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Environmental and Economic Benefits of Climate Change Mitigation and Adaptation in Antarctica

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Environmental and Economic Benefits of Climate Change Mitigation and Adaptation in Antarctica

Abstract

In ASOC's view, the relevance of the ongoing international climate negotiation process to the Antarctic context continues to lie along three axes:

Climate change mitigation involves human interventions to reduce the emissions of greenhouse gases. Within the global context, energy consumption and greenhouse gas emissions from human activities in Antarctica are small. However, collectively, National Antarctic Programs have accrued two decades of experience in deploying energy efficiency and renewable energy applications at small and large scales. This experience demonstrates that reducing greenhouse gas emissions from human activities in Antarctica can bring about local and global environmental benefits as well as proven cost savings. In addition, the global symbolic value of focusing on reducing emissions from human activities in Antarctica – long considered as one of the world's most logistically challenging environments - cannot be underestimated.

Climate change adaptation strategies will need to be adopted in the Antarctica region as the rapid environmental changes taking place may exceed the natural abilities of many organisms to cope. While adaptation is a relatively new concept in the management of the Antarctic region, it is an integral component of the global response to climate change and is becoming a vigorous field of science and practice in other parts of the world. Establishing a representative network of marine protected areas (MPAs) and marine reserves will be essential for building up ecosystem resilience and buffering against the impacts of climate change. The Ross Sea, an area already identified as a priority for protection, is an area where sea ice is likely to persist and will provide a refuge for sea ice-dependent species in the future as sea ice disappears from other areas. Also, all economic activities that take place in Antarctica, particularly extractive activities such as fisheries, should be managed in a precautionary way, taking special account of climate change effects. The implementation of biosecurity measures will also help to increase ecosystem resilience by reducing the threat of invasion by non-native species.

Climate science will continue to play an important role in informing climate policy decisions worldwide. ASOC supports the continuation of collaborative and cooperative research of global significance in the Antarctic region. At the same time, we underline the importance of leading by example by minimizing the climate impacts of research and logistics activities through reducing greenhouse gas emissions wherever possible.

1 Introduction

From 7 to 19 December 2009, the fifteenth Conference of the Parties (COP 15) to the United Nations Framework Convention on Climate Change (UNFCCC) took place in Copenhagen, Denmark. Continuing on from earlier meetings, negotiations at COP-15 focused on how the populated parts of the globe could work together to mitigate and adapt to climate change, with little direct reference to Antarctica. In this paper, we explore three key issues that relate to the management of Antarctica in the context of climate change:

- **Climate change mitigation**: Greenhouse gas emissions of Antarctic activities, how to reduce them, and the environmental and economic advantages of their reduction;
- **Climate change adaptation:** Management strategies that could limit the vulnerability of Antarctica's ecosystems to the negative impacts of climate change; and
- **Climate science:** Scientific research and monitoring from Antarctica plays an important role in informing policy decisions, providing the evidence, and in reminding the world of the urgency to address climate change.[1]

1.1 Climate Change Mitigation

Within the global context, energy consumption and greenhouse gas emissions from human activities in Antarctica are small. However, activities in and travel to Antarctica are resource intensive and the emission of greenhouse gases, relative to the number of people involved in the activities, is high. Based on best estimates and certain assumptions, a person visiting Antarctica in the 2004/5 season emitted more CO_2 during his / her visit as the average African or Latin American or Asian did from his / her total use of fossil fuels during the course of 2005 (Shirsat and Graf, 2009 and ASOC estimates, see following text for more details). The greenhouse gas emissions produced during the typical two-week holiday of an Antarctic tourist equal the emissions produced by the average European in twenty months time (Lamers and Amelung, 2007).

At the same time, National Antarctic Programs have accrued two decades of experience in using advanced energy management controls, robust energy efficiency measures, encouragement of behavioral change, improved insulation, innovative snow removal techniques to reduce energy demands. Solar collectors, solar panels and wind turbines have further reduced the need for fossil fuel. Energy efficiency measures, small-scale renewable energy applications, and management of energy needs through technical means and behavioral change have the added advantages of being flexible, portable, relatively cheap and requiring little infrastructure. The ambition to run entire stations or field camps on 100% renewable energy is increasingly common and feasible, though not entirely feasible at all locations. This experience demonstrates that it is feasible to reduce greenhouse gas emissions from human activities in Antarctica and doing so can save costs and bring about local and global environmental benefits (Tin et al., in press[2]).

This paper examines existing best estimates of greenhouse gas emissions of human activities in Antarctica, summarizes the experiences of National Antarctic Programs in deploying energy efficiency and renewable energy applications, and discusses feasibility and environmental and economic benefits.

[1] Climate science will be discussed summarily in this paper.
[2] The views expressed in Tin et al., in press are those of the co-authors and do not represent the official policies of National Antarctic Programs or national governments.

1.2 Climate Change Adaptation Strategies

The climatic changes currently underway will continue for centuries even under the best case scenarios and the rapid environmental changes taking place as a result of climate change may exceed the natural abilities of many Antarctic organisms to cope. In this context, strategies for reducing the vulnerability climate-sensitive ecosystems and species will be increasingly important for management, as species ranges shift, and as the timing of key seasonal events, and weather and current patterns change. In the climate policy context, such strategies are referred to as adaptation. While adaptation is a relatively new concept in the management of the Antarctic region, it is an integral component of the global response to climate change and is becoming a vigorous field of science and practice in other parts of the world.

In this paper we will explore some of the concepts and examples of climate change adaptation that are in use worldwide, and examine possible climate change adaptation options for the Antarctic and the Southern Ocean based on future impacts of climate change described by SCAR's Antarctic Climate Change and the Environment (ACCE) report.

1.3 Climate Science

The research priorities of climate change in Antarctica will not be explored in-depth in this paper, but it is worth to discuss them summarily. SCAR's ACCE report provides an in-depth discussion of this and other topics and interested readers are referred to this excellent report for more details. However, we would like to acknowledge the important role that scientific research and monitoring from Antarctica will continue to play in informing policy decisions, providing the evidence, and in reminding the world of the urgency to address climate change. Antarctic science will continue to contribute to building the case for the long-term goal in global emissions reductions and in informing the development of climate change adaptation plans.

While ASOC strongly supports the continuation of collaborative and cooperative Antarctic and Southern Ocean research and monitoring of global importance (e.g., Constable and Doust, 2009), we would like to underline the importance of maintaining consistency and avoiding self-contradiction in the approach to the problem of climate change. This implies minimizing the impact on climate wherever possible (through reductions in greenhouse gas emissions) while contributing towards understanding and addressing climate change (through climate change research).

2 Climate Change Mitigation

Reduction of greenhouse gas emissions from human activities in Antarctica is a win-win course of action. It:

- contributes towards mitigation of global climate change;
- limits local pollution and the human footprint in Antarctica;
- leads by example and sends an important symbolic signal to the rest of the world on the need and the feasibility to address climate change;
- reduces costs.

Activities in and travel to Antarctica are resource intensive and the emission of greenhouse gases, relative to the number of people involved in the activities, is likely to be high (relative to the global average). Reduction of such emissions could be achieved through the adoption of alternative energy systems, coordination of transport, identification of best practices (Norway and UK, 2008), improvement in energy efficiency, education and reduction in energy needs (Tin et al., in press).

2.1 Local and Global Environmental Benefits

There is no single estimate of the greenhouse gas emissions of all the human activities in the Antarctic region. Total emissions are likely to be small due when compared to global emissions due to the relatively low level of human presence. Emission intensities (i.e., tons of carbon dioxide (CO_2) emitted per person) are likely to be high because of the large distances traveled to get to and within Antarctica and the Southern Ocean and heating needs. Using information from IAATO, extrapolating from limited information from National Antarctic Programs and basing on certain logical assumptions, Shirsat and Graf (2009) made the first comprehensive best estimates of atmospheric emissions arising from human activities in Antarctica. For the 2004/5 season, they estimated that power generation, vehicular, marine and airborne traffic in the Antarctica region emitted a total of 208 ktons of CO_2.

To put this into a global context, approximately 50,000 people[3] traveled to Antarctica during the 2004/5 season. Therefore, roughly speaking, each person was accountable for the emission of 4 tons of CO_2 during his / her stay in Antarctica, which typically lasted from several days to several months. According to the International Energy Agency (IEA, 2009), the global average CO_2 emission from the combustion of fossil fuel is estimated at 4.2 tons per person for the year 2005. This value varies geographically. The average African was accountable for 0.9 tons of CO_2 emissions through his / her use of fossil fuels in 2005; the average Latin American, 2.1 tons and the average Asian (China not included), 1.25 tons. At the other end of the spectrum, the average North American was accountable for 19.29 tons of CO_2 emissions through his / her use of fossil fuels in 2005; the average European 8.34 tons This shows that a person visiting Antarctica in the 2004/5 season emitted more CO_2 during his / her visit as the average African or Latin American or Asian did from his / her total use of fossil fuels during the course of 2005.

Focusing on the total contribution of Antarctic tourism to greenhouse gas emissions, Lamers and Amelung (2007):

- incorporated the emissions generated by tourists traveling from their home countries to and from gateway cities in the Southern Hemisphere, and the emissions generated by cruises, land-based activities and overflights in Antarctica; and
- calculated their total greenhouse gas emissions (including CO_2 and other greenhouse gases, arriving at a contribution in tons of CO2-equivalent).

They reported that in the 2004/5 season, Antarctic tourism was accountable for 425 ktons CO_2-equivalents of greenhouse gas emissions. To put this into perspective, the average emissions for an Antarctic tourist are more than three times as high as those who visit the Seychelles and 43 times as high as the per capita emissions of a visit to the Rocky Mountains in the United States[4]. With per-capita emissions of around 15 tonnes CO_2-eq, Antarctic tourism is a very energy intensive industry. The greenhouse gas emissions produced during the typical two-week holiday of an Antarctic tourist equal the emissions produced by the average European in twenty months time (Lamers and Amelung, 2007).

Burning fossil fuels produces not only CO_2 but also other atmospheric emissions such as sulphur dioxide, mercury and lead. Reducing the amount of fossil fuels burned in Antarctica also contributes towards:

- reducing the risk of local pollution;
- protecting the scientific values of the clean environment of Antarctica; and
- reducing the extent and intensity of the human footprint in Antarctica.

2.2 Leading By Example

Within the global context, energy consumption and greenhouse gas emissions from human activities in Antarctica are small. However, as the only continent collectively managed internationally, and playing an important role in the study of global climate change, there is an ethical importance to reducing emissions and leading by example using best practice (ATCPs, 2008). It is important to be consistent and avoid self-contradiction in the approach to the problem of climate change: while helping to solve the problem (through

[3] According to the International Association of Antarctica Tour Operators (IAATO, 2010) more than 46,000 passengers, staff and crew travelled to Antarctica in the 2004/5 season. According to the Council of Managers of National Antarctic Programs (COMNAP, 2009) all the research stations in Antarctica combined have a simultaneous peak capacity of about 4,500 people (Tin et al., 2008). There were probably more than 50,000 people in Antarctica in 2005 as this estimate does not take into account the rotation of personnel at research stations nor personnel related to the fishing industry.

[4] The difference is largely attributable to the differences in the distance between the home country of the tourist and the destination.

research and monitoring) it is important not to make the problem worse (by emitting more greenhouse gases than absolutely necessary) at the same time. The global symbolic value of focusing on reducing emissions from human activities in Antarctica – long considered as one of the world's most logistically challenging environments – cannot be underestimated (Norway and UK, 2008).

2.3 Two Decades of Experience in Energy Efficiency and Renewable Energy in Antarctica

One of the earliest experiences of energy efficiency and renewable energy in Antarctica was the pilot alternative energy system used at the base that ASOC member Greenpeace operated in Ross Island between 1987 and 1992. The system combined solar and wind power, and through annual improvements eventually allowed for a considerable reduction in fuel consumption (with a peak reduction of approximately 36% for 1991) (Greenpeace, 1994; Roura, 2004). Over the past two decades, facility managers of National Antarctic Programs have used a mix of different technologies and approaches to enhance energy efficiency and embrace renewable energy in Antarctic operations (Tin et al., in press[1]). Advanced energy management controls, robust energy efficiency measures, encouragement of behavioral change, low energy instrumentation, improved insulation, innovative snow removal techniques and cogeneration have contributed towards reducing energy demands. Solar collectors, solar panels and wind turbines have further reduced the need for fossil fuel. Energy efficiency measures, small-scale renewable energy applications, and management of energy needs through technical means and behavioral change have the added advantages of being flexible, portable, relatively cheap and requiring little infrastructure. The ambition to run entire stations or field camps on 100% renewable energy is increasingly common and feasible, though not entirely feasible at all locations.

Examples include (Tin et al., in press[1]):

- Energy consumption at Rothera station has been reduced through changing space heating from electrical to hot water, retrofitting lighting systems, fitting freezers with energy saving devices, enhancing insulation within buildings and encouraging staff to actively save energy whenever possible. New buildings are optimized for minimum snowdrift in order to reduce the energy needed for snow clearance.

- The walls and ceilings at Wasa station have 30-50 cm rock wool insulation, all windows are triple glazed and there are no windows facing south. Most of the power is generated by solar panels. Scientists and logisticians are very conscious about the limited power that they have at their disposal, and they get together to discuss their energy needs, energy conservation and alternatives prior to each field season.

- All space heating needs at Concordia station are met using waste heat recovered from the cooling system and the exhaust of diesel generators.

- Two commercial-size wind turbines at Mawson station have been functioning since 2002, resulting in fuel savings of around 30% per year. A wind turbine, specially designed for use on the ice shelf, has been in use at Neumayer station since 1991. Its outstanding performance has led to the decision to construct five additional wind turbines coupled with a diesel generator to meet all of the electricity needs of the station. The diesel generator will only serve to backup the wind turbines and it is expected that only 25% of its full output will be needed over the course of the year. The new wind farm on Ross Island has the eventual goal of providing 100% of the energy of Scott Base and meeting part of the power requirements of McMurdo station.

- Syowa station makes use of solar panels, solar collectors and a solar hot water system to provide energy for electricity, and air and water heating.

- The summer energy needs of Princess Elisabeth station is designed to be met entirely by its nine wind turbines and over 300 m^2 of solar panels.

- At Cape Royds, solar panels meet almost all of the energy needs of two researchers living and studying the penguin colony over a period of three months during summer each year. Low-power electronics, small-scale wind turbines and solar panels have enabled instrumentation to function in Antarctica continuously and autonomously throughout the year.

Years of successful operation at these facilities demonstrate that even in one of the world's most difficult environments, well designed and well-engineered energy efficiency programs can make a substantial contribution to reducing energy use, displacing imports and minimizing environmental impacts.

2.4 Proven Economic Benefits

Although subject to some limitations, economic cost-benefit analyses can provide some indication of the costs and benefits of introducing energy efficiency and renewable energy in Antarctica. However, in Antarctica as elsewhere, the results of such analyses should be treated with care and considered only as indicators of parts of a complex reality[5]. Despite the shortcomings of economic cost-benefit analyses, the following information provides an indication of some of the costs and benefits of renewable energy systems in Antarctica.

- Undiscounted simple payback period for the wind farm project at Mawson station is estimated to be from 5 to 12 years, depending on assumptions made on the cost of fuel landed and stored in Antarctica. Since commissioning, the wind farm has provided an average annual fuel saving of around 32%, equivalent to a saving of 2918 t of carbon dioxide during the first six years of operation (Tin et al., in press[1]).

- The hypothetical installation of nine 100 kilowatt (kW) wind turbines at South Pole station is estimated to cost approximately US $4.3 million and would result in potential net savings of almost US $18 million over a 20-year project life (Baring-Gould et al., 2005).

- The possible installation of wind turbines of approximately 1 megawatt (MW) at McMurdo is estimated to cost US $2–3 million. Total fuel consumption would potentially be reduced by between 600,000 and 1,200,000 l/year resulting in net savings of between US$1 million and US$4 million over a 20-year project life (presuming a simple undiscounted payback rate) (Baring-Gould et al., 2005).

- At SANAE IV station, the hypothetical installation of a 100 kW wind turbine is estimated to reduce the cost per kWh produced by potentially up to 20%, with a simple undiscounted payback period of about 10 years (Teetz et al., 2003).

- A flatplate solar thermal system at SANAE IV could potentially save over 10,000 l of fuel annually and have a short payback period of 6 years (Teetz et al., 2003).

Antarctic research stations are often designed for a lifetime of at least 20-25 years. Payback periods of 6-20 years are short in comparison. Such short payback periods should largely justify the costs of investing into energy efficiency and renewable energy applications, especially as more collective experience is accrued and best practices can be shared.

3 Building Ecosystem Resilience and Climate Change Adaptation Strategies

3.1 What and Why

Adaptation: actions that limit the vulnerability of a system to the negative consequences of climate change (Hoffman, 2009)

Vulnerability: the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change (Parry et al., 2007)

Resilience: the amount of change or disturbance that can be absorbed by a system before the system is redefined by a different set of processes and structures (Julius et al., 2008)

[5] Results from cost-benefit analyses are often subject to change as a result of fluctuati… prices, the cost of transporting fuel and installation costs. Conservative estimates are… rarely accommodate hard-to-monetize external cost savings, such as reduced risk of c… atmospheric emissions, or hidden cost savings such as annual reduced transport costs… (Tin et al., in press).

The climatic changes currently underway will continue for centuries even under the best-case scenarios. Strategies for protecting climate-sensitive ecosystems will be increasingly important for management, as species ranges and interactions shift, the timing of key seasonal events change, and weather and current patterns change. In response to threats posed by climate change, more and more managers and policy-makers are considering and implementing adaptation and resilience strategies. This means - taking action to limit the vulnerability of a system to the negative consequences of climate change. If we fail to look at how our policies and practices might be affected by climate change, we run the risk of investing time, money, and political capital in plans that are at best irrelevant and at worst maladaptive. While adaptation is a relatively new concept in the management of the Antarctic region, it is an integral component of the global response to climate change and is becoming a vigorous field of science and practice in other parts of the world.

A preeminent example is Australia's Great Barrier Reef Climate Change Action Plan (GBRMPA, 2007). This adaptation plan focuses on strategies for:

- maintaining and building resilience such as reducing local stressors (i.e. water quality threats, physical damage, human disturbance or coastal development);
- protecting adequate and appropriate spaces (i.e. transition or alternate habitats zones allowing distribution and abundance shifts); and
- maintaining key functional groups in the ecosystem (i.e. herbivores in coral systems).

The World Union on Conservation (IUCN) has also developed tools and strategies to help managers support the resilience of mangroves, seagrasses and coral reef systems to climate change (Björk et al., 2008; McLeod and Salm, 2006; Grimsditch and Salm, 2006). These include:

- identifying and fully protecting communities (of the species of interest) that are at risk of succumbing to climate change, and
- protecting multiple samples of the full range of communities and from a wide geographical range.

In the Arctic, initiatives to consider climate change adaptation are also under way. These include the Arctic Council Sustainable Development Working Group's project on "Vulnerability and Adaptation to Climate Change in the Arctic" (Njåstad et al., 2009) and the International Polar Year 2007-2008 (IPY) project "Community Adaptation and Vulnerability in Arctic Regions" (Smit et al., 2008), aimed at improving the understanding of how Arctic communities are affected by environmental changes in order to contribute to the development of adaptive strategies and policies.

As discussed in the SCAR ACCE report, species have a limited number of responses that enhance survival in changing environments (Turner et al., 2009, P. 364). Individuals could change their physiological tolerance or move to locations where conditions are better, populations could evolve new capacities or tolerances, or species could shift their ranges to track favorable conditions. Many Antarctic organisms are long-lived and produce few offspring during a lifetime (P. 364, 381), limiting rates of evolution. Antarctic terrestrial biota have evolved to thrive under the special environmental conditions of Antarctica, at the expense of reduced competitive ability, leaving them vulnerable to the impact of colonization by competitors that may be at more advantage under changed conditions (P. 356). Migratory species that spend at least part of their life cycles in the Antarctica region could possibly move to other sites where conditions are more favorable. However, they may equally be vulnerable to climate change, given that their low latitudes breeding areas may be subject to different impacts (P. 383).

The rapid environmental changes taking place as a result of global climate change may exceed the natural abilities of many Antarctic organisms to cope. Climate adaptation plans can help to increase the resilience of ecosystems and allow them to have a better chance of withstanding the stresses brought about by climate change.

3.2 Some Basic Principles

Increasing the resilience of a natural system is a standard goal of conservation; intact ecosystems have more resources for withstanding stresses. Natural systems are already affected by an array of naturally occurring and human induced stresses, from habitat fragmentation to pollution to invasive species. Climate change will add another layer of stress to this complex matrix of interactions. Fortunately, many best management practices that exist to address traditional non-climate stresses can also address climate impacts (Hansen et al., 2003).

Some people worry that it is not possible to take adaptation action now because there is still so much uncertainty, so much we do not know. In scientific predictions, uncertainty always exists—it can only be reduced, not eliminated. The wisest course is to take an active adaptive management approach in which we take action to reduce vulnerability based on existing information but establish research and monitoring programs that allow us to periodically evaluate and adjust management strategies. There are incipient examples of this in the Antarctic Treaty System, such as the commitment of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) to develop a feedback management of Antarctic krill fisheries, which is yet to be fully developed.[6]

Increasing ecosystem resilience to climate change falls under three broad principles (Hansen et al., 2003; Hoffman, 2009):

3.2.1 Protect Adequate and Appropriate Space

As a result of climate change, many species are changing where they feed, grow, or breed, and when they engage in key life history behaviors such as reproduction and migration. It will become increasingly important to take into account projected impacts of climate change when designing new protected area systems, and to expand protected area spatial scales through buffer zones and corridors to aid species range shifts or individual migration. Planning will now require an eye for potentially dramatic future changes; thinking about not only current but also future configurations of habitats, communities, and ecosystems. Protecting not just space but functional groups, keystone species, climatic refugia (i.e., areas that are less likely to change), and multiple microhabitats within a biome to provide adequate representation is essential.

3.2.2 Reduce non-climate stresses likely to interact with climate change

Climate change is not occurring in a vacuum. There are myriad stresses affecting natural systems, including overharvest, invasions by non-native species, and pollution. There is limited research on interactions between and cumulative effects from climate and non-climate stresses. To support ecosystem resilience, the number of simultaneous stresses faced by the ecosystem must be reduced. Rates of harvest or human disturbance that have been viewed as 'sustainable' in the past will become unsustainable if climate change alters population growth rates or leads to mis-matches between life history patterns and the environmental signals to which they evolved. Changes in temperature, salinity, and ocean acidity will render some pollutants more toxic. The precautionary principle suggests that we add "insurance factors" to regulations governing a variety of non-climate stressors to minimize the risk of natural systems flipping to alternative stable states.

3.2.3 Manage for Uncertainty

Climatic variability is a fact of life, but the long-term directional climate change we are currently experiencing is different. While not unprecedented in the history of the world, it is unprecedented in the history of modern humans, and there are therefore a great many unknowns as we look towards the future. To remain effective, management systems must be able to incorporate uncertainty and to respond to new information and unforeseen circumstances in a timely fashion. Adaptive management, including deepened precaution and scenario planning, provide frameworks for how to address this.

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[6] **For more details, please refer to ASOC's submission: Antarctic krill fisheries and rapid ecosystem change: the need for adaptive management**

4 Developing Adaptation and Resilience Plans for the Antarctic and Southern Ocean

There are several ways to approach the development of adaptation and resilience plans. One is to look at the physical or chemical changes and their possible biological effects, then develop ways to reduce the changes and minimize the effects. Another is to start with a particular place, species, or resource of interest, identify the key factors for maintaining the health of that place/species/resource, and to look at how climate change might affect those factors. Regardless of approach, it is important to remember that there is a wide range of options for action, from the do-nothing approach to the extremely expensive and interventionist.

The following is an example of possible adaptation options for the Antarctic marine and terrestrial ecosystems. These adaptation ideas are meant to stimulate creative thinking on ways to decrease the vulnerability of Antarctic ecosystems to climate change.

4.1 Marine Ecosystems

4.1.1 Future Scenario

According to the SCAR ACCE report, between now and 2100 all components of the ecosystem closely related to the sea ice will show significant changes in their ecological performance in response to the predicted 33% reduction of sea ice extent. In areas with an originally high krill population size the population is likely to stabilize at a lower level. The implication is that over the long term all main krill consumers will experience serious food limitations. The minke whale will lose 5-30% of its ice-associated habitat, while for blue, humpback, fin and sperm whales a compression of foraging habitat along Southern Ocean fronts is suggested. The ice-bound emperor and Adélie penguins and crabeater, Weddell, leopard and Ross seals will likely become extinct locally due to changes in both habitat and food web dynamics. Species of any systematic group with a sufficient initial population size and circumpolar distribution are expected to survive at least in the Pacific sector south of Australia and New Zealand, where according to predictions the sea ice is likely to remain relatively stable (Turner et al., 2009, P. 384-385).

4.1.2 Possible Adaptation Options

- Develop spatial protection schemes that can accommodate changes in distribution rather than relying solely on fixed protected areas.
- Anticipate shifts in range and distribution, and manage areas into which species may move in such a way that they will be capable of supporting the species of interest.
- Develop feedback management approaches to krill fishing that take account of the combined impacts of fishing and climate change
- Identify and protect areas most likely to maintain stable sea ice. The Ross Sea, in the Pacific sector of the Southern Ocean is a prime location. In addition to being a climate refugium, the Ross Sea, as the region of the world's oceans least impacted by human activity, can also serve as an excellent reference site for the study of climate change impacts. Such research will be important to inform adaptive management decisions for the rest of the Southern Ocean.

The above options are in accordance with a key recommendation of the April 2009 CEP/SC-CAMLR workshop. The workshop agreed that a representative system of MPAs would serve the purpose of conserving representative components of Antarctic marine biodiversity and could also be designed in such a way to:

- act as scientific reference areas, for example to help understand how to manage activities in the face of climate change impacts, and
- provide areas to increase the resilience of the Antarctic marine ecosystem to climate change or other impacts.

4.2 Terrestrial ecosystems

4.2.1 Future scenario

The frequency of freeze-thaw events and occurrence of minimum temperatures are predicted to increase under climate change. The tolerance limits of arthropods and continental bryophytes could readily be exceeded, although lower lethal temperatures show substantial capacity for both phenotypic plasticity and evolutionary change. Increasing aridity is likely on the continent in the long term. Local reduction in water availability in terrestrial habitats can lead to desiccation stress and subsequent changes in ecosystem structure. High amongst future scenarios is the likelihood of invasion by more competitive non-native species, as warmer temperatures and increased human visitation combine to make it easier for non-native species to colonize and establish themselves (Turner et al., 2009, P. 355, 356). The cumulative effects of:

- climate change (e.g., changes in precipitation and temperature);
- higher probability of establishment of non-native species;
- increased disturbance from human activities through increased human visitation (e.g., trampling) are not well understood.

4.2.2 Possible Adaptation Options

- Implement appropriate biosecurity measures across different spatial scales and applied to different biological groups (see Hughes and Convey, 2009 for more details).
- Consider restriction on human visitation and direct disturbance to reduce the number of different concurrent stresses.
- Protect multiple populations within each species as insurance against the loss of one population, and to increase the chances that some individuals will be resistant.

To increase the resilience of Antarctic terrestrial ecosystems to climate change would require more holistic and strategic designations of a network of protected areas. The adoption at the ATCM XXXI of Resolution 3 (2008) (Environmental Domains Analysis) provides a tool that could help to do so by offsetting geographical bias in the designation process and taking environmental risks into account (New Zealand, 2009). The protection of inviolate areas may also need to be considered in order to protect the wilderness and scientific values of key high-risk areas for the future.

5 Closing Remarks

Antarctica plays an integral role in the Earth's climate system. Climate research in Antarctica is essential for improving our understanding of global climate change. However, scientific research and all other human activities in Antarctica also contribute to the problem of global climate change through their intensive use of fossil fuels. The total contribution is small in the global context but is disproportionately high for each individual. This disproportionate contribution needs to be acknowledged and reduced wherever possible, sending an important symbolic signal to the rest of the world on the urgent need and the feasibility to address climate change. The deployment of energy efficiency and renewable energy applications is a cost-effective way to reduce greenhouse gas emissions from human activities in Antarctica and needs to be greatly encouraged.

Antarctica is an important location to study climate change but it is also greatly impacted by climate change. The rapid environmental changes taking place may exceed the natural abilities of many Antarctic organisms to cope. Climate adaptation plans can help to increase the resilience of ecosystems and allow them to have a better chance of withstanding the stresses brought about by climate change. Many best management practices that address traditional non-climate stresses may also address climate impacts. Networks of protected areas, implementation of biosecurity measures are all existing tools that can be used to increase the resilience of Antarctic ecosystems and buffer against the impacts of climate change. While climate change adaptation is a relatively new concept in the management of the Antarctic region, it is an integral component of the global response to climate change and is becoming a vigorous field of science and practice in other parts of the world. Antarctic managers and decision makers need to embrace the concept of climate change adaptation.

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