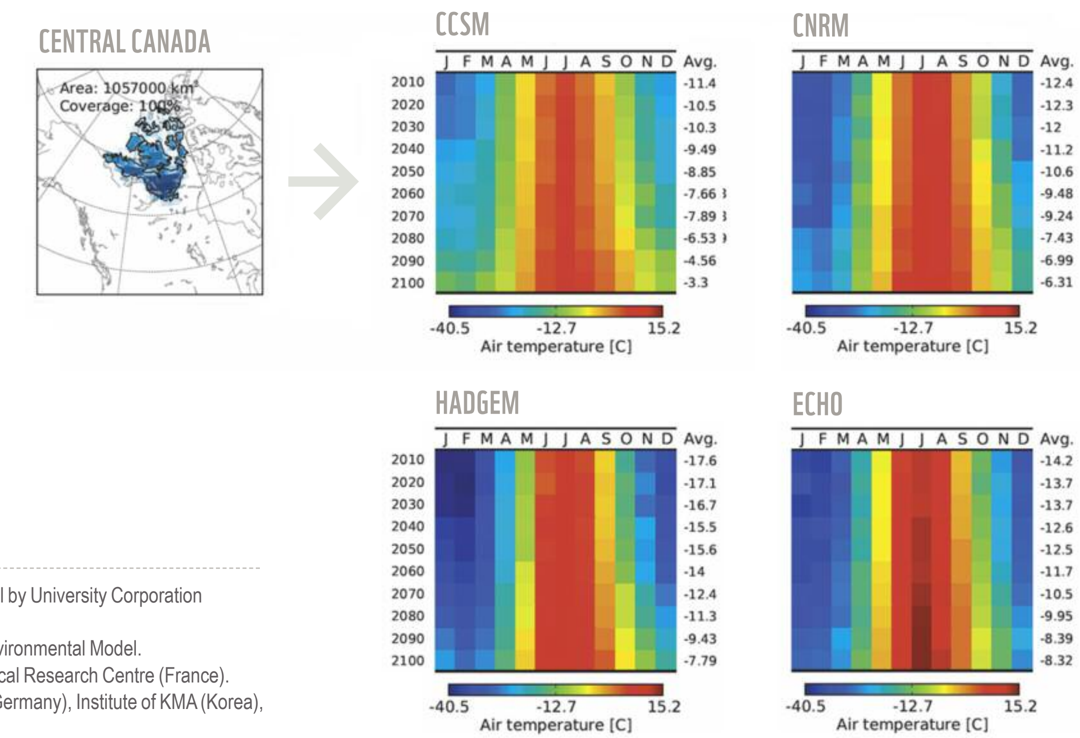
CCSM: Community Climate System Model by University Corporation for Atmospheric Research (USA).

estimate likely changes to the ecological impact of sea ice as a driver. These estimated changes, in turn, can be used to reveal whether the combinations of drivers responsible for the exceptional productivity and diversity at key features will continue in this resilience-relevant role despite changes to their performance caused by climate (Fig. 4.2 and 4.3).

Using drivers as the link, Step 3 of RACER's persistence analysis uses GCM forecasts to assess whether key features are likely to continue as local sources of region-wide ecosystem resilience in a changed climate. While this link is clearest between the GCM variables and the relevant drivers at work across the regions, experts play a pivotal role in evaluating how forecasted climate changes to the region-wide environment can affect the drivers of productivity and diversity at key features. These experts, who live or conduct research in the ecoregion, are asked to use GCM-based predictions of change to regional-scale climate variables to determine the degree and direction of change to the large-scale drivers at work across the ecoregion. They are then asked to evaluate how change to these region-wide drivers affects the performance of the key feature drivers of exceptional productivity and diversity.

USING DRIVERS AS THE LINK, RACER USES GCM FORECASTS TO ASSESS WHETHER KEY FEATURES ARE LIKELY TO CONTINUE AS LOCAL SOURCES OF REGION-WIDE ECOSYSTEM RESILIENCE.

FIGURE 4.3
SURFACE AIR TEMPERATURE PROJECTED BY FOUR GENERAL CIRCULATIONS MODELS (GCMs) FOR THE CENTRAL CANADA ARCTIC ECOREGION.
Source: Huard 2010.



CCSM: Community Climate System Model by University Corporation for Atmospheric Research (USA).
HADGEM: Hadley Centre (UK) Global Environmental Model.
CNRM: Model of the National Meteorological Research Centre (France).
ECHO: Model by the University of Bonn (Germany), Institute of KMA (Korea), and the Model and Data Group].

GLOBAL CLIMATE MODELLING

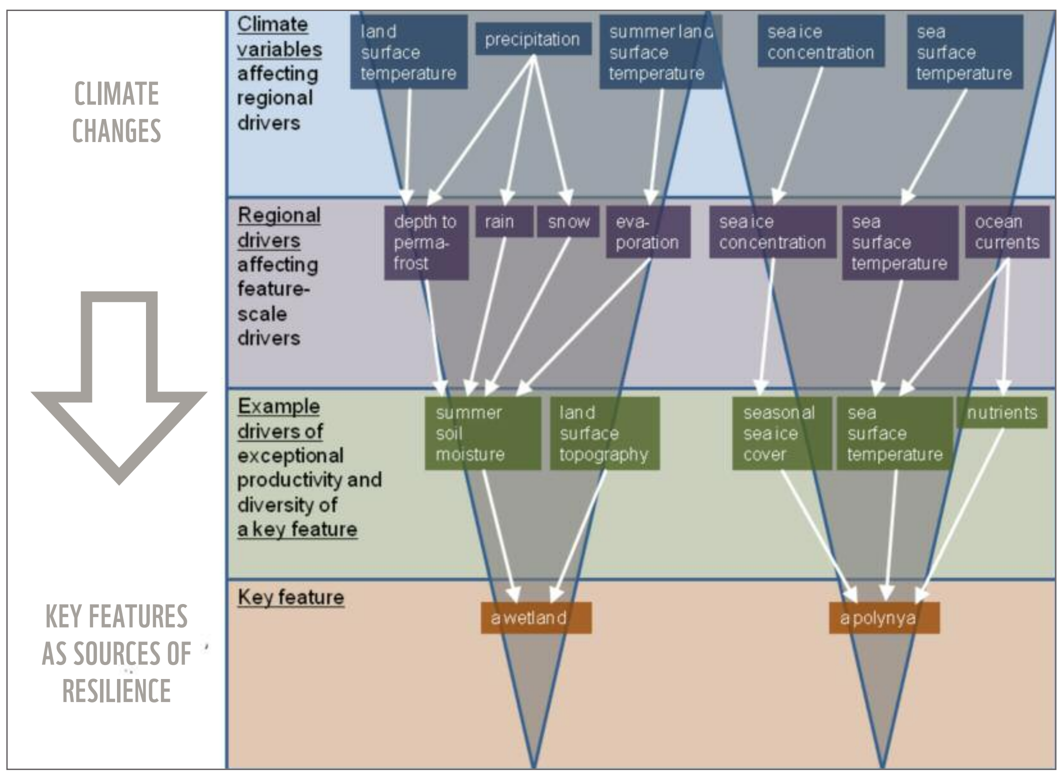
RACER uses forecasts from current General Circulation Models (GCMs) to predict climate-related changes to ecologically significant variables within ecoregions for the remainder of this century. GCMs are a broad group of internationally developed computerized models designed and tested to forecast likely effects of global climate change on rain, snow, temperature, ice, and many other variables for different greenhouse gas emission scenarios into the future. GCMs form the basis of the predictions and warnings by the Intergovernmental Panel on Climate Change (IPCC 2007).

Although the unique relationship between the ocean, land, and atmosphere in the Arctic often complicates these forecasts (e.g., through unexpected lag periods or difficult-to-anticipate climate feedbacks), the prediction accuracy of several GCMs has been proven in the region. RACER relies on data from four of these models that have shown the best agreement between climate projections and reality in the Arctic (Fig. 4.3.). Similarly, RACER uses GCM results for a realistic greenhouse gas emission scenario that reflects a “business as usual” outlook. The so-called A2 scenario offers results for all four selected GCMs (Fig. 4.5). The scenario matches current observations closely and projects a degree of warming for the year 2100 in line with predictions resulting from current global commitments to the reduction of greenhouse gas emissions.

Twenty variables were selected from the GCM data for the RACER analysis. Variable values relevant to the ecoregions were then calculated from nearby GCM values using a weighted average from the GCM data grid to accommodate the irregular shape of the region (Fig. 4.6). The details of this method are described in Huard 2010.

BY FOCUSING ON THE DRIVERS RESPONSIBLE FOR PRODUCTIVITY AND DIVERSITY, RACER CAN GAUGE THE LIKELY IMPACT OF CLIMATE CHANGE ON THE ROLE OF KEY FEATURES AS SOURCES OF ECOSYSTEM RESILIENCE.

FIGURE 4.4
SCALING THE EFFECTS OF CLIMATE CHANGE DOWN TO KEY FEATURES. Source: WWF.



ECOSYSTEM DRIVERS AND CONSERVATION

Climate change is predicted to become a significant and growing threat to arctic ecology in the 21st century. Biodiversity, habitats, and the ecological services arctic people depend on are all expected to face change. But accurately predicting what will happen and what conservationists can do about it has so far proved difficult.

Frequently, attempts to forecast the future involve research that correlates the present status of species and ecosystems with climate variables and then uses a climate model to forecast the future distribution of these species and systems based on assumptions about their requirements and biology. RACER takes another approach.

By focusing on the drivers responsible for productivity and diversity–the engines of ecosystem functioning–RACER can gauge the likely impact of climate change on the role of key features as sources of ecosystem resilience. By establishing the likelihood that regional ecosystems will persist, RACER can inform decisions about the biodiversity and resources that depend on these ecosystems for survival. Resource management and conservation can also use RACER's understanding of the drivers at work to target their efforts at protecting the land and sea features that generate these forces that affect living systems.

For the first time, RACER provides a functional approach to arctic conservation that makes a direct connection between the resilience of ecosystems–ecosystems vital to arctic plants, animals, and people–and the drivers responsible for them. This connection permits an essential view of climate change as affecting the characteristics of features responsible for ecosystem functioning. It is a new way to draw management and planning attention to the forces behind the productivity and diversity that living systems in the Arctic and elsewhere depend upon.

EXPERTS PLAY A PIVOTAL ROLE IN EVALUATING HOW FORECASTED CLIMATE CHANGES TO THE REGION-WIDE ENVIRONMENT CAN AFFECT THE DRIVERS OF PRODUCTIVITY AND DIVERSITY.

FIGURE 4.5
CARBON EMISSIONS PROJECTED BY THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) SRES A2 SCENARIO (SEE SIDEBAR, GLOBAL CLIMATE MODELLING) AND ACTUAL GLOBAL CARBON EMISSIONS.
Source: WWF, using data from IPCC 2000 and CDIAC 2011.

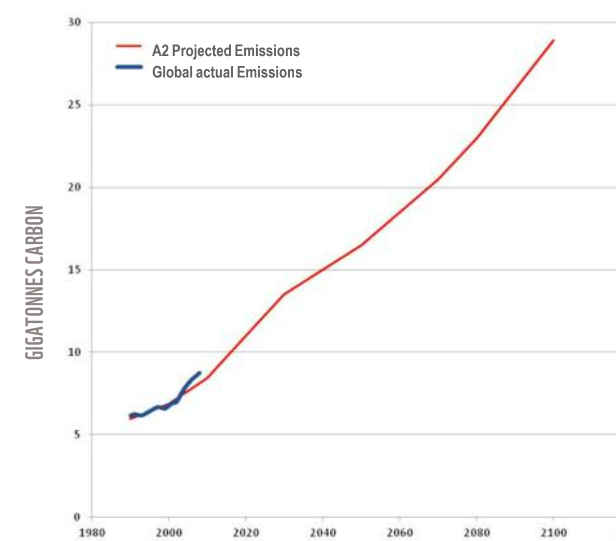
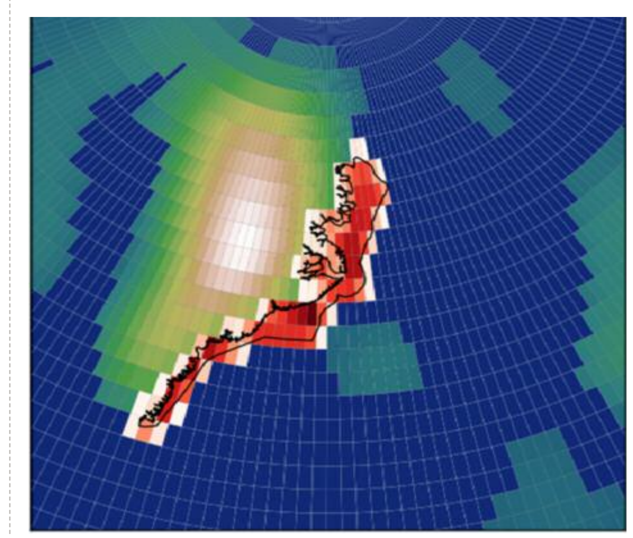


FIGURE 4.6
AN EXAMPLE OF HOW CLIMATE VARIABLES ARE SCALED FROM NODE POINTS TO ECOREGIONS.
Source: WWF.
The black polygon shows an example ecoregion (Eastern Greenland), while the grid lines show the global grid for which General Circulation Model (GCM) variable values are available. The depth of red colour within and around the ecoregion indicates the relevance of a grid point value for calculating the weighted average of a variable for the ecoregion..



RACER ACADEMICS AND EXPERTS

RACER uses the opinions of multiple experts to evaluate and interpret results and bridge several steps in the assessment method. These experts include northern residents, researchers, and academics living in the ecoregions or with extensive, long-term research experience there. Experts help in the collection and interpretation of evidence identifying key features (described in Chapter 3) and are central to assessing whether key features will continue to support region-wide ecosystem resilience in the face of projected changes in climate.

After global climate model data is used to estimate the direction and degree of change to ecoregional-scale drivers, the opinions of experts are instrumental in interpreting the "likelihood" that the feature-scale drivers (influenced by ecoregional-scale drivers) will continue to support exceptional productivity and diversity for identified key features. This interpretative step is critical to assessing the capacity of key features to confer resilience to ecoregions into the future. A list of many of the individuals who have been instrumental advisors to RACER case studies so far is provided in the Acknowledgements of this handbook (page 73).

A MARINE CASE STUDY: THE BEAUFORT CONTINENTAL COAST AND SHELF

THE BEAUFORT CONTINENTAL COAST AND SHELF is a biologically rich, rectangular undersea ecoregion that lies along the coast of northern Alaska and northwestern Canada. RACER's assessment of this important ecoregion is on-going, but the results and description provided here illustrate the RACER method.

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The marine case study described here demonstrates how the RACER approach can reveal conservation targets important to spatial planning and management.

The Beaufort Continental Coast and Shelf ecoregion stretches along 1,100 km of mainland shore as a narrow (up to 120 km wide), relatively shallow (up to 100-200 m deep) shelf that drops off quickly to the north into the deep Canada Basin (Fig. 5.1). The mainly flat seabed is significantly interrupted by the undersea Mackenzie and (smaller, shallower) Kugmallit Canyons. Several smaller rivers flowing into the region are dwarfed by the size and importance of the powerful Mackenzie River which pours into the sea at a large delta. The shelf is bounded by the marine Barrow Canyon to the West and the Amundsen Gulf to the East (Carmack and Macdonald 2002; Carmack et al. 2006; Cobb et al. 2008; Fortier et al. 2008; Ingram et al. 2008).

The Beaufort Continental Coast and Shelf ecoregion provides important migratory habitats for various species of marine mammals (whales), fish, and breeding birds. Large numbers of these species travel to the region in vast (continentally and globally significant) numbers to breed in summer, taking advantage of the season's dramatic surge in plankton growth. In winter, many return to the Bering-Chukchi marine ecoregions or further south along the Pacific Coast (CAFF 2001; Carmack and Macdonald 2002; AHDR 2004; Cobb et al. 2008; Stephenson and Hartwig 2010). Habitat variety in the region (thanks to the influence of the Mackenzie River, glacial features, post-glacial evolutionary history, shelf-edge influences, and ice scour disturbances) contributes to relatively high species diversity on the seafloor (see, for example, Chapman and Kostylev 2005; Cusson et al. 2007).

Subsistence hunters have thrived along the Beaufort Sea coast for millennia with traditional camps and settlements often located close to headlands and river mouths to take advantage of seasonally available fish, birds, whales, and other marine mammals (Cobb et al. 2008; Braund et al. 2010). In the past 40 years, industrial oil and gas exploration and development has been gathering momentum, accelerating the transition of coastal communities from subsistence harvesting to a wage-dominated economy (AHDR 2004; Nuttall 2005; Leduc 2010).

Increasing industrial activity and accelerating climate-related impacts in the ecoregion add urgency to the need for a strategic, forward-looking approach to regional natural resource use and fish and wildlife management (for example, see Aagaard and Carmack 1994; ACIA 2004; Walsh 2008). RACER's assessment provides conservation targets to encourage resilience in the Beaufort Continental Coast and Shelf and to help this unique and ecologically important arctic area respond and adapt to rapid change.

KEY FEATURES IMPORTANT FOR RESILIENCE

RACER began its pilot rapid assessment of ecosystem resilience in the Beaufort Continental Coast and Shelf ecoregion in 2009. The work–involving an analysis of satellite remote sensing data (see, for example, Tremblay et al. 2011), relevant scientific literature, and expert evaluation–has so far identified and located eight marine key features as places of current and future conservation importance for the ecoregion. These places were first identified and mapped, because they are relevant to the resilience of the regional-scale ecosystem now. Second, they were assessed as likely to continue to provide major support to the marine ecosystem resilience despite climate change forecasts in the future. Changes to the key features listed for this ecoregion may follow as the RACER assessment is being finalised (e.g., identifying near-shore lagoons and river mouths important for migrating water birds, fish and hunters or acquiring new refined information about the seabed terrain that may suggest areas of exceptional habitat variety and ocean-floor species diversity).

The eight key features described here were identified by lines of evidence that suggest exceptional productivity or diversity (or both) during certain times of the year when plankton is most abundant and wildlife and Inuit hunters tend to congregate in these areas. This ecological vitality is used to infer the importance of these features as sources of ecological resilience for the wider ecoregion. The methods used in this evaluation are explained in general in the earlier chapters of this handbook and are described in more detail on the RACER website (www.panda.org/arctic/racer). The resulting map of key features (Fig. 5.4) is intended to inform discussions about the best management approaches to safeguard the exceptional productivity and/or diversity of these places (and the drivers responsible for them) to better fortify the resilience inherent in the larger ecosystem.

The second part of RACER evaluates the likelihood that key features will continue to contribute to region-wide resilience when

THE BEAUFORT CONTINENTAL COAST AND SHELF ECOREGION PROVIDES IMPORTANT MIGRATORY HABITATS FOR VARIOUS SPECIES OF MARINE MAMMALS, FISH, AND BREEDING BIRDS.

21st century climate change affects the drivers at work in these ecologically vital places. The main drivers behind the exceptional productivity and/or diversity of the ecoregion's key features are described in Table 5.1. Drivers susceptible to the impacts of climate change, such as sea surface temperature, sea ice (see Fig. 5.3), and salinity, figure prominently in the ecological performance of key features. But climate-impervious drivers, such as seabed terrain responsible for nutrient-rich upwelling, are also important. These drivers will provide an important focus for future conservation efforts.

Some of the features described here show areas of overlap with others. Often, this reflects an alignment of both high biological productivity and habitat variety (diversity). For key features that overlap adjacent RACER ecoregions, we show their full extent beyond the ecoregion boundary.

1. BARROW CANYON AND POLYNYA

At the western edge of the ecoregion, the Barrow Canyon is a steep-sided, undersea canyon off Point Barrow, Alaska. Here, relatively warm, salty, and biologically rich Pacific Ocean water circulates northwards through the Bering Strait and contributes to an upwelling of sea-bottom nutrients and minerals caused by the seabed topography. These characteristics also correspond with a large recurring polynya (where waters are deeper than 20 m) during winter and spring. The combined result of these drivers–undersea topography, seasonal ice cover, currents, and sea surface temperature–is a key feature with very significant open water habitat to support high productivity and with varied undersea terrain providing multiple habitats for a diverse array of species. These characteristics, in turn, support large marine mammals and other animals that provide predictable hunting opportunities for local Inuit and other northern residents. Despite substantial expected changes to sea surface water temperature, salinity, and sea ice concentration forecast by relevant General Circulation Models (GCMs), nutrient upwelling and habitat heterogeneity are expected to continue to contribute to exceptional productivity and diversity in a climate-altered future. After consulting with experts, RACER determined that the likelihood was *high* that this key feature would remain a source of ecosystem resilience for the ecoregion through to 2100.

2. MACKENZIE CANYON

Just beyond the mouth of the Mackenzie River, the Mackenzie Canyon is a broad undersea canyon that contributes to an upwelling responsible for the vertical mixing of nutrients, minerals, and photosynthetic life. This important key feature affects the dynamics and availability of nutrients delivered to the shelf from the Mackenzie

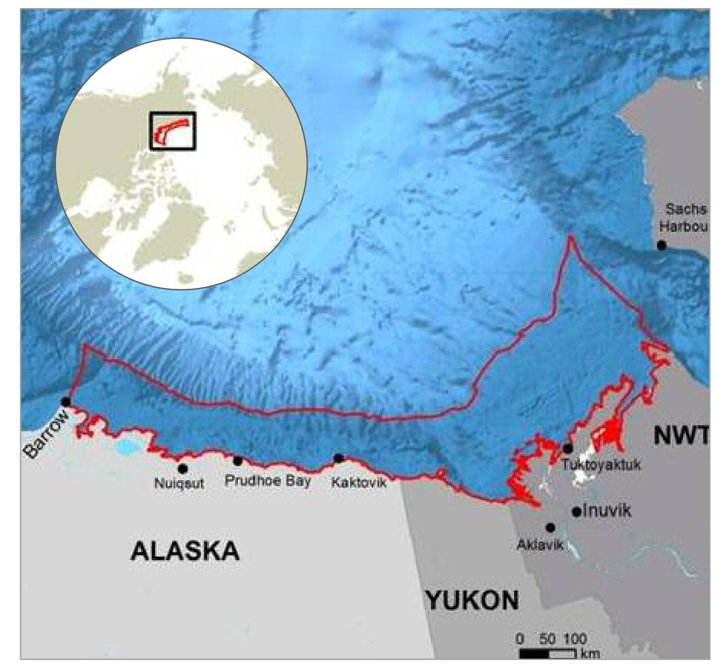
ECOREGION CHARACTERISTICS

The Beaufort Continental Coast and Shelf is biologically rich. The ecoregion's few major rivers, including the Mackenzie River in Canada and the Colville River in Alaska, as well as many smaller watercourses deliver vast amounts of ecologically important nutrients, sediments, and freshwater to the shelf. The Mackenzie River, for example, is responsible for a large estuarine system over the Canadian portions of this shelf and ranks fourth among circum-Arctic marine systems for freshwater input and first for sediment (largely due to the enormous drainage including many areas south of the permafrost boundary; see Fig. 5.1).

Predominantly eastward currents just above the seabed (about 200 m depth) bring salty, nutrient-rich Pacific–and some Atlantic-origin–waters to the ecoregion. Although the clockwise Beaufort Gyre current dominates water movement on the shelf, other complex currents operate at different depths at different times, generating eddies that carry nutrients. Layers of salty versus fresh water are highly variable at different depths. For example, Pacific-origin water (via the Bering Strait) is rich in nutrients and relatively low in salt at depths of between 40 and 280 m. In deeper water, salty Atlantic water is most common (Carmack and Wassmann 2006).

THE CASE STUDY EXAMPLE DEMONSTRATES HOW THE RACER APPROACH CAN REVEAL CONSERVATION TARGETS IMPORTANT TO SPATIAL PLANNING AND MANAGEMENT IN THE ARCTIC.

BATHYMETRY



WATERSHEDS

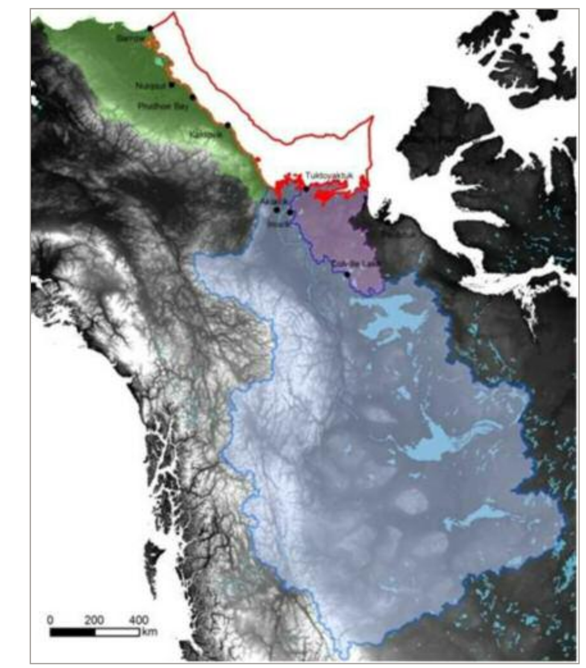


FIGURE 5.1
THE BEAUFORT SEA AND CONTINENTAL SHELF ECOREGION.
Source: WWF.

- Southern Beaufort Sea Drainage
- Mackenzie River
- Other

ECOREGION CHARACTERISTICS (CONTINUED FROM PREVIOUS PAGE)

Annual and seasonal effects play a large role in the ecology of the region. Sea-ice cover, volume of riverine discharge, surface air and water temperatures, and the clearness of the water all change with the seasons and across years. Throughout winter, floe rafting at the edge of the land-fast ice near the Mackenzie River builds stamukhi–thick ice ridges parallel to the coast that trap and hold large amounts of freshwater until the spring melt. Until recent years, the ecoregion was typically mainly covered with ice from October until May-June, but recent years have seen sharp increases in the total duration of the ice-free period. Wind and waves, meanwhile, influence the movement and impact of water from the Mackenzie River, and affect the size of shore leads (gaps between pack ice and the land-fast ice) and polynyas (areas of open water regularly occurring in winter/spring, surrounded by ice). Figure 5.2 summarizes the seasonal patterns of the main physical and biological characteristics of the current Beaufort Continental Coast and Shelf ecosystem.

THE BEAUFORT CONTINENTAL COAST AND SHELF IS BIOLOGICALLY RICH…ANNUAL AND SEASONAL EFFECTS PLAY A LARGE ROLE IN THE ECOLOGY OF THE REGION.

River watershed. As a consequence, plankton productivity is high and many fish and other animals congregate around the area to feed at different times of year. Upwelling created by the canyon slope, river outflows, and currents combine with a varied sea-bottom terrain to create significant habitat heterogeneity and, consequently, species diversity. Thus, like the Barrow Canyon, the Mackenzie Canyon is a key feature comprised of four main drivers–sea-bottom topography, seasonal ice cover, currents, and sea surface temperature–responsible for outstanding productivity (thanks to high nutrient input) and diversity. After expert consultation, RACER assessed how climate-affected variables forecast to change in the region–surface water temperature, salinity, and sea ice concentration–might affect these feature-scale drivers. The assessment concluded the predicted climate changes are not expected to interfere with the functioning of this key feature's main drivers through to 2100. RACER concluded that the likelihood was *high* that this key feature would remain an important source of ecosystem resilience within this century.

3. MACKENZIE RECURRING SHORE LEADS

Open-water shore leads–waterway openings between the mobile pack ice and the land-fast ice–are found at times in winter and spring across the Beaufort Continental Coast and Shelf (Stirling and Cleator 1981; Eiken et al. 2005), but the most frequently recurring leads in this ecoregion (>17 per cent probability) occur not far from the mouth of the Mackenzie River. These Mackenzie Recurring Shore Leads can vary markedly in width–from a few meters up to 70 km across–depending on prevailing ice and wind conditions. Although productivity is low during the winter, open water conditions in the spring allow light to penetrate and encourage early phytoplankton blooms. These seasonal surges in productivity also make this key feature a crucial habitat during the spring migration for water birds and marine mammals (Stirling and Cleator 1981; Cobb et al. 2008; Audubon Alaska and Oceana 2010; Stephenson and Hartwig 2010). Like the previously mentioned Beaufort key features, the Mackenzie Recurring Shore Leads encourage exceptional ecological vitality mainly through the combined effects of four drivers: undersea topography, seasonal ice cover, currents, and sea surface temperature. This vitality (seasonally high productivity and diversity) ensures these shore leads are a key feature that is a source of region-wide ecosystem resilience. GCM forecasts for climate-affected variables relevant to the ecoregion suggest marked changes are expected for surface water temperature, salinity, sea ice concentration and precipitation. These are likely to have some impact on three of the drivers important to this key feature (seabed terrain will be mainly unaffected). However, after expert consultations, the RACER assessment suggests these forecast changes are unlikely to substantially interfere with the drivers of exceptional productivity and diversity for this key feature. Thus, RACER determined the likelihood was *medium-to-high* that this key feature would remain an important source of ecosystem resilience for the ecoregion for this century.

INCREASING INDUSTRIAL ACTIVITY AND ACCELERATING CLIMATE-RELATED IMPACTS IN THE ECOREGION ADD URGENCY TO THE NEED FOR A STRATEGIC, FORWARD-LOOKING APPROACH.

4. KUGMALLIT CANYON

The marine Kugmallit Canyon is not as deep or as steep-sided as the Mackenzie Canyon, but this key feature is nevertheless an area of relatively varied sea-bottom topography, including a shallow trough (or canyon) and an area of undulating seabed, responsible for habitat and species diversity. The undersea terrain is also thought to be important for water upwelling that contributes (at times) to the availability of nutrients and to plankton productivity. This, in turn, provides prime feeding conditions for marine mammals such as bowhead whales. The key feature also benefits from the river plume of nutrients and minerals from the nearby Mackenzie River and from oceanic currents that contribute to upwelling. A similar suite of four drivers–sea-bottom terrain, sea ice cover, currents, and sea surface temperature–account for much of the exceptional productivity and diversity at this key feature, and the main forecasted changes to water temperature, ice concentration, and salinity are not expected to disrupt this source of ecological strength into the future. Based on its expert evaluation, RACER concluded that the likelihood was *high* that this key feature would remain a source of ecosystem resilience for the ecoregion through the remainder of this century.

5. MACKENZIE PLUME

The vast majority of the near-surface primary production in this ecoregion is found within this key feature. Although large quantities of dissolved organic material and sediment can be found right at the mouth of the Mackenzie River, the far-larger plume that billows from the river delta across a large area of the continental shelf feeds exceptional plankton growth and other productivity and makes this an important key feature for this ecosystem. Indeed, the plume is responsible for enormous inputs of nutrients and freshwater to the ecoregion and to the entire arctic basin. Water circulation patterns in the area also heavily influence the availability of these nutrients. Large concentrations of many species depend on this key feature, especially during the biologically productive, open-water season (Cobb et al. 2008; Stephenson and Hartwig 2010). On the other hand, the plume area is characterized by limited habitat variety and its consequent negative impact on species diversity. The four main drivers at work at this key feature–nutrients, salinity, water currents, and sea surface temperature–enable the remarkable outstanding

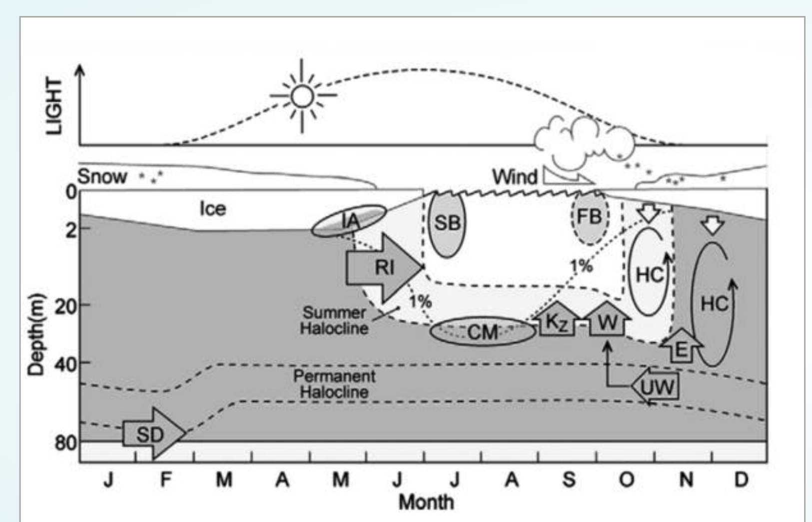


FIGURE 5.2
AN ILLUSTRATION OF THE PHYSICAL PROCESSES AFFECTING THE SEASONAL PATTERN OF PRIMARY PRODUCTION ON AN ARCTIC SHELF.

Kz is vertical diffusion; W is vertical velocity; E is entrainment; RI is river inflow; HC is haline convection; SD is shelf drainage; UW is upwelling; IA is ice algae; SB is spring bloom; FB is fall bloom, and CB is chlorophyll maximum. The 1 per cent light level is depicted by the fine dashed line. Stratification is denoted by the bold dashed line. The light-shaded domain represents the summer mixed–layer. Source: Carmack et al. 2006.

CLIMATE MODEL FORECASTS SUGGEST MARKED CHANGES TO SURFACE WATER AND AIR TEMPERATURE, SALINITY, SEA ICE CONCENTRATION, AND PRECIPITATION IN THE WATERSHED OF THE MACKENZIE RIVER.

productivity but also make this feature more susceptible than some others to climate impacts. Climate model forecasts suggest marked changes to surface water and air temperature, salinity, sea ice concentration, and precipitation in the watershed of the Mackenzie River. Experts considered the degree and direction of these impacts on the drivers important to the Mackenzie Plume key feature, and they concluded that the effects of change would not substantially offset the expected ecological performance of this important source of ecoregional productivity. Based on these conclusions, RACER determined that the likelihood was *medium-to-high* that this key feature would remain an important source of ecosystem resilience for the ecoregion in the decades to come.

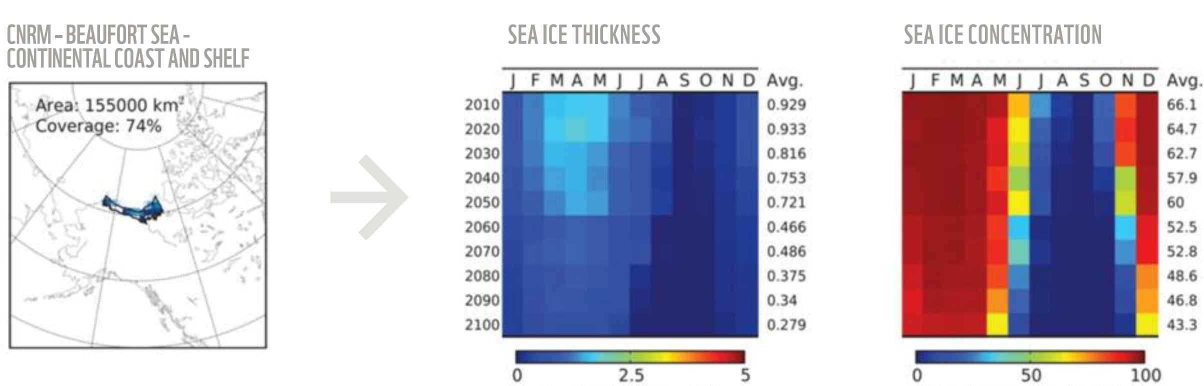
6. CAPE BATHURST SLOPE

The Cape Bathurst Slope is an area of diverse seabed topography that sits at and just beyond the eastern edge of the ecoregion. The complex water circulation patterns at this key feature contribute to surges in energy and nutrient transport at different times of year. Though not a canyon or a trough, the Cape Bathurst Slope is the site of significant upwelling and mixing of nutrient-rich water under different conditions (Williams and Carmack 2008). These characteristics contribute to exceptional productivity, and very high concentrations of plankton, seabed life, water birds, and marine mammals (especially bowhead whales) can be found regularly at certain times of year at this key feature (Cobb et al. 2008). Meanwhile, the undersea terrain at the Bathurst Slope is also varied and provides a mix of habitats to support exceptional sea-bottom species diversity (Cusson et al. 2007). The main drivers that combine to create the exceptional ecological performance of this key feature are considered to be the sea-bottom topography, water circulation, surface water temperature, and nutrients. The influential variables for which GCMs forecast changes in the ecoregion are sea surface temperature and sea ice concentration. These are expected to impact many of the drivers of ecological vitality at this key feature (with, of course, no effect on undersea terrain) to a degree that influences but does not disrupt the area's outstanding productivity and diversity. This evaluation by consulting experts helped RACER conclude that the likelihood was *medium-to-high* that this key feature would remain a source of ecosystem resilience for the ecoregion to the year 2100.

7. CAPE BATHURST-AMUNDSEN GULF POLYNYA

This well-known, large polynya at the eastern end of the ecoregion is highly variable. In some years, the open water conditions of this feature extend into the region of the Beaufort Continental Coast and Shelf (often overlapping with the Cape Bathurst Slope key feature above) (Stirling and Cleator 1981; Cobb et al. 2008;

FIGURE 5.3
PROJECTIONS FOR SEA ICE THICKNESS AND SEA ICE CONCENTRATION BASED ON A GENERAL CIRCULATION MODEL (GCM) FOR THE BEAUFORT CONTINENTAL COAST AND SHELF ECOREGION THROUGH TO THE 21ST CENTURY. Source: Huard 2010.

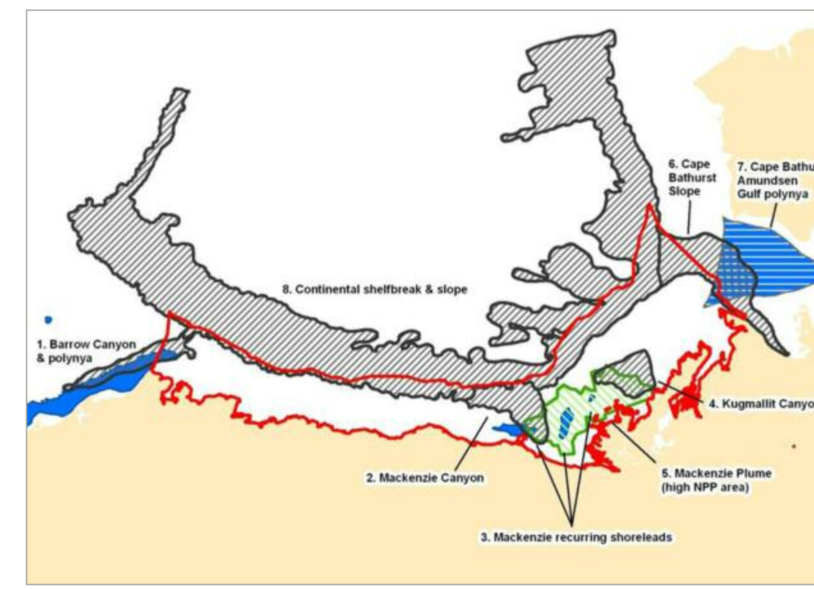


SEASONAL SURGES IN PRODUCTIVITY MAKE THE MACKENZIE RECURRING SHORE LEADS A CRUCIAL HABITAT DURING THE SPRING MIGRATION FOR WATER BIRDS AND MARINE MAMMALS.

FIGURE 5.4
KEY FEATURES OF THE BEAUFORT CONTINENTAL COAST AND SHELF ECOREGION.
Source: WWF.

LEGEND
- RACER Study Unit M27
- Bathymetric Features
- High Productivity Areas (NPP – 90th Percentile)
- Cape Bathurst Polynya
- Probability of Shoreleads Occuring between Dec and Apr (17 – 47 %)

KEY FEATURES
1. Barrow canyon and polynya
2. Mackenzie canyon
3. Mackenzie recurring shoreleads
4. Kugmallit canyon
5. Mackenzie plume (high NPP area)
6. Cape Bathurst slope
7. Cape Bathurst – Amundsen Gulf polynya
8. Continental shelfbreak & slope



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THE MACKENZIE PLUME IS RESPONSIBLE FOR ENORMOUS INPUTS OF NUTRIENTS AND FRESHWATER TO THE ECOREGION AND TO THE ENTIRE ARCTIC BASIN.

Ingram et al. 2008; Stephenson and Hartwig 2010). In winter, absolute biological productivity is low at this key feature, but the open water of the polynya allows the early spring return of longer days of sunlight to influence plankton blooms and other biotic activity. The result is seasonally exceptional productivity with a significant impact on life at the eastern extremes of the Beaufort Continental Coast and Shelf. The ecological performance of this key feature is also influenced by the sea-bottom topography that lends habitat variety and is thought to support considerable benthic diversity. The main drivers responsible for the exceptional performance of this key feature are considered to be seasonal ice cover, undersea terrain, water circulation, and sea surface temperature. When experts considered the region-wide changes forecast by GCMs for four relevant climate-affected variables–surface air temperature, sea surface temperature, salinity, and sea ice concentration–they determined the feature-scale drivers would be affected but were likely to continue to contribute to seasonally exceptional ecological activity in the future. Based on these conclusions, RACER evaluated the likelihood that this key feature would remain a source of ecoregion-wide resilience for this century as *medium*.

8. CONTINENTAL SHELF BREAK AND SLOPE

The Continental Shelf Break and Slope comprise a large, mostly very-deep-water key feature that occurs along the northern boundary of the ecoregion. (The shelf is considered to be the seabed above depths of 1000 m). Marked sea-bottom heterogeneity, even at significant depths, contributes to habitat variety and is consequently thought to support high levels of species diversity–although little is known of the undersea organisms and communities living in these habitats. Productivity, meanwhile, is considered quite low in the deep water, but currents contribute to some transport and mixing of deep-sea stored nutrients that support biotic activity nearer to the surface. Undersea terrain and water circulation, therefore, are identified as the two main drivers at this key feature. Climate change impacts expected from climate model forecasts suggest the most relevant effects will be retreating ice cover and changes to salinity. Importantly, these create the potential for a positive effect on ecological vitality for this key feature as ice opens to increase sunlight penetration and allows changes to wind fields and effects on the open water in combination with water circulations to trigger the re-suspension (and altered dynamics) of deep sediments, including nutrients (see Carmack and Macdonald 2002; Carmack et al. 2006 for further consideration). RACER considered these conclusions in its determination that the likelihood was *high* that this key feature would be an important source of ecosystem resilience for the ecoregion later this century.

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TABLE 5.1
THE LIKELY PERSISTENCE OF KEY FEATURES IN THE FACE OF CLIMATE CHANGE.
The likelihood that key features will continue to confer resilience to the ecoregion in the future is scored as high (H), medium (M), or low (L) based on projected changes to main climate variables using GCMs and their effect on geophysical drivers.
Source: WWF.

CLIMATE VARIABLES:
Sea Surface Temperature (SST);
Salinity; Sea-Ice Thickness, Sea-Ice Concentration (SIC);
Precipitation (P); Surface Air Temperature (SAT).
Persistence index: H – high; M – medium; L – Low
* Relevant for the Mackenzie plume is the precipitation over the watershed of the Mackenzie River, i.e. outside the Beaufort coast and shelf ecoregion.

KEY FEATURE	MAIN DRIVERS	CURRENT BIOLOGICAL PRODUCTIVITY & HABITAT HETEROGENEITY	MAIN CHANGES TO GCM CLIMATE VARIABLES	ASSESSED PERSISTENCE OF KEY FEATURE'S FUTURE ABOVE-AVERAGE PRODUCTIVITY / DIVERSITY
Barrow canyon & polynya	Benthic topography Seasonal Ice Cover Water circulation/currents Sea Surface Temperature	High productivity and benthic habitat heterogeneity; warm saline Pacific water incursions.	SST Salinity SIC	H
Mackenzie canyon	Benthic topography Seasonal Ice Cover Water circulation/currents Sea Surface Temperature	High riverine plume nutrient inputs & heterogeneity, with upwelling driven by currents.	SST Salinity SIC	H
Mackenzie recurring shoreleads	Benthic topography Seasonal Ice Cover Water circulation/currents Sea Surface Temperature	Low absolute winter productivity, but open water regime allows light penetration/biotic activity.	SST Salinity SIC P	M-H
Kugmallit canyon	Benthic topography Seasonal Ice Cover Water circulation/currents Sea Surface Temperature	High riverine plume nutrient inputs & heterogeneity, with upwelling driven by currents.	SST Salinity SIC	H
Mackenzie plume	Salinity Nutrients Water circulation/currents Sea Surface Temperature	High sediment-laden nutrient inputs, but low habitat heterogeneity. Water circulation patterns influence nutrient availability.	SST Salinity SIC SAT P*	M-H
Cape Bathurst slope	Benthic topography Water circulation/currents Sea Surface Temperature Nutrients	Habitat heterogeneity high, with resultant diversity of benthic fauna and current-induced nutrient availability.	SST SIC	M-H
Cape Bathurst-Amundsen Gulf polynya	Benthic topography Seasonal Ice Cover Water circulation/currents Sea Surface Temperature	Low absolute winter productivity, but open water regime allows light penetration/biotic activity.	SST Salinity SIC SAT	M
Continental shelfbreak and slope	Benthic topography Water circulation/currents	Low productivity currently in deep water, but very extensive high seabed habitat heterogeneity.	Salinity SIC	H

A TERRESTRIAL CASE STUDY: EASTERN CHUKOTKA

THE EASTERN CHUKOTKA ECOREGION is a biologically and geographically varied region at the extreme eastern limits of north-eastern Eurasia. Reaching to the tip of the continent where the Bering Strait separates present-day Siberia from Alaska, the almost 370,000 km² region is bordered by 2,000 km of winding coastline.

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These spectacular shores include the Kolyuchinskaya Bay coast of the Chukotka Sea to the north and the Anadyr Bay shores of the Bering Sea to the south. The western, terrestrial boundary of the ecoregion crosses the Chukotka plateau along the Pekulney Mountain Ridge before it follows the large Anadyr River to the sea in the south (Fig. 6.1).

For its northern latitude and widespread permafrost, the ecoregion nevertheless boasts relatively high plant and animal diversity. For example, relic species and communities—such as those found in areas of cryophilic steppe—reflect past biogeographic exchange with North America during periods of the Pleistocene when lower sea levels revealed the Beringia land bridge. The region's coasts are also well-known as home to polar bears, walrus, whales, seabirds and waterfowl, as well as salmon and whitefish that have been traditionally harvested by indigenous communities for millennia. The biological variety is mirrored by the region's diverse landscape, which includes the Chukotka plateau, coastal lowlands, intermountain valleys, many inland lakes, and, in the south, the large Anadyr River flowing out to Anadyr Bay on the Bering Sea.

Chukchi and Inuit peoples have hunted and fished in the region for millennia and were joined, more recently, by early Russian settlers. Traditional pursuits include harvesting marine mammals and fish as well as reindeer herding. (In 2010, for example, 116 Gray Whales and two Bowhead Whales were harvested in the Eastern Chukotka ecoregion. Altogether, 662.3 tons of marine mammals were hunted and 774.5 kilograms of walrus tusk and 1814 skins of marine mammals were taken in the same year.)

A large "ethno-natural park," known as "Beringia," covers a significant part of the Chukotka Peninsula (more than 3 million hectares). Meanwhile, growing industrial development occurs in patches elsewhere in the ecoregion. The environmental impact of this industry—including coal, gold, tin and wolfram mining, oil and gas excavation, fisheries, and energy generation—is exacerbated by related construction and local infrastructure, such as development around the City of Anadyr and in other settlements such as Lawrentia, Egvekinot, and Provideniya. Roads and other means of transportation remain poorly developed, and unrestricted overland travel (in trucks and all-terrain vehicles) affects the ground vegetation.

Authority over the ecoregion is shared. The ecoregion comprises approximately half of the Chukotka Autonomous Region and includes the Chukotsk and Providensky Districts, along with parts of the Iultinsky and Anadyrsky Districts. Thus, the administrative and institutional resources of these four municipal districts are likely to be important to the conservation of biodiversity and to promoting climate change adaptation in protected area networks.

FIGURE 6.1
THE EASTERN CHUKOTKA ECOREGION

EASTERN CHUKOTKA ECOREGION IS REMARKABLE FOR THE EXCEPTIONAL VARIETY OF ARCTIC VEGETATION COMMUNITIES REPRESENTED IN THE REGION.

KEY FEATURES IMPORTANT FOR RESILIENCE

Nine terrestrial key features were identified during RACER's pilot rapid assessment of ecosystem resilience in the Eastern Chukotka ecoregion from 2009 to 2011. The assessment combined data reflecting landscape diversity, biodiversity, and the location of indigenous communities (reflecting traditional land-use and use of natural resources). A general method for the analysis is described in more detail in Chapters 3 and 4 of this handbook and on the RACER website (www.panda.org/arctic/racer). Relevant information sources for the Eastern Chukotka ecoregion included data on biodiversity from the Conservation of Arctic Fauna and Flora working group (CAFF 2000, Tishkov 2009), climate information from the Arctic Climate Impact Assessment (ACIA 2005), satellite image data and regional statistics for Chukotka Autonomous Region of the Russian Federation (www.chukotka.org). The method for interpreting remote sensing information , satellite image data, regional statistics for Chukotka Autonomous Region of the Russian Federation (www.chukotka.org), and the CAVM map (Fig. 6.2) is described in Chapter 3.

Mapping key plant habitats, Important Bird Areas (IBAs), wetlands, "salmon" water bodies, areas of rare plants and animals, and the location of regional specially protected natural areas (existing and potential) also played a role in the assessment (Krever et al. 2009). The RACER analysis in this ecoregion is on-going and other key features that are potentially significant as sites of conservation importance may be added to this list in the future.

The locations of the nine key features in the Eastern Chukotka ecoregion are illustrated in Fig. 6.3. Distinguished by their relatively high levels of productivity (see, for example, Fig. 6.4), their exceptionally varied topography (indicating landscape diversity), and/or more direct evidence of unusually high biotic diversity, these key features represent sites of potentially vital conservation importance. The key feature map is intended to inform discussions about the best management approaches to safeguard the exceptional productivity and diversity of these places (and the drivers responsible for them) to better fortify the resilience inherent in the region-wide ecosystem.

Table 6.1 describes the main drivers identified as responsible for the exceptional productivity and/or diversity of the Eastern Chukotka's key features. Drivers include those susceptible to the impacts of climate change, such as temperature, precipitation, soil moisture, as well as those impervious to climate effects, such as topography and soil type. These drivers are used in the second part of the RACER method to evaluate the likelihood that the ecoregion's key features will continue to contribute to region-wide resilience despite 21st century climate change (see Fig. 6.6).

ECOREGION CHARACTERISTICS

Eastern Chukotka ecoregion is remarkable for the exceptional variety of arctic vegetation communities represented in the region (Fig. 6.2). Much of this diversity is related to unique qualities of the climate brought about by the simultaneous impact of the Arctic and Pacific Oceans which meet and mix at the Bering Strait and influence complex circulation patterns in the atmosphere.

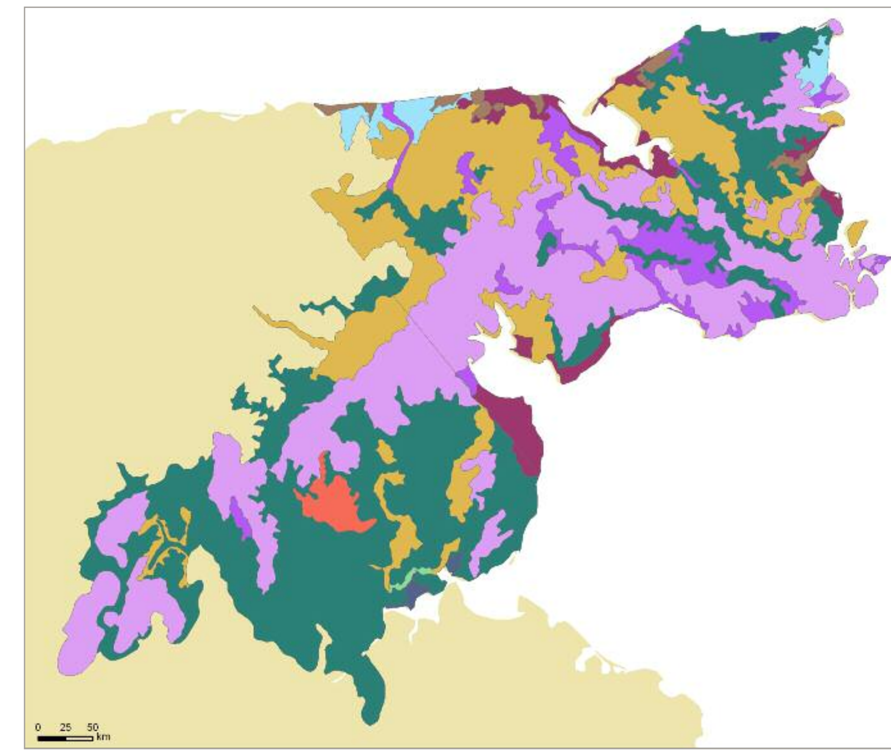
In general, winters in the continental areas of Eastern Chukotka are very cold, often dropping to -30°C and -40°C. Areas with high atmospheric pressure prevail, and strong winds and snowstorms, which can last for days at a time, are typical along the coast. Summers are short, cold and rainy, and areas with low atmospheric pressure prevail. Snow remains through the season on the mountain slopes along with patches of ice on many rivers. Summer snowstorms are also common.

Overall, the average annual air temperature is below freezing (-7.4°C in Anadyr), with July temperatures of 4°C to 11°C and January temperatures of -21°C to -40°C. Precipitation in the region is 300 to 350 mm per year, and winds—which frequently change direction between north and south within a short period—blow at average speeds of 5 to 12 m/sec with gusts of up to 40 to 50 m/sec.

Vegetation and plant communities found in the Eastern Chukotka ecoregion include the following: (1) typical and southern arctic tundra, including sedge and low shrub tundra, shrub tundra, and high-altitude mountain analogues of these habitats; (2) zonal and intra-zonal (riparian and mountain) shrub thickets (e.g., willow, alder, and birch spp.) and creeping shrubs; (3) fragments of forest vegetation, including larch woodlands in the extreme south, areas of creeping shrubs (e.g., pine, juniper, and rhododendron) in the center of the region, and "islands" of riparian forest (with poplar, willow and birch spp.) throughout; (4) bogs, marshes and mires (e.g., peatlands, wet lowland grass and moss fens) along the coastline and in lowland areas of the ecoregion; (5) coastal

THE REGION'S COASTS ARE ALSO WELL-KNOWN AS HOME TO POLAR BEARS, WALRUS, WHALES, SEABIRDS AND WATERFOWL, AS WELL AS SALMON AND WHITEFISH THAT HAVE BEEN TRADITIONALLY HARVESTED BY INDIGENOUS COMMUNITIES FOR MILLENNIA.

FIGURE 6.2
ARCTIC VEGETATION CLASSES FOR THE EASTERN CHUKOTKA ECOREGION.
Source: CAVM Team 2003.



ECOREGION CHARACTERISTICS (CONTINUED FROM PREVIOUS PAGE)

floodplain and alpine meadows dominated by sedges and a rich diversity of forbs; (6) cryo-arid communities, fragments of steppe vegetation and so called "steppoids" found at the extreme north and east of the region (including grasses, forbs and other vegetation found on near-bare carbonate rocks); and (7) thermophilic vegetation complexes of forbs and grasses located near the abundant hot springs within the ecoregion.

Meanwhile, environmental stresses faced by these ecological communities continue to intensify. Overgrazing of reindeer pastures is one problem, along with fire damage and mechanical destruction along winter transportation routes and on routes used by all-terrain vehicles. Thermal erosion is widespread, especially close to settlements and in areas where all-terrain vehicle traffic is frequent (e.g., river crossings and along slopes). Threats from industrial development include oil and gas exploration, mining for coal, gold, tin and wolfram, and the construction of railroads and roads. Other potential impacts may arise from wind energy development and intensified shipping along the Northern Navigation Route.

Pollution concerns in the ecoregion include solid waste (including metal fuel barrels, cans, and domestic and industrial waste around settlements and commercial facilities), air pollution from coal heaters, diesel power generators, and water contamination (because of an absence of purification systems for the region's settlements and commercial facilities). Another conservation problem is widespread poaching (including the illegal hunting of polar bears, walrus and water birds, as well as illegally taking raptors for export to falconry centers in Arab countries). Illegal logging and fuel-wood harvesting are also having an impact in the region's riparian forests and islands of forest vegetation.

THREATS FROM INDUSTRIAL DEVELOPMENT INCLUDE OIL AND GAS EXPLORATION, MINING FOR COAL, GOLD, TIN AND WOLFRAM, AND THE CONSTRUCTION OF RAILROADS AND ROADS.

Below, brief descriptions of nine key features—and the RACER assessments of their likely persistence in the years to come—are arranged according to five key feature *types* within the ecoregion. Pairs of key features sharing the same type are those for which the drivers of productivity and diversity are similar and for which the impact of climate change on their likely persistence is considered effectively the same.

1. MIDDLE MOUNTAIN RIDGES (THE PEKULNEY MOUNTAIN RIDGE AND THE SOUTHERN RIDGES OF THE CHUKOTKA UPLANDS)

The Pekulney Mountain Ridge (key feature #1) and Southern Ridges of the Chukotka Uplands (key feature #2) are middle mountain ridges characterized by rolling landforms and terraces as well as vertical vegetation belts ranging from subarctic tundra to alpine deserts. The Pekulney Mountain Ridge is a long, north-south mountain ridge that marks the western boundary of the Eastern Chukotka ecoregion while the Southern Ridges of the Chukotka Uplands is a central mountain ridge midway to the end of the ecoregion's peninsular tip. While the chilling effects of altitude along with rocky soils limit biological productivity for these two key features, their highly varied terrain (see Fig. 6.5) is nevertheless an important driver affecting diversity. This terrain provides habitat to a variety of plant species, including relic plants and vegetation communities. This diversity distinguishes these key features as important well-springs of ecoregion resilience. Relevant General Circulation Models (GCMs) forecast higher temperatures, reduced precipitation, and longer summer dry periods for these mountainous key features as a result of climate change. These predictions also anticipate some melting of the deep-soil permafrost. While the result is likely to be a longer summer growing period, the negative effects of projected increases in drought and colder winters will likely offset any increases in seasonal productivity. However, the exceptional heterogeneity of these key features will remain unaffected by climate change and will continue to contribute to above average diversity for this feature. Expert consideration of this influence of climate helped RACER conclude that there was a *high* likelihood that these two mountain-ridge key features would remain as sources of ecosystem resilience for the ecoregion through to 2100.

2. COASTAL MOUNTAINS (OF CAPE DEZHNEV/CHEGITUN RIVER AND OF PROVIDENIYA AND SENYAVIN STRAIT)

The Coastal Mountains of Cape Dezhnev/Chegitun River (key feature #3) and those in the area of Provideniya and Senyavin Strait (key feature #4) occupy the twin tips of the extreme eastern end of the Chukotka Peninsula. The varied landscape of these two key features is characterized by treeless plateaus, valleys, and mountains edged by sea cliffs and rocky shoreline. Patches of bare rocks interrupt large, rolling meadows and areas of remarkably diverse vegetation. While the poor soil and rugged topography make productivity variable or poor for these mountainous key features, the exceptional heterogeneity of the landscape and seashore ensure diversity that is higher than average for the ecoregion. Indeed, these key features are well-known for their species richness and vegetation diversity and are established sites for traditional hunting. They also support many significant seabird colonies considered Important Bird Areas (IBAs) by BirdLife International. Walrus rookeries are also present. This diversity and variety add substantially to the capacity of these key features to contribute to ecoregion-wide resilience. Models of climate change (GCMs) predict significant decreases in precipitation and longer dry periods for these coastal mountains as the century progresses. The forecasts also suggest permafrost in these areas will melt to greater depths during the summer. While these changes are expected to have a significant impact on the ecology of these features, the unique and varied terrain is expected to continue to support diversity important to region-wide resilience. RACER experts suggest the likelihood the key features will remain sources of ecosystem resilience throughout this century are *medium to high*.

NINE TERRESTRIAL KEY FEATURES WERE IDENTIFIED DURING RACER'S PILOT RAPID ASSESSMENT OF ECOSYSTEM RESILIENCE IN THE EASTERN CHUKOTKA ECOREGION.

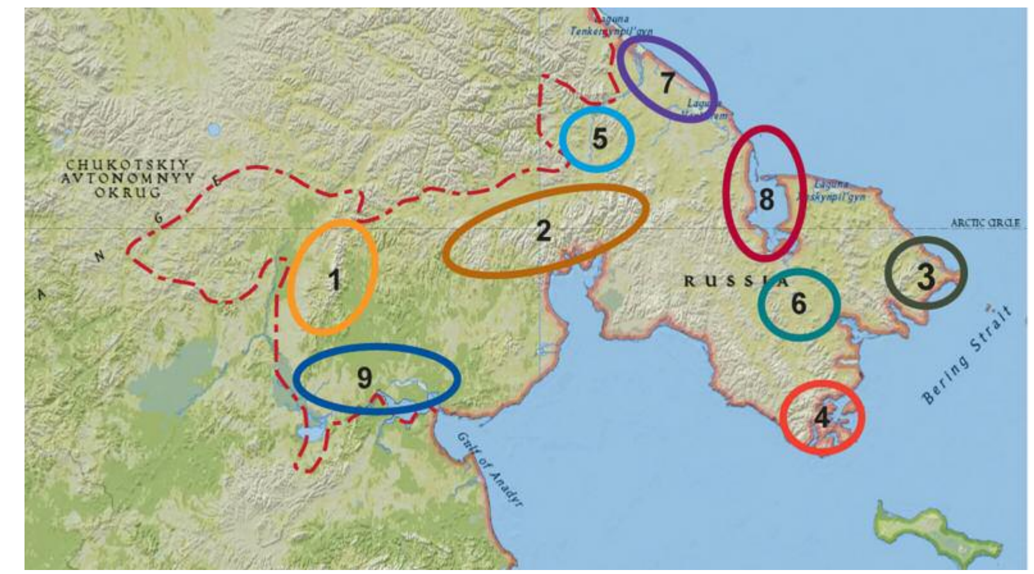


FIGURE 6.3
KEY FEATURES OF THE EASTERN CHUKOTKA ECOREGION.
Source: WWF.

- Eastern Chukotka Ecoregion Delineation
- 1. Pekulney Mountain Ridge
- 2. Southern Ridges of the Chukotka Uplands
- 3. Coastal Mountains of Cape Dezhnev/Chegitun River
- 4. Coastal Mountains of Provideniya and Senyavin Strait
- 5. Amguema River Valley
- 6. Mechigmen Valley
- 7. Vancaremskaya Lowlands
- 8. Kolyuchinskaya Bay
- 9. Western Anadyr Lowlands

THE KEY FEATURE MAP IS INTENDED TO INFORM DISCUSSIONS ABOUT THE BEST MANAGEMENT APPROACHES TO SAFEGUARD THE EXCEPTIONAL PRODUCTIVITY AND DIVERSITY OF THESE PLACES (AND THE DRIVERS RESPONSIBLE FOR THEM) TO BETTER FORTIFY RESILIENCE.

3. INTERMOUNTAIN VALLEYS (THE AMGUEMA RIVER VALLEY AND THE MECHIGMEN VALLEY)

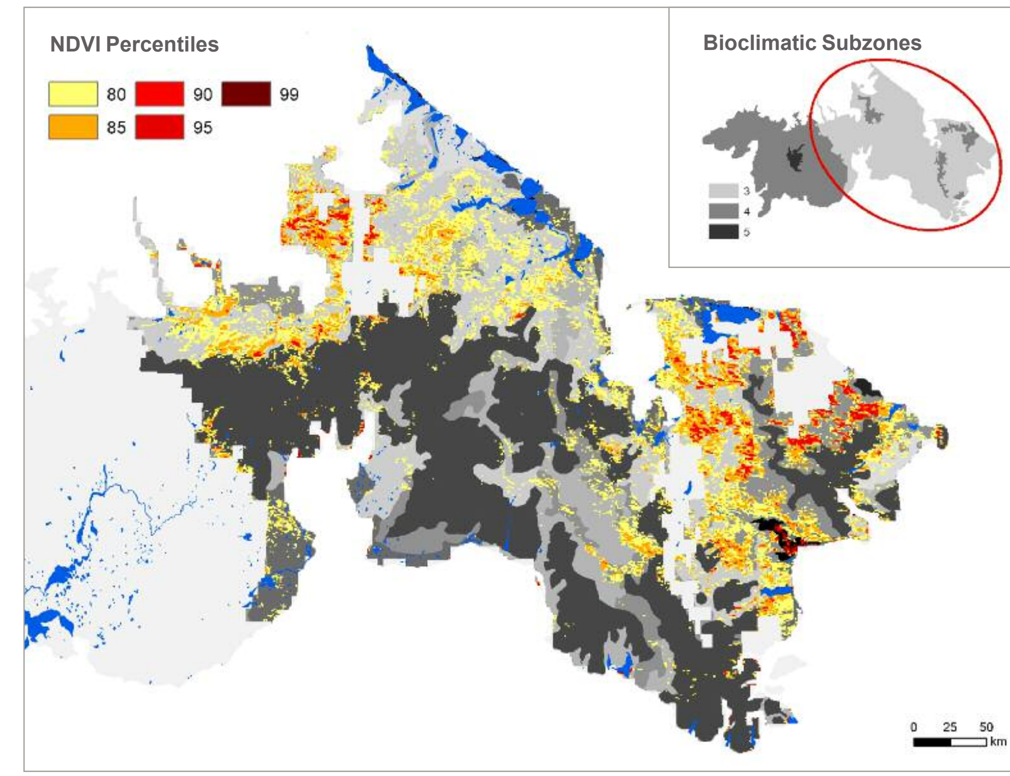
The Amguema River Valley (key feature #5) and the Mechigmen Valley (key feature #6) are intermountain valleys that interrupt the generally higher terrain of the ecoregion midway and toward the east, near the Chukotka Peninsula tip. Protected from ocean impacts by mountain ridges, including steep-sloped moraines, these valley areas are warmer than the regional average and support more southerly vegetation that includes low arctic shrub thickets, meadow steppe and steppe communities. The relatively lush, bright-green steppe vegetation of lichens, forbs and tiny shrubs makes these key features important for reindeer grazing by traditional Chukotka reindeer herders. Wetlands and other low-lying areas are characterized by varieties of grasses and sedges. The moist soils and warmer temperatures ensure high productivity for these key features (see Fig. 6.4) that contributes to resilience throughout the ecoregion. Biodiversity and landform heterogeneity in these valleys, meanwhile, are not as exceptional. An examination of climate impacts using forecasts from General Circulation Models (GCMs) suggests the remainder of the century will see decreasing precipitation, longer dry periods, increasing days of frost, and an increasing depth of the permafrost melt for these two key features. These changes are expected to affect crucial soil moisture but not enough to severely reduce productivity in these sheltered valleys. RACER experts assessing this impact concluded that there was a *medium* likelihood that these two key features would remain sources of region-wide ecosystem resilience for the rest of the century.

4. COASTAL LOWLANDS (THE VANCAREMSKAYA LOWLANDS AND THE KOLYUCHINSKAYA BAY LOWLANDS)

The Vancaremskaya Lowlands (key feature #7) and the Kolyuchinskaya Bay Lowlands (key feature #8) are low, wet, coastal plains located along the northern shores of the Chulkotka Peninsula. These stark coastal basins with rocky shores and alluvial soils are home to numerous lakes, wetlands, and coastal beaches that support a variety of birds and marine mammals—especially walrus. Although the landscape is far less heterogeneous than elsewhere in the ecoregion and productivity is low, the exceptional biodiversity of these Arctic Ocean shoreline areas makes them significant features for contributing to region-wide resilience. Forecasts of changes to climate variables (using GCMs) are anticipated to affect the drivers of this exceptional vitality through decreasing precipitation and a deeper melting of the permafrost as this climate-altered century progresses. This diminished moisture (less rain and snow as well as the increased soil drainage of wetlands resulting from a deeper thaw) is likely to have a significant drying effect on the wetlands

PAIRS OF KEY FEATURES SHARING THE SAME TYPE ARE THOSE FOR WHICH THE DRIVERS OF PRODUCTIVITY AND DIVERSITY ARE SIMILAR AND FOR WHICH THE IMPACT OF CLIMATE CHANGE ON THEIR LIKELY PERSISTENCE IS CONSIDERED EFFECTIVELY THE SAME.

FIGURE 6.4
AREAS OF EXCEPTIONALLY HIGH TERRESTRIAL NET PRIMARY PRODUCTIVITY FOR THE EASTERN CHUKOTKA ECOREGION (Bioclimatic Subzone 3).
Source: WWF.



Based on ten year median (2000-2010) of peak seasonal (June-August) Normalized Difference Vegetation Index (NDVI; Rouse et al. 1973) calculated from MODIS monthly reflectance at 1000m resolution (MOD13A3). Shades of grey are vegetation classes (see Fig. 6.2 for explanation).

THESE KEY FEATURES REPRESENT SITES OF POTENTIALLY VITAL CONSERVATION IMPORTANCE.

THE NEGATIVE EFFECTS OF PROJECTED INCREASES IN DROUGHT AND COLDER WINTERS WILL LIKELY OFFSET ANY INCREASES IN SEASONAL PRODUCTIVITY.

and coastal marshes that make these landscape features so attractive to wildlife. After evaluating this climate impact, RACER experts concluded that despite the importance of these key features to current resilience across the ecoregion, the likelihood was *low* that they would continue in this role after they are transformed by continued climate change.

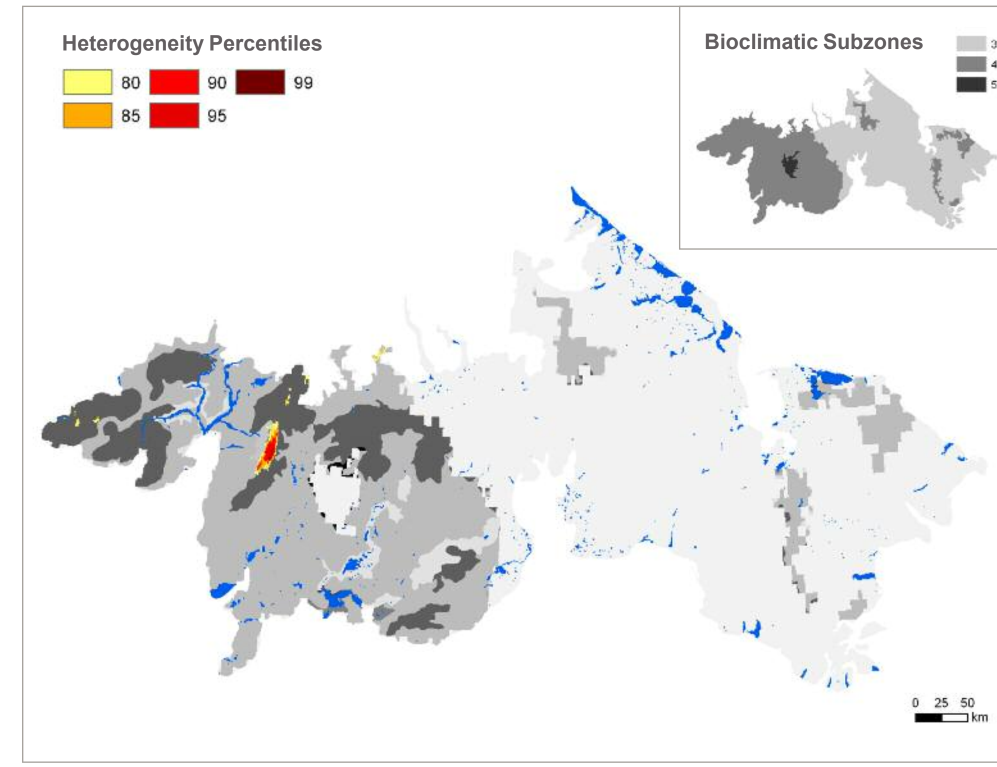
5. WESTERN ANADYR LOWLANDS

The Western Anadyr Lowlands (key feature #9) mark the southwestern corner of the Eastern Chukotka ecoregion. This key feature includes the low terrain surrounding the Anadyr River where it meets Anadyr Bay. This area is characterized by numerous wetlands and lakes with areas of grassland and tundra, shingle beaches, and sea cliffs along rocky shores. Rich, fluvial soils encourage significant productivity. The many rivers and water bodies regularly interrupt the landscape, contributing to a mosaic of different shorelines, freshwater and land features, and creating an exceptional variety of habitats for diverse species of plants, birds and other wildlife. Many places within this key feature are known as traditional harvesting areas, including rivers used for salmon fishing. Indeed, exceptional landform heterogeneity and biodiversity make this key feature an important wellspring of ecosystem resilience for the entire ecoregion. General Circulation Models (GCMs) reflecting climate forecasts for the remainder of this century suggests this key feature will be most affected by climate-related decreases in precipitation and by a deeper seasonal melting of the soil permafrost. These changes are expected to affect available moisture and may lead to a draining and drying of some of the area`s many wetlands, resulting in impacts on wildlife and other diversity. Yet, RACER experts concluded that the effect of these changes will be mediated somewhat by the feature's large drainage catchment, which is expected to continue to supply water to offset some drying effects. Alterations to habitat availability, meanwhile, are already common in this changeable riverine area, and these changes may not be significantly more intense with the addition of climate effects. Based on this assessment, RACER scientists determined that the likelihood of this key feature remaining a source of ecosystem resilience to 2100 is *medium*.

DRIVERS INCLUDE THOSE SUSCEPTIBLE TO CLIMATE CHANGE, SUCH AS TEMPERATURE, PRECIPITATION, SOIL MOISTURE, AS WELL AS THOSE IMPERVIOUS TO IT, SUCH AS TOPOGRAPHY AND SOIL TYPE.

THE FORECASTS ALSO SUGGEST PERMAFROST IN THESE AREAS WILL MELT TO GREATER DEPTHS DURING THE SUMMER.

FIGURE 6.5
AREAS OF SIGNIFICANT LANDFORM HETEROGENEITY IN THE EASTERN CHUKOTKA ECOREGION.
(Bioclimatic Subzone 4).
Source: WWF.



* Significance of landform heterogeneity is defined here as the upper 80th percentile of values for the ecoregion. See method details on pages 32 and 33.

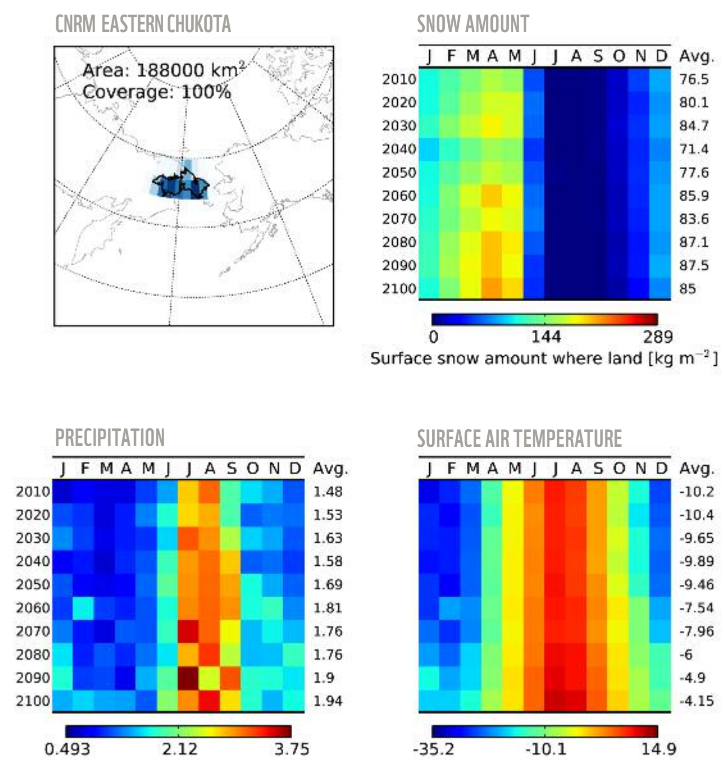
Shades of grey are vegetationclasses (see Fig. 6.2 for explanation).

USING DRIVERS AS THE LINK, RACER USES GCM FORECASTS TO ASSESS WHETHER KEY FEATURES ARE LIKELY TO CONTINUE AS LOCAL SOURCES OF REGION-WIDE ECOSYSTEM RESILIENCE.

FIGURE 6.6

EXAMPLES OF CLIMATE VARIABLES (SNOW AMOUNT, PRECIPITATION, AND AIR TEMPERATURE) PROJECTED BY ONE GENERAL CIRCULATION MODEL (GCM) FOR THE EASTERN CHUKOTKA ECORREGION.

Source: Huard 2010.



CNRM: Model of the National Meteorological Research centre (France)

TABLE 6.1

THE LIKELY PERSISTENCE OF KEY FEATURES IN THE FACE OF CLIMATE CHANGE.

The likelihood that key features will continue to confer resilience to the ecoregion in the future is scored as high (H), medium (M), or low (L) based on projected changes to main climate variables using GCMs and their effect on geophysical drivers.

Source: WWF.

CLIMATE VARIABLES:
Surface Air Temperature (SAT);
Precipitation (P);
Surface Snow Amount (SSA);
Soil Moisture (SM).

PERSISTENCE INDEX:
H – high; M – medium; L – Low

KEY FEATURES	MAIN DRIVERS	CURRENT BIOLOGICAL PRODUCTIVITY (BP) & HABITAT DIVERSITY (HD)		MAIN CHANGES TO GCM CLIMATE VARIABLES	ASSESSED PERSISTENCE OF KEY FEATURE'S FUTURE ABOVE-AVERAGE PRODUCTIVITY / DIVERSITY
		BP	HD		
1 Pekulney Mountain Ridge	Temperature, Snow cover	Low	High	SAT P SSA	H
2 Southern Ridges of the Chukotka Uplands	Temperature, Snow cover	Low	High	SAT P SSA	H
3 Coastal Mountains of Cape Dezhnev/Chegitun River	Temperature, Snow cover	Low	High	SAT P SSA	M-H
4 Coastal Mountains of Provideniya and Senyavin Strait	Temperature, Snow cover	Low	High	SAT P SSA	M-H
5 Amguema River Valley	Precipitation, Permafrost	High	Medium	SAT P SSA SM	M
6 Mechigmen Valley	Precipitation, Permafrost	High	Medium	SAT P SSA SM	M
7 Vancaremskaya Lowlands	Temperature Permafrost	Low	Low	SAT P SSA SM	L
8 Kolyuchinskaya Bay	Temperature Permafrost	Low	Low	SAT P SSA SM	L
9 Western Anadyr Lowlands	Temperature Precipitation Permafrost	High	High	SAT P SSA SM	M

CONCLUSION

ARCTIC CONSERVATION NEEDS A NEW APPROACH. Change in the region – faster and more extensive than at any other time in recorded history – will soon outpace efforts to hold the line; we can no longer simply react to environmental pressures as they arise or attempt to preserve species and habitats as they are. The future is becoming less predictable. Change is more certain. Surprise is more likely.

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The purpose of RACER is to change the way we deal with change in the Arctic. RACER is a tool that equips environmental or land management agencies and organizations with a new, forward-looking view of arctic conservation that sees the regions of the Arctic as functioning ecosystems first. In this way, RACER critically widens the focus of conventional conservation to an ecosystem perspective. It highlights the need for conservation to recognise people's influence and dependency on the enduring values and services that functioning ecosystems provide, rather than attempting to preserve particular plants, animals, or habitats.

RACER is an instrument to manage change by maintaining the ecological machinery responsible for the conditions that living things–and northern communities–need. When this machinery is working well, ecosystems have the resilience to adapt to change–to cope with shocks and respond to opportunities while continuing to function in much the same kind of way.

RACER succeeds by focusing on the main engines that keep ecosystems working through change and, importantly, on the drivers that fuel these engines. These engines are productivity (providing energy to food webs and people) and diversity (fortifying the links in biological interactions). The drivers behind these engines are the geographic, climatic, and ecological characteristics (sea ice, slopes, soils, currents, etc.) of a place–the consequence, in other words, of the landscape or sea features found there.

For the first time, RACER offers a way forward for a functional and strategic approach to arctic conservation. Instead of locating habitats or species ranges, RACER maps places characterized by their ecological functions, drawing management and planning attention to the forces behind the productivity and diversity important to arctic living systems. At the same time, RACER uses resilience thinking to strategically equip today's decisions with conservation targets that are ecologically meaningful and geographically discrete. It provides a more careful evaluation of changes to ecosystem engines and their drivers based on scientifically established scenarios of future conditions.

In these times of rapid arctic change, effective stewardship of arctic natural resources requires a new way of thinking. Recognizing the future value of these resources is vital not just for northern communities–to safeguard their livelihoods and cultural identity–but also for the planet affected by the Arctic's global influence on the atmosphere and oceans, as well as on world fisheries and migrating birds and mammals. Forward-looking stewardship is especially relevant in times when people everywhere are already exceeding the services the Earth's system is able to grant to them.

→ RACER IS AN OVERDUE, NEW WAY FORWARD THAT HELPS SAFEGUARD THE FUNCTIONING ECOSYSTEMS AT THE HEART OF ARCTIC LIFE.

IN THESE TIMES OF RAPID CHANGE, EFFECTIVE STEWARDSHIP OF ARCTIC NATURAL RESOURCES REQUIRES A NEW WAY OF THINKING.

RACER poses a first answer to this stewardship challenge. By identifying key features where important drivers will continue to support exceptional ecological vitality, RACER finds the places that confer resilience to ecosystems across arctic regions now–and for the remainder of this climate-altered century. RACER provides a tool–missing until now–that translates future threats and pressures to the arctic environment into effective forward-looking action. It empowers arctic peoples to address the challenges that rapid arctic change poses for their environment and their way of life.

RACER is, in other words, a starting point for discussions among stakeholders.

To the Arctic Council and its associated groups, RACER offers an instrument for understanding and applying the concept of resilience. Its practical application of a forward-looking ecosystem approach promises to stimulate policies that will improve the management of arctic natural resources at a time of mounting pressure from climate change, industrial development, and other interests.

To regional and local planners and managers RACER offers a tool for identifying geographically discrete conservation targets that will remain significant through this climate-altered century and for initiating stakeholder discussions about how to manage and safeguard these targets.

Finally, to experts involved in biodiversity research, monitoring, and conservation, RACER provides a framework to advance our understanding of the functional role of biodiversity for arctic ecosystems, for the services they provide, and for people.

This view of the living Arctic is what distinguishes RACER. By anticipating the continued functioning of arctic ecosystems in the climate-altered future, RACER enhances the likelihood of maintaining important natural values and ecosystem services in the Far North despite accelerating change. It is an overdue, new way forward that promises the greatest number of conservation options by safeguarding the functioning ecosystems that are at the heart of arctic life.

THE PURPOSE OF RACER IS TO CHANGE THE WAY WE DEAL WITH CHANGE.

REFERENCES

Aagaard K, Carmack EC. 1994. The Arctic Ocean and climate: a perspective. Pp. 4–20 in: Johannessen OM, Muench RD, Overland JE, editors. *The Polar Oceans and their Role in Shaping the Global Environment. Geophysical Monograph* 85. Washington, DC: American Geophysical Union. 525 p.

ACIA (Arctic Climate Impact Assessment). 2004. *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*. Cambridge: Cambridge University Press [cited 2011 Dec 7]. [140 p.]. Available from: http://www.acia.uaf.edu.

Arctus inc., WWF. 2011. *Rapid Assessment of the Marine Primary Productivity Trends in the Arctic Ocean and its Surrounding Seas.* (Internal Report). Ottawa: WWF. 112 p.

ADHR (Arctic Human Development Report). 2004. *Arctic Human Development Report*. Akureyri, Iceland: Stefansson Arctic Institute [cited 2011 Dec 7]. [242 p.]. Available from: http://www.svs.is/AHDR/AHDR%20chapters/English%20 version/ Chapters%20PDF.htm

Allaby M. 2010. *A Dictionary of Ecology (Fourth Edition)*. Oxford: Oxford University Press Inc. [cited 2011 Oct 5]. Available from: http://www.oxfordreference.com.

Andersen T, Carstensen J, Hernandez-Garcıa E, Duarte CM. 2009. Ecological thresholds and regime shifts: approaches to identification. *Trends in Ecology and Evolution* 24: 49–57.

Arctic Council. 2004. *Arctic Marine Strategic Plan*. Iceland: PAME International Secretariat [cited 2011 Dec 7]. [20 p.]. Available from: http://www.pame.is/images/stories/AMSP_files/ AMSP-Nov-2004.pdf

Arctic Council. 2011. *Nuuk Declaration on the Occasion of the Seventh Ministerial Meeting of The Arctic Council*. Nuuk, Greenland: Arctic Council. [cited 2011 Dec 7]. [6 p.]. Available from: http://library.arcticportal.org/id/eprint/1254

Arrigo KR. 2005. Marine microorganisms and global nutrient cycles. Nature 437: 349–355.

Audubon Alaska & Oceana. 2010. *Arctic Marine Synthesis: Atlas of the Chukchi and Beaufort Seas. 1st edition*. [cited 2011 Dec 7]. [44 sections]. Available from: http://ak.audubon.org/birds-science-education/arctic-marine-synthesis-atlas-chukchi-and-beaufort-seas.

Barber DG, Lukovich JV, Keogak J, Baryluk S, Fortier L, Henry GHR. 2008. The changing climate of the Arctic. *Arctic* 61 (Suppl. 1): 7–26.

Braund SR & Associates. 2010. *Subsistence Mapping of Nuiqsut, Kaktovik, and Barrow. Final Report for U.S. Dept. of Interior*. Anchorage, Alaska: Minerals Management Service, U.S. Dept. of Interior. 349 p.

CAFF (Conservation of Arctic Flora and Fauna). 2001. *Arctic Flora and Fauna: Status and Conservation*. Helsinki, Finland: Arctic Council CAFF. 272 p.

CAFF (Conservation of Arctic Flora and Fauna). 2007. *Circumpolar Biodiversity Monitoring Program: Five-Year Implementation Plan*. Tromsø, Norway: Arctic Council CAFF. 39 p.

Carmack EC, Macdonald RW. 2002. Oceanography of the Canadian Shelf of the Beaufort Sea: A setting for marine life. *Arctic* 55 (Suppl. 1): 29–45.

Carmack EC, Wassmann P. 2006. Food webs and physical-biological coupling on pan-Arctic shelves: unifying concepts and comprehensive perspectives. *Progress in Oceanography* 71: 446–477.

Carmack EC, Barber D, Christensen J, Macdonald R, Rudels B, Sakshaug E. 2006. Climate variability and physical forcing of the food webs and the carbon budget on panarctic shelves. *Progress in Oceanography* 71: 145–181.

CAVM Team. 2003. *Circumpolar Arctic Vegetation Map. Scale 1:7,500,000. Conservation of Arctic Flora and Fauna (CAFF) Map No. 1*. Anchorage, Alaska: U.S. Fish and Wildlife Service.

CDIAC (Carbon Dioxide Information Analysis Center). 2011. *Fossil-Fuel CO2 Emissions*. [Internet] Tennessee: U.S. Department of Energy [cited 2011 Dec. 7]. Available from: http://cdiac.ornl.gov/trends/emis/meth_reg.html.

Chapman AS, Kostylev VE. 2005. *Distribution, abundance and diversity of benthic species from the Beaufort Sea and western Amundsen Gulf – a summary of data collected between 1951 and 2000. Geological Survey of Canada Open File # 5498*. Ottawa: Geological Survey of Canada. 42 p.

Cobb D, Fast H, Papst MH, Rosenberg D, Rutherford R, Sareault JE, editors. 2008. *Beaufort Sea Large Ocean Management Area: Ecosystem Overview and Assessment Report. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2780*. Winnipeg, Manitoba: Fisheries and Oceans Canada. 199 p.

Cusson M, Archambault P, Aitken A. 2007. Biodiversity of benthic assemblages on the Arctic continental shelf: historical data from Canada. *Marine Ecology Progress Series* 331: 291–304.

Eicken H, Shapiro LH, Gaylord AG, Mahoney A, Cotter PW. 2005. *Mapping and characterization of recurring spring leads and landfast ice in the Beaufort and Chukchi Seas. US MMS Rep. OCS Study 2005-068*. Anchorage, Alaska: U.S. Department of the Interior. 141 p.

Folke C, Carpenter S, Walker B, Scheffer M, Elmqvist T, Gunderson L, Holling CS. 2005. Regime shifts, resilience and biodiversity in ecosystem management. *Annual Review of Ecology Evolution and Systematics* 35: 557–581.

Fortier L, Barber D, Michaud J, editors. 2008. *On Thin Ice: a synthesis of the Canadian Arctic Shelf Exchange Study (CASES)*. Winnipeg, Manitoba: Aboriginal Issues Press. 215 p.

Goebel T, Waters MR, O'Rourke DH. 2008. The Late Pleistocene Dispersal of Modern Humans in the Americas. *Science* 319: 1497–1502.

Gunderson L. 2000. Ecological Resilience–In Theory and Application. *Annual Review of Ecology Evolution and Systematics* 31:425–439.

Huard D. 2010. *RACER-WWF Report on Climate Change Scenarios. Internal report to WWF-Canada*. Toronto: WWF.

Ingram RG, Williams WJ, van Hardenberg B, Dawe JT, Carmack EC. 2008. Seasonal circulation over the Canadian Beaufort Shelf. In: Fortier L, Barber D, Michaud J, editors. *On Thin Ice: a synthesis of the Canadian Arctic Shelf Exchange Study (CASES)*. Winnipeg, Manitoba: Aboriginal Issues Press. p. 13–36.

IPCC. 2000. *Emissions Scenarios*. Cambridge, UK: Cambridge University Press. 570 p.

IPCC. 2007. *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press. 996 p.

Kerr JT, Ostrovsky, M. 2003. From space to species: ecological applications for remote sensing. *Trends in Ecology and Evolution* 18: 205–299.

Koivurova T, Molenaar EJ. 2009. *International Governance and Regulation of the Marine Arctic: Overview and Gap Analysis*. Oslo, Norway: WWF International Arctic Programme. 44 p.

Krever V, Stishov M, Onufrenya I. 2009. *National protected areas of the Russian Federation: Gap analysis and perspective framework*. Moscow: WWF/The Nature Conservancy/MAVA. 80 p.

Lawrence DM, Slater AG. 2005. A projection of severe near-surface permafrost degradation during the 21st century. *Geophysical Research Letters* 32: L24401.

Leduc TB. 2010. *Climate Culture Change: Inuit and Western Dialogues with a Warming North*. Ottawa, Ontario: University of Ottawa Press. 267 p..

Milutinovic S, Bertino L. 2011. Assessment and propagation of uncertainties in input terms through an ocean-color-based model of primary productivity. *Remote Sensing of Environment* 115: 1906–1917.

Nuttall M, Berkes F, Forbes F, Kofinas G, Vlassova T, Wenzel G. 2005. Hunting, Herding, Fishing and Gathering: Indigenous Peoples and Renewable Resource Use in the Arctic. In: *Arctic Climate Impact Assessment*. Cambridge, UK: Cambridge University Press. p. 649–690.

Pimm SL, Lawton JH, Cohen JE. 1991. Food web patterns and their consequences. *Nature* 350: 669–674.

O'Reilly JE, Maritorena S, Mitchell BG, Siegel DA, Carder KL, Garver SA, Kahru M, Mcclain C. 1998. Ocean color chlorophyll algorithms for SeaWiFS. *Journal of Geophysical Research, Oceans* 103: 24937–24953.

Rocchini D, Balkenhol N, Carter GA, Foody GM, Gillespie TW, He KS, Kark S, Levin N, Lucas K, Luoto M, Nagendra H, Oldeland J, Ricotta C, Southworth J, Neteler M. 2010. Remotely sensed spectral heterogeneity as a proxy of species diversity: recent advances and open challenges. *Ecological Informatics* 5: 318–329.

Scheffer M, Carpenter S, Foley JA, Folke C, Walker B. 2001. Catastrophic shifts in ecosystems. *Nature* 413: 591–596.

Spalding MD, Fox HE, Allen GR, Davidson N, Ferdaña ZA, Finlayson M, Halpern BJ, Jorge MA, Lombana A, Lourie SA, Martin KD, Mcmanus E, Molnar J, Recchia CA, Robertson J. 2007. Marine ecoregions of the world: A bioregionalization of coastal and shelf areas. *Bioscience* 57: 573–583.

Stephenson SA, Hartwig L. 2010. *The Arctic Marine Workshop: Freshwater Institute Winnipeg, Manitoba, February 16-17, 2010. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2934*. Winnipeg, Manitoba: Fisheries and Oceans Canada. 67 p.

Stirling I, Cleator H. 1981. *Polynyas in the Canadian Arctic. Occasional Paper No. 45*. Edmonton, Alberta: Canadian Wildlife Service. 73 p.

SWIPA. 2011. *Snow, Water, Ice and Permafrost in the Arctic: Executive Summary*. Oslo, Norway: Arctic Monitoring and Assessment Programme [cited 2011 Dec 7]. [16 p.]. Available from: http://www.amap.no/swipa/.

Tishkov AA. 2009. Conservation of biodiversity and ecosystems in the Russian Arctic. In: Golovach S, Makarova O, Penev LD, Editors, *Species and Communities in Extreme Environments*. Sophia-Moscow: Pensoft Publishers and KMK Scientific Press. 255-276 pp.

Tremblay J É, Bélanger S, Barber DG, Asplin M, Martin J, Darnis G, Fortier L, Gratton Y, Link H, Archambault P, Sallon A, Michel C, Williams WJ, Philippe B, Gosselin M. 2011. Climate forcing multiplies biological productivity in the coastal Arctic Ocean. *Geophysical Research Letters* 38: L18604.

UNEP/GRID-Arendal. 2010. *Arctic conservation area (CAFF), topographic map, ABA version (2010)*. [Internet]. UNEP/GRID-Arendal Maps and Graphics Library [cited 2011 Dec 8]. Available from: http://maps.grida.no/go/graphic/arctic-conservation-area-caff-topographic-map-aba-version-2010.

Walker DA, Gould WA, Maier HA, Raynolds MK. 2002. The Circumpolar Arctic Vegetation Map: AVHRR derived base map, environmental controls and integrated mapping procedures. *International Journal of Remote Sensing* 23:2552–2570.

Walker DA, Raynolds MK, Daniels FJA, Einarsson E, Elvebakk A, Gould WA, Katenin AE, Kholod SS, Markon CJ, Melnikov ES, Moskalenko NJ, Talbot SS, Yurtsev BA, the CAVM Team. 2005. The Circumpolar Arctic Vegetation Map. *Journal of Vegetation Science* 16: 267– 282.

Walsh JE. 2008. Climate of the Arctic environment. *Ecological Applications* 18: 3–22.

Wang M, Overland JE. 2009. A sea ice free summer Arctic within 30 years? *Geophysical Research Letters* 36: L07502.

Williams WJ, Carmack EC. 2008. Combined effect of wind-forcing and isobaths divergence on upwelling at Cape Bathurst, Beaufort Sea. *Journal of Marine Research* 66: 645–663.

WWF International Arctic Programme. 2009. *Arctic Climate Feedbacks: Global Implications*. Oslo, Norway: WWF [cited 2011 Dec 7] [97 p.] Available from: http://www.panda.org/arctic/climatefeedbacks.

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Bélanger, Simon, Université du Québec a Rimouski, Canada
Bluhm, Bodil, University of Alaska Fairbanks, USA
Braund, Stephen, Stephen Braund & Associates, USA
Callaghan, Terry, Abisko Research Station, Sweden
Chernova, N.V., Russian Academy of Sciences, St. Petersburg, Russia
Cleary, Jesse, Duke University, USA
Cuyler, Christine, Greenland Institute of Natural Resources, Greenland
Derocher, Andrew, University of Alberta, Canada
Eicken, Hajo, University of Alaska Fairbanks, USA
Ferguson, Steve, Fisheries and Oceans Canada, Canada
Forbes, Don, Natural Resources Canada, Canada
Forbes, Bruce, University of Lapland, Finland
Gavrilo, Maria, Arctic and Antarctic Research Institute St. Petersburg, Russia
Gibson, Georgina, University of Alaska Fairbanks, USA

Gobeil, Jean-Francois, Environment Canada, Canada
Gradinger, Rolf, University of Alaska Fairbanks, USA
Hannah, Charles, Fisheries and Oceans Canada, Canada
Harwood, Lois, Fisheries and Oceans Canada, Canada
Hik, David, University of Alberta, Canada
Hinzman, Larry, University of Alaska Fairbanks, USA
Huard, David, Ouranos, Canada
Huntington, Henry, Pew Environment Group, USA
Kelly, Brendan, NOAA (currently at USA NSF), USA
Klenk, Nicole, University of New Brunswick, Canada
Kofinas, Gary, University of Alaska Fairbanks, USA
Larouche, Pierre, Fisheries and Oceans Canada, Canada
Lee, David, Nunavut Tunngavik Inc., Canada
McLennan, Donald, Parks Canada, Canada
Melling, Humfrey, Fisheries and Oceans Canada, Canada
Miller, Pam, Northern Alaska Environment Center, USA
Mueller, Derek, Carlton University, Canada
Nagy, John, University of Alberta, Canada
Nirlungayuk, Gabriel, Nunavut Tunngavik Inc., Canada
Petryashov, V.V., Russian Academy of Sciences St Petersburg, Russia
Pogrebov, V.B., Eco-Project Consultancy, Russia
Popov, A.V., Arctic and Antarctic Research Institute St. Petersburg, Russia
Puzachenko, Mikhail, Moscow State University, Russia
Quakenbush, Lori, Alaska Department of Fish and Game, USA
Razzhivin, Volodya, Russian Academy of Science St. Petersburg, Russia
Reist, Jim, Fisheries and Oceans Canada, Canada
Richard, Pierre, Fisheries and Oceans Canada, Canada
Richardson, Evan, University of Alberta, Canada
Rupp, Scott, University of Alaska, USA
Sarkar, Sahotra, University of Texas, USA
Smith, Melanie, Audubon Alaska, USA
Springer, Alan, University of Alaska Fairbanks, USA
Stirling, Ian, University of Manitoba, Canada
Tishkov, Arkady, Russian Academy of Sciences, Russia
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THE WWF RACER TEAM INCLUDES

Agbayani, Selina, Canada
Alidina, Hussein, Canada
Elias, Victoria, Russia
Evans, Susan, Canada
Ewins, Peter, Canada
Geitz, Miriam, Global Arctic Programme
Hamilton, Neil, Global Arctic Programme
Hummel, Monte, Canada
Lombana, Al, USA
Mirbach, Martin von, Canada
Pauley, Kendra, Canada
Polet, Gert, Netherlands
Price, Steven, Canada
Slavik, Dan, Canada
Snider, James, Canada
Sommerkorn, Martin, Global Arctic Programme
Spiridonov, V.A., Russia
Stewart, Craig, Canada
Stishov, Mikhail, Russia
Tesar, Clive, Global Arctic Programme
Williams, Margaret, USA

WWF GLOBAL ARCTIC PROGRAMME

Our vision is that effective international stewardship shields the Arctic from the worst effects of rapid change by promoting healthy living systems to the benefit of local peoples and all humanity. We are the coordinators of a focused international effort by WWF to achieve that vision.

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CONTACT:

Martin Sommerkorn, Head of Conservation,
Email msommerkorn@wwf.no Phone +47 222 05 309

Clive Tesar, Head of Communications and External Relations,
Email ctesar@wwfcanada.org Phone +1 613 232 2535

www.panda.org/arctic

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Why we are here
To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature.

RACER SETS THE STAGE FOR RENEWED DISCUSSIONS ABOUT WHERE CONSERVATION EFFORTS SHOULD FOCUS AND WHAT THESE EFFORTS SHOULD BE. ROBERT W. CORELL