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A conceptual approach to climate change and ecosystem management in Antarctica

ANTA601

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Abstract

Since the beginning of Antarctic exploration measures have been progressively implemented as attempts to protect the Antarctic environment from human induced disturbances. Historically these disturbances were of a scale that they could be managed via regulations over fixed spatial areas.

Present methods for delineating boundaries for ecosystem protection, under the ATS do not account for the natural migration and variation of ecosystems. Areas where changes occur rapidly, such as ice shelves, clearly illustrate the limitations of the fixed aerial projection approach.

Ecosystem management in Antarctica cannot be undertaken as a uniform approach. It needs to be informed by the spatial and temporal scales, and physical attributes of the ecosystems concerned. Strategies should be derived from both the natural and cultural context of Antarctica.

We propose that ecosystem management principles could be derived from any number of cartographic principles including longitude, latitude, network and elevational projections. In addition, acceptance and recognition of dynamic natural edges is also key to effective management. Managing human activity as part of the ecosystem is not separate to strategies such as the temporal sequencing of visitation, minimising introduction of competitor species, localised physical interventions and cultural engagement will all be important.

Integrating management across marine and terrestrial environments is also at the core of the issue. The division between the administration of management in marine and terrestrial ecosystems, whilst logistically easier to apply, does not assist in the development of an integrated and creative approach to ecosystem management.

Currently the issue of consensus decision-making that underpins the ATS limits the potential for future innovations in this area. Should climate continue to change as predicted, the present system will need to be modified for the purpose of protected areas to be realised. This report provides a stepping of point for that creative process when the environmental and political incentives to change become unavoidable.

Introduction/Background

Global climate has undergone dramatic changes over the past 50 years, with much of the change being attributed to anthropogenic activity, namely an increase in carbon dioxide and other green house gases being released into the atmosphere since the beginning of the industrial revolution.

In recent years, particularly since the discovery of the Antarctic ozone hole in the 1980s, the magnitude of climate change impacts on the environments, societies and economies of the planet has thrust Antarctic science in to the global spotlight. This report draws on the flip-side of that discussion and, rather than discussing the effects of climate change on the planet at large, examines the effects of climate change on Antarctica itself with particular attention to the protection of Antarctic Ecosystems and species. The focus of this report is to review current ecosystem management practices and explore new ecosystem and species based management responses to climate change scenarios in the most vulnerable parts of the Antarctic including the Southern Ocean.

For the purpose of this report 'ecosystem' is defined as being made up of plants, animals, microorganisms, soil, rocks, minerals, water sources and the local atmosphere interacting with one another (Biology Online, 2011). 'Vulnerable' species and ecosystems are defined as those that are most susceptible to the effects of climate change in the future. Polar species in particular are more vulnerable to the effects of climate change as they are specially adapted to cope with a narrow range of environmental conditions. SCAR (2007) states that 'Species that fail to adapt to climate change requirements exceeding the organisms internal flexibility limits, or fail to migrate, will become extinct'. However the report fails to address the possibility that there may not be a viable ecosystem left for species to migrate to.

Due to the large temporal and spatial variation of ecosystems across Antarctica the threats to the ecosystems are also variable. Most notably factors influencing ecosystem change can be derived from climate change alone, or from a combination of climatic and anthropogenic influences.

As climate changes, the questions we will need to face are:

Can ecosystem management change too?; how do we protect Antarctica's most valuable species and ecosystems?; and is it even possible to ensure sufficient protection in Antarctica and the Southern Ocean

What threatens ecosystems in Antarctica?

Antarctic ecosystems vary widely both in their size and in the temporal duration of their cycles. Many stresses can occur on an animal as the environment around it changes. The ability for an organism to adapt to these changes is highly variable. The main climate induced changes are likely to be the increase in temperature, ocean acidification, and deoxygenation.

Organisms all have physical optima at which they function. When the environment around them changes the organism tries to change to cope. In the case of temperature, organisms change their internal thermostat. This will only work to a point however. Once the organism is under stress for a prolonged period or the stress increases then it can no longer adapt and will perish. Organisms will vary in their ability to be able to cope with temperature rise. Bivalves are only able to cope with a 1 or 2 degree increase before they are unable to perform their essential tasks. Some fish have been shown to adapt to a 5 to 10 degree variance if left to gradually adapt over time.

Another change that will affect benthic organisms especially is ocean acidification. Mollusks and bivalves as well as other shelled organisms are especially sensitive to pH change in the ocean. The shells of these organisms are made from calcite and aragonite, which naturally occurs, dissolved in the water, in the form of $CaCO_3$. As pH decreases the amount of $CaCO_3$ available in ocean water for organisms to make their shells out of decreases. This stress on the organism cannot be helped and may lead to a decrease in overall benthic population.

There are 3 methods in which organisms can adapt to the change in environment. As previously mentioned organisms can use the margins of internal physiology flexibility and capacity to sustain new biological requirements. The previously mentioned temperature changes and tolerance by fish and scallops is an example of this. Another way organisms can adapt is alter the range of biological capacity (SCAR, 2007). This is very similar to the previous flexibility in physiology. It is highly dependent on the magnitude and the rate of change. The ability is linked to the reproductive speed of the animal. Mutation rate, the number of reproductive events and the generation time all influence the rate in which an organism can adapt. The final possibility is to migrate to favorable conditions. The ability to migrate is dependent on the movements of the animals. Whales and fish will be able to migrate easier than a scallop or even a sea anemone, because they are free movers. The only way sessile organisms are able to migrate is with their offspring being established in differing and more appropriate environments (SCAR, 2007).

Importantly Antarctic Ecosystems also vary in location, and in the level of interest they present for human beings, either as places to visit for science, for commercial activity, or for enjoyment. For example, a remote ecosystem which presents little commercial value will suffer less from human disturbance than one which is relatively accessible and already integrated into the global market place [Fig 1]. In a world where resource depletion is increasingly an issue, human exploitation may pose further considerable challenges for some Antarctic ecosystems in the future.

In summary it is thought that future threats to Antarctic ecosystems may be derived either solely from climate change in remote area, or from a combination of climate induced and human induced change in areas which are of greater interest and are more accessible [Fig 1].

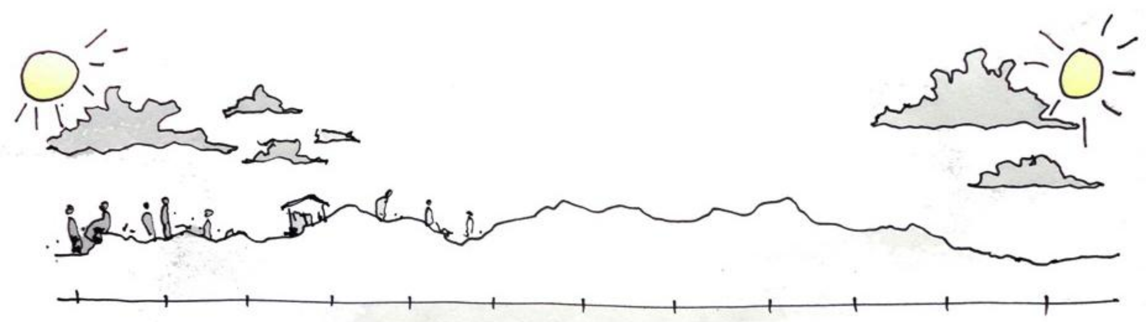

Figure 1 The species and ecosystems in this study fall at different point in this range of influences.

Climate Change Projections

Projections for future climate change used in this report are largely derived from the 2009 report by SCAR 'Antarctic Climate Change and the Environment', combined with data from the IPCC. These documents identify the main changes anticipated in the next 100 years as:

- Increased temperature
- Increased acidity in the Oceans
- Increased CO_2 in the atmosphere
- West Antarctic Ice-sheet (WAIS) decay
- Decreased sea ice – up to 40%
- Increased coastal precipitation

Concurrently anthropogenic factors such as:

- Increased commercial exploitation
- Fishing
- Prospecting – bioprospecting and minerals
- Increased Scientific activity
- Increased Tourism

Ecosystems will change in response to these scenarios, for these reasons the effects of climate change are critical to decisions which are made about ecosystem management.

Existing Management of Antarctic Ecosystems

Measures have been progressively implemented to protect the Antarctic environment from human disturbance. Historically ecosystems were relatively stable and these disturbances were of a scale that they could be managed via regulations over fixed geographical areas.

The Madrid Protocol (1991) laid the guidelines for the establishment of a system of Antarctic Specially Protected Areas (ASPAs) [Fig 2] and Antarctic Specially managed areas (ASMAs). The Protocol on Environmental Protection to the Antarctic treaty (1991) states "parties shall seek to identify, within a systematic environmental-geographical framework, and to include in the series of Antarctic Specially Protected Areas:

a) Areas kept inviolate from human interference so that future comparisons may be possible with localities that have been affected by human activities;

b) Representative examples of major terrestrial, including glacial and aquatic, ecosystems and marine ecosystems;

c) Areas with important or unusual assemblages of species, including major colonies of breeding native birds or mammals;

(d) The type locality or only known habitat of any species;

(e) Areas of particular interest to on-going or planned scientific research;

(f) Examples of outstanding geological, glaciological or geomorphological features;

(g) Areas of outstanding aesthetic and wilderness value;

(h) Sites or monuments or recognised historic value; and

(i) Such other areas as may be appropriate to protect the values set out in paragraph 1 above.”

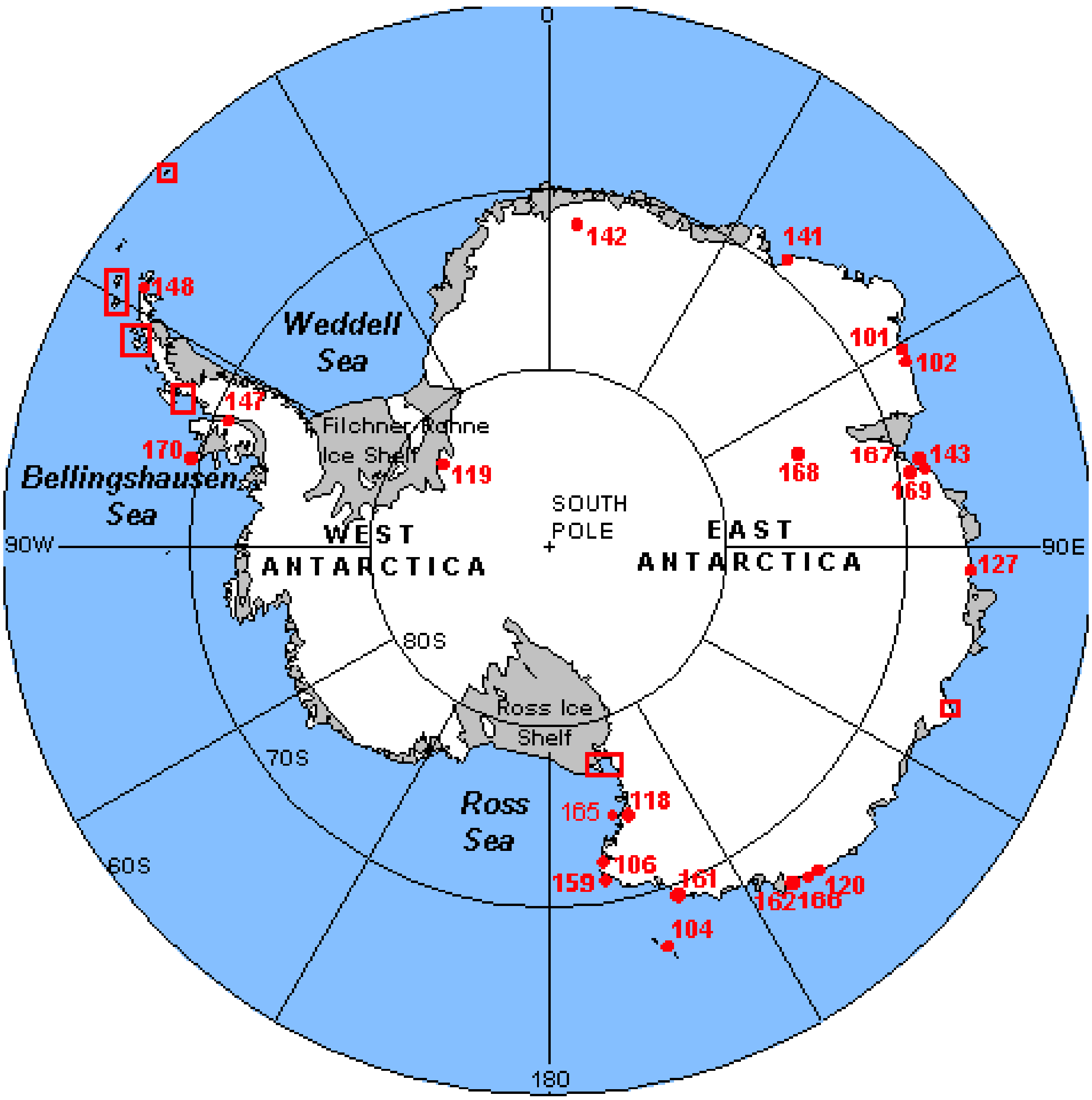

Figure 2 Map showing current ASPAs

Whilst the level of human disturbance it was possible to inflict remained smaller than the spatial units themselves, such a system has proved an effective means of ensuring the ongoing viability of populations, ecosystems and specially protected areas. With climate change this is no longer the case.

Late in the twentieth century the international community began to become increasingly aware that the human ability to negatively impact the Antarctic environment had the ability to spatially and temporally encompass whole ecosystems or even entire continents. Unlike an inadvertent scrape of the boot over an ancient soil surface or carelessly discarded waste from a remote field station, an emerging understanding of climate change, has brought new disturbances, which are bigger than the environments themselves.

Currently the protection of the Antarctic marine area is undertaken by the Committee of the Conservation of Antarctic Living Marine (CCAMLR). CCAMLR divides the southern ocean into three main statistical sub areas, which are then broken into smaller statistical sub-areas. It is from these areas that information which determines the allocation of fishing quotas is drawn. As with the system of ASPAs and ASMAs this current management allows no distinction to be made between anthropogenically induced change to the system, and changes that occur solely due to variation in the natural system.

Given the size of this topic, a comprehensive and interconnected system of protected areas for all Antarctic Species and Ecosystems is far beyond the remit of this report, and is indeed an issue of such complexity that it evades definition by peak international bodies. This report focuses on the development of organizational and management principles for a representative selection of species and ecosystems to a conceptual level of detail, unhindered by conventions and barriers presented by the ATS consensus decision making process.

Methods

Given the vastness of this topic, a comprehensive and interconnected system of protected areas for all Antarctic Species and Ecosystems is far beyond the remit of this report and is indeed an issue of such complexity that it evades definition by peak international bodies. This report focuses on the development of new organizational and management principles for a representative selection of species and ecosystems to a conceptual level of detail. A representative selection of both terrestrial and marine ecosystems was derived through the following method.

The Environmental Domain Analysis, 2007 (EDA) is a data derived, spatially explicit delineation of environmental classifications in Antarctica. It was developed intended for use in the identification of priority sites for environmental protection, environmental monitoring and risk assessment associated with human activities. This system provides a way to categorise valuable data that has not been collected systematically, or is not easily available to assess the extent and importance of human pressures at a regional level.

The EDA provides 21 classifications of terrestrial environment in Antarctica based on 5 broad brush environments. These five broad-brush classifications were chosen as broad domains for use in this study
The five broad-brush domains are: Central Antarctic Ice Sheet, Coastal Continental Margin, Ice Shelves and Floating Glaciers, Mountainous and Ice Free Rock and the Peninsula and Offshore Islands.

The EDA broad domains only represent terrestrial environments. In order to extend the framework for this study a sixth domain was added. As this is a management issue, for the purposes of this report four marine ecosystem types identified by Treguer & Jacques (1992) were combined with the CCAMLR area to describe the extent of the Antarctica Marine Environment.

Once these six broad ecosystem classifications for both terrestrial and marine environments of Antarctica was established they were then ranked in terms of their vulnerability to climate change in the future using information from the SCAR report Antarctica Climate Change and the Environment (2009). Having established a vulnerability gradient for the broad domains ecosystems and species within each domain were selected as cases studies.

Each of the case studies begins with an outline of the biophysical aspects of the ecosystem or species in consideration. This is followed by an assessment of key issues for the case studies including biophysical and cultural induce challenges presented by climate change, followed by concepts for management which respond to these issues. [Fig 3]

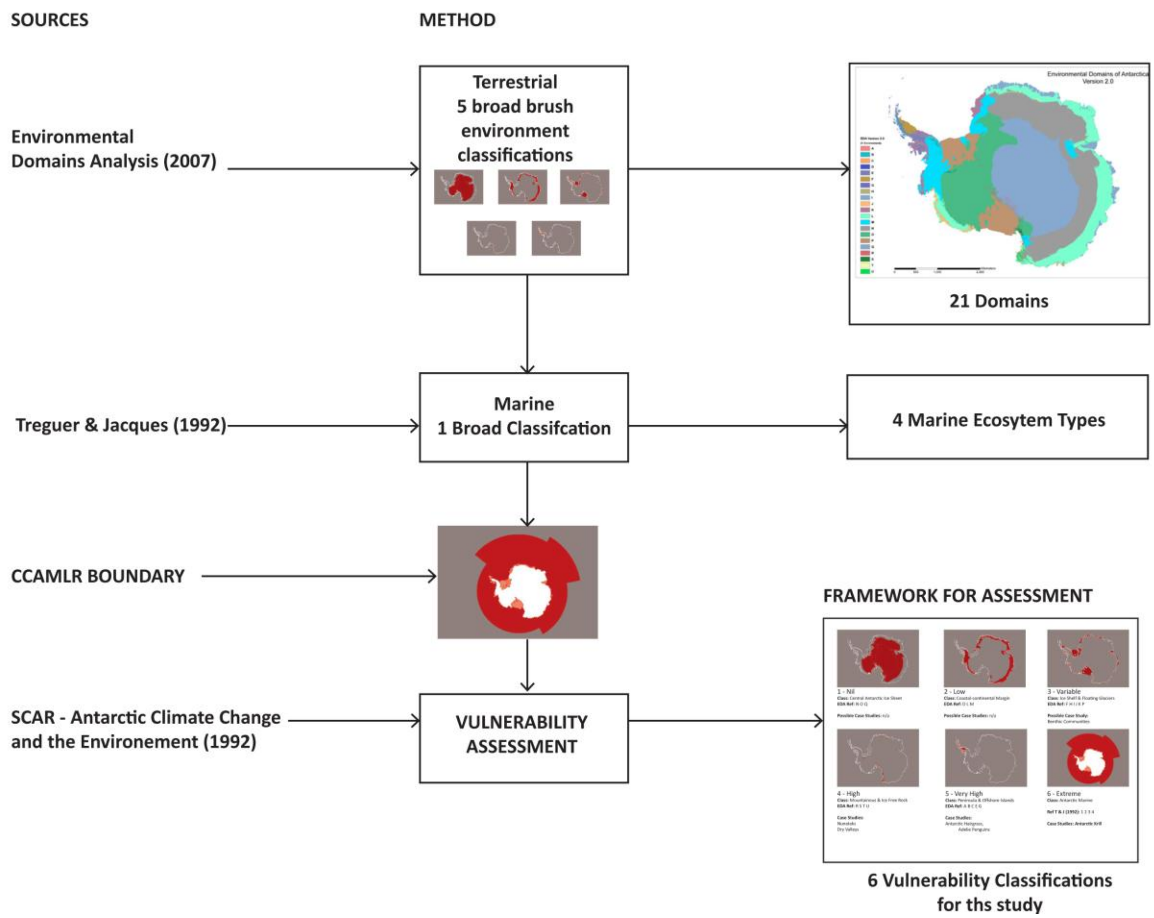

Figure 3 Process towards framework for assessment

Case Studies

Case studies were Identified for each domain based on a review of the literature. Broad Classification 1, the Central Antarctic Ice Sheet and Broad Classification 2, the Coastal Continental Margin were quickly identified as being at low vulnerability to climate change, primarily due to an absence of species and the little change that is anticipated in these areas. They are not discussed further in this report.

The vulnerability of Broad Classification 3 Ice sheets and Floating Glaciers is considered variable as whilst the larger ice sheets are stable smaller icesheets around the Peninsula have already experienced rapid collapse. The case study for this area examines benthic communities under the ice sheet.

Broad Classification 4 Mountainous and Ice-free zones display a high vulnerability to climate change. Nunataks and Dry Valleys are examined as case studies in this area.

Broad Classification 5 Peninsula and Offshore Islands present a very high vulnerability to climate change compounded by human influences. Management case studies examine

Antarctic Hairgrass and Adelie Penguins at ecosystem and single species level.
Broad Classification 6 Antarctic Marine identifies Antarctic Krill as a case study as it is a key species across all ecosystem types. Management concepts are developed in response to both biophysical and culturally derived threats. [Fig 4]

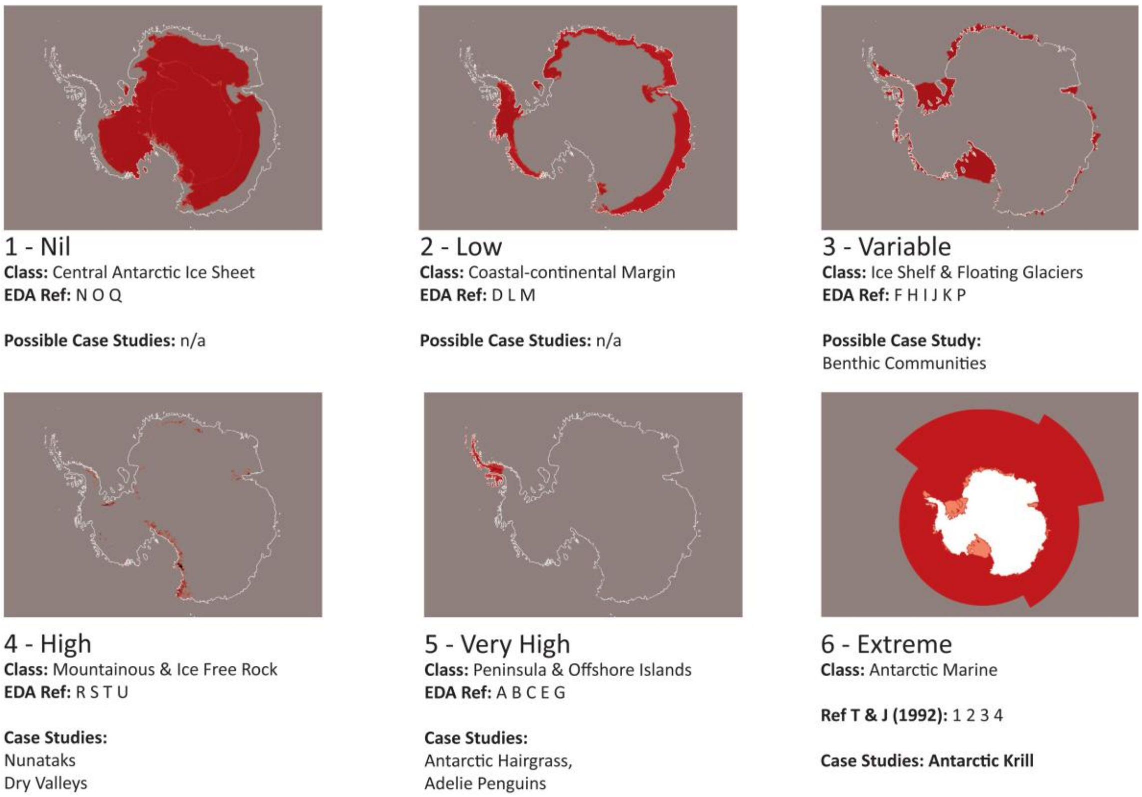

Figure 4 Broad classifications with degrees of vulnerability and case studies identified

Broad Class 3 - Ice Shelves and floating Glaciers

Ice Shelves are diverse in both environment and location. Often they have a blunt edge in which iceberg calving occurs. Within the Environmental Domains report (2007), 6 areas form the "broad brush" referred to as: Ice Shelves and other Floating glaciers. These include; Larsen Ice shelf, East Antarctic low latitude glacier tongues, East Antarctic ice shelves, Southern latitude coastal fringe ice shelves and floating glaciers, northern latitude ice shelves as well as the Ross and Ronne-Filchner ice shelves.
Within the fore mentioned areas there are a range of variations in temperatures (12°C), wind speed (7m/sec), as well as area. The Smallest ice shelf region is that of Coastal fringe shelves at 74,984km. The largest is the Ross and Ronne-Filchner shelves at 926,631km

(EDA, 2007). Overall Ice shelves take up 1,566,950 km2, equivalent to around ten percent of the continental shelf (Gutt et. al. 2010). It is this diversity, which means that each shelf must be studied at an individual level (figure 3).

Climate change has major influences on ice shelves. As the temperature increases both within the ocean and within the air, the rate of melt increases. Temperature also influences the rate of cracking. As the shelf weakens through ice loss and cracking increases and it is more prone to fall away. Other influencing factors are those which are more prevalent under the ice. Increased acidity, deoxygenation, and fluxuation in CO2 levels are contribute to the overall loss in ice shelves (SCAR, 2010).

Ecosystems

Currently there is an overall lack of information about inhabitants of ice shelves (Griffiths, H.J., 2010). Due to their thickness, the sea floor of ice shelves is often only studied from between the cracks in the ice. Even then it is extremely hard to bring samples up cleanly from that depth (Lipps et. al, 1979). Until the use of unmanned submersibles, many of the images from under the ice are from cameras dropped into the water (Lipps et.al. 1979). The major life forms are that of benthic communities. This includes such things as sea stars, anemones, mollusks and sponges. To survive under such thick ice organisms must adapt to a very limited food supply and restricted light. All of the organisms are highly dependent on the ocean currents and the gradual ice melt do bring fine food particles to the area. Although predominantly benthic, fish and krill have also been known to frequent ice shelf areas. Krill often use the ice shelf - sea ice interface for egg laying (Smetacek & Nicol, 2005). There is a high diversity among the communities under the ice. This diversity can also be observed within the shelves themselves. An organism that is present at one location may not be at another. This variation can also be observed within individual shelves. What is prominent at the outer shelf edge may not be further inward (Bruchhausen et. al, 1979). It is often the case that colonization is patchy rather than rare (Kaiser, S., Barnes, D.K.A., Brandt, A., 2007). The organisms themselves are slow to react to environmental changes (Smetacek, & Nicol, 2005, Lipps et. al. 1979). Their tolerance zones are often very small so that even a 2 degree change in temperature can lead to stress on an animal. Many of the animals are sessile, so can not actively escape changes.

As the shelves collapse and the climate and environment changes the organisms may not be able to adapt rapidly enough, and may become extinct.

Case Study

An example of this is the Larsen Ice shelves on the Antarctic Peninsula (Gutt et. al., 2010). When the sea floor under Larsen A, B and C are compared they can give a good indication of the recolonization process of the ocean floor. A through C are in order from the northern tip of the peninsula towards the south.

Larsen A collapsed in 1992, Larsen B collapsed in 2002, and Larsen C is still remaining. Due to the slow rate of colonisation by the benthic communities, the remaining sea bed in the A and B areas demonstrate the time involved in establishment of these communities (Gutt et. al. 2010). The major factors which influence the organisms once the shelf is gone are the presence in icebergs, the change in ocean circulation, exposure to rough seas, and lastly the increased exposure to ocean dynamics (SCAR). These freshly open areas will be incorporated into the fluctuations of temperature and oxygen levels that occur at coast lines.

Icebergs, as they calve, form great gouges in the ocean floor beneath them. These deep gouges destroy up to 90% of the communities below (Gerdes,et. al, 2008, SCAR, 2007). Gerdes et. al. (2008) replicated the gouging effects using a modified bottom trawl (artificial). The area tested showed a negative impact on fauna, up to a point where the dominant fish species in the area changed (Gerdes et. al., 2008). The study also looked at the effects that fishing may have in the area.

Overall trawlers will have a less detrimental effect than ice bergs due to the nature of the trawling. Nets are weighted so that only a small top section of the sediment is disturbed. This does not however dismiss the negative effect they are having. Trawling affects turbidity for days to weeks afterwards (Gerdes et. al., 2008). This increase in suspended sediment has detrimental effects on the filter feeders. This decreases their ability to feed, clogging their lophophores, placing them under further stress.

It is important that these organisms are not placed under further stress during recovery. Therefore we must protect them both before and after the ice shelf is gone.

Management

There are several conceptual methods for management plans that could be applied. Any form of protection will allow research to occur but will restrict major activities that will affect the organisms underneath. The point is to protect a section of the shelf to allow for

study later on, as well as to allow the area to be as undisturbed as possible. Once the shelf is gone then the area of protection will still remain. Research in the protected area will also be restricted further to that which cannot be done in another part of the exposed sea floor.
The Latitudinal method follows the line of latitude to designate an area an ASPA or something similar [Fig 5]. The protection will run from land out into the exposed open sea. This type of exclusion zone will make it difficult for vehicles to cross without a permit. This method may be better for areas which have shelves facing in a differing orientation to that of the example.
The Longitudinal method follows a similar lead to that of latitude [Fig 5]. This however will allow for easier access across the shelf, although it does not extend to the open ocean region. This means that the area on the cusp between the ocean and shelf may not be protected until the shelf retreats.

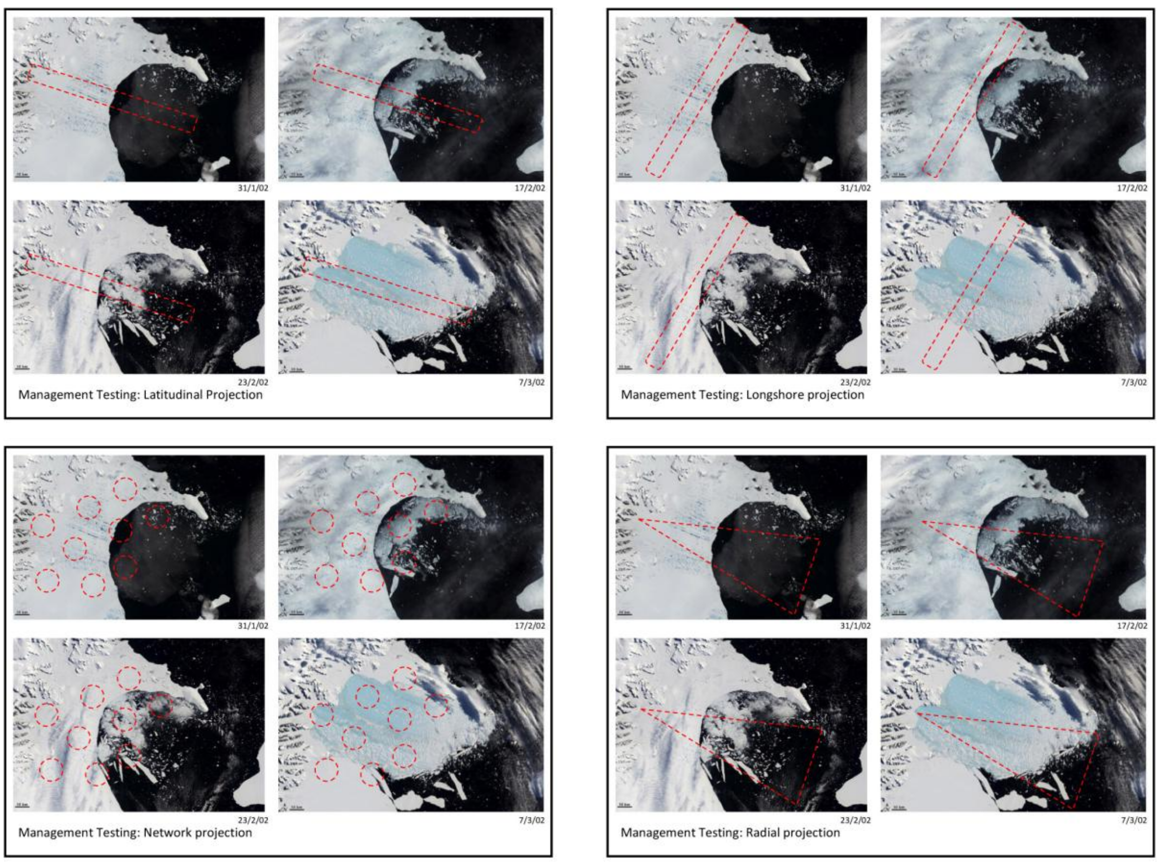

Figure 5 Conventional aerial projections over Larsen B iceshelf collapse, a rapid ecosystem collapse.

A Network method is a series of areas which protect the sections most at risk during changes [Fig 5]. It also allows for protection of a variable number of smaller locations. It can give protection to a number of areas that are representative of that particular shelf flora.

This allows greater ease in transport across the shelf. It will also allow science to occur in a greater range of places in the area.

Radial protection will extend from a small point on the land to a large portion of the shelf edge and out into the open ocean [Fig 5]. It will give greatest protection to the edge of the ice shelf as it retreats. It is this edge of the shelf that often has the highest diversity of organisms. Although it is still portioning off a large section off the ice shelf, transport across maybe less of an issue due to the decrease in protected area closer towards land.

There is no exact and perfect method for the protection of ice shelves. The ones mentioned above are merely in the beginning stages of possibility. They are there to act as a basis for future discussion on the topic. It is important however that the protection remains in place even if the ice shelf no longer remains. The ocean communities below such shelves are diverse and unknown. They will act as future habitats for other organisms in the area as the ocean changes with the variation in climate. Therefore further research is needed on what is present now, so that future predictions of communities can be made.

Broad Classification 4 - Mountainous and Ice Free Rock

According to the Environmental Domains Analysis of Antarctica (2007). Mountainous and Ice Free Rock covers a total of 115128 square kilometers, which is approximately 0.84% of the entire area of the Antarctic Continent. Most of the Mountainous and Ice-free rock areas are manifested as either Nunataks or Dry valleys, each of which contain their own unique ecosystem. They can be further classified into sub-regions:

- Transantarctic Mountains Geologic (ASPA119)
- McMurdo-South Victoria Land Geologic (ASPA 105, 121, 122, 123, 124, 131, 137, 138, 154, 155, 156, 161 + ASMA2)
- Inland Continental Geologic (ASPA161)
- Northern Victoria Land Geologic (ASPA118)

These sub-regions contain 15 ASPAs, which is over 20% of total ASPAs, all situated within 0.84% of the continent.

Dry Valleys

The McMurdo Dry valley region forms the largest relatively ice free area on the Antarctic Continent, covering approximately 4800 square kilometres. The dry valleys area is extremely cold, arid and windy, making it a cold desert ecosystem. This is caused by a ‘rain shadow’ effect, as air rolling down from the Antarctic plateau to the coast is forced over the Transantarctic Mountains, where it is cooled and condensed, and moisture is released in the form of snow.

Average annual precipitation in Dry Valley areas is on average less than 100mm water equivalent. This means that available water is a result of summer glacial melt and ephemeral streams, ice-covered ponds and lakes, as well as near snowfields and snow patches (McMurdo Dry Valleys, 2011).

The Dry Valleys are an important area for scientific research particularly in areas such as past climate change records based on remnant glacial formation. Large seasonal shifts in water phase can also be observed, which is important to the study of climate change, and the study of conditions similar to that of ancient earth and contemporary Mars.

Ecosystem

For approximately four to ten weeks during the Austral summer melt-water streams draining from alpine glaciers become a distinctive feature of the barren landscape. These streams support diverse ecological communities, which persist over this brief annual period of productivity, despite the extreme conditions.

These ecosystems primarily consist of cyanobacteria which grows in streams as mats. Chlorophytes and diatoms are also common. Fauna consist of nematodes, rotifers and tradigrades Simmons et al. (2008).

Research has primarily been conducted in the Wright, Taylor and Miers Valleys.

Stream flow is mainly controlled by climatic conditions in the source area. In addition to showing inter-annual variation average streamflow rates can show considerable daily variation during the summer, depending on insolation and air temperature. Research indicates that in addition to being related to variation in melt-water generation associated with meltwater characteristics of the glacier some of the variation is also related to stream length and geomorphology.

Implications for Management

As the Antarctic continent warms it is likely that the annual melt period will be extended, meaning more water is available to the Dry Valley ecosystems. This will also mean that more care must be taken when visiting the area. The defined boundaries of ASPAs need to reflect the increasingly transient nature of present environmentally defined boundaries. We propose extending protection to include an ASMA/ASPA 'buffer' zone around the known ecosystem in the valley area, in order to prevent damage to the areas around current melt-water streams, that are likely to become home to ecosystems as meltwater flows increase and the stream bed spreads into adjacent areas. This concept can also be applied to meltwater pools and lakes.

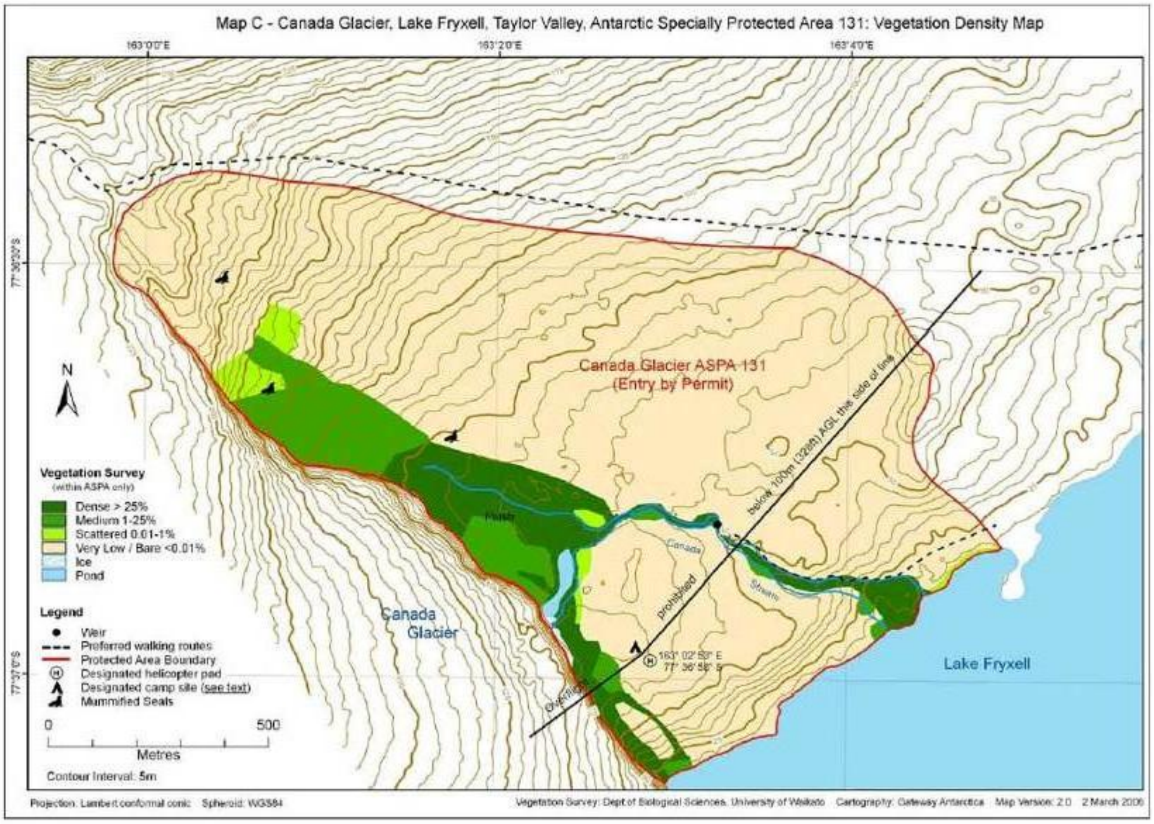

Figure 6 Naturally Derived ASPA boundaries could be more effectively managed with dynamic boundaries.

For example the ASPA area around the Canada glacier effectively has three boundaries [Fig 6]. One is a linear, anthropogenically determined boundary, which follows a walking track along the edge of the area. There is a sizeable buffer zone between this boundary and the existing ecosystem. However the remaining two boundaries of the ASPA are determined by the extent of the Canada glacier on one side, and by lake Fritzel on the other. As climate changes, these natural boundaries will change too. As temperatures increase the glacier will retreat and meltwater discharge will increase the lake level. Our management strategy will improve on the current ASPA boundary, allowing it to move dynamically as the natural system changes.

Access to the areas will also be restricted at the time of peak flows. This recognises that during the melt period the ecosystem is at its most vulnerable. As climate changes the possibility of transfer of species from one area to another by anthropogenic means is also increased. As the chance of this occurring is greatest during the melt period in the Austral summer, the number of humans travelling between Dry Valley areas will be severely restricted in order to limit the extent to which anthropogenically assisted transfer of biota occurs (McKnight et al. 1999).

Nunataks

Nuntaks are isolated mountain peaks that protrude through the Antarctic ice sheet. They are classified in the Mountainous/Snow free Ground category of the EDA. The snow free nature of this region allows small ecosystems to become established in these areas. As the peaks are dark coloured they heat up when exposed to sunlight, this then causes adjacent snow to melt providing a source of moisture, which is necessary for these ecosystems to exist.

Species that live in these remote areas include nemitodes, tardigardes, rotifers, lichens, algae, liverworts and moss. Antarctic Snow Petrels are also known to nest on some Nunataks. These birds also increase the prosperity of the ecosystem by providing additional nutrients, which allows soils to develop, and provide sustenance for microfauna in particular algae and nematodes which thrive when supported by organic material associated with a petrel population Bostrom, & Sohlenius (2008)

Future Change

SCAR (2009) reports that there is less confidence in large warming trends around the coast than smaller changes over the high interior; this is due to large uncertainty over sea ice and ocean projections. This illustrates the challenges of the large scale, and subsequent large variation in climate across the continent. This poses a problem when defining management strategy, as future changes are not likely to be uniform across the continent, but vary between each area, and each mountain range. SCAR describes the changes as a ‘patchwork’ across the Antarctic ice sheet, with a combination of both growth and loss expected, and that no single driver will dominate in all areas. Localised response also depends on regional climate and ice sheet sensitivities. The quantification of precipitation changes is particularly important for resolving uncertainty in future change, particularly for Nunataks as this will be the main factor that determines management strategy for the future. Data and modelling indicate that ice loss and future ice sheet behaviour will be episodic, and both snowfall and melt are likely to increase later this century.

Implications for Management

As mentioned above, it is extremely difficult to quantify the likely effects of climate change on Nunatak ecosystems, due to local and regional climate variability. Due to this uncertainty we propose to extend a zone of protection around known existing ecosystems, in order to accommodate the possibility of both a rise in altitude of the ecosystem, due to increased snowfall, or a lower altitude population, which is likely to occur as melting lowers the existing snowline. This is illustrated in Figue 7 below.

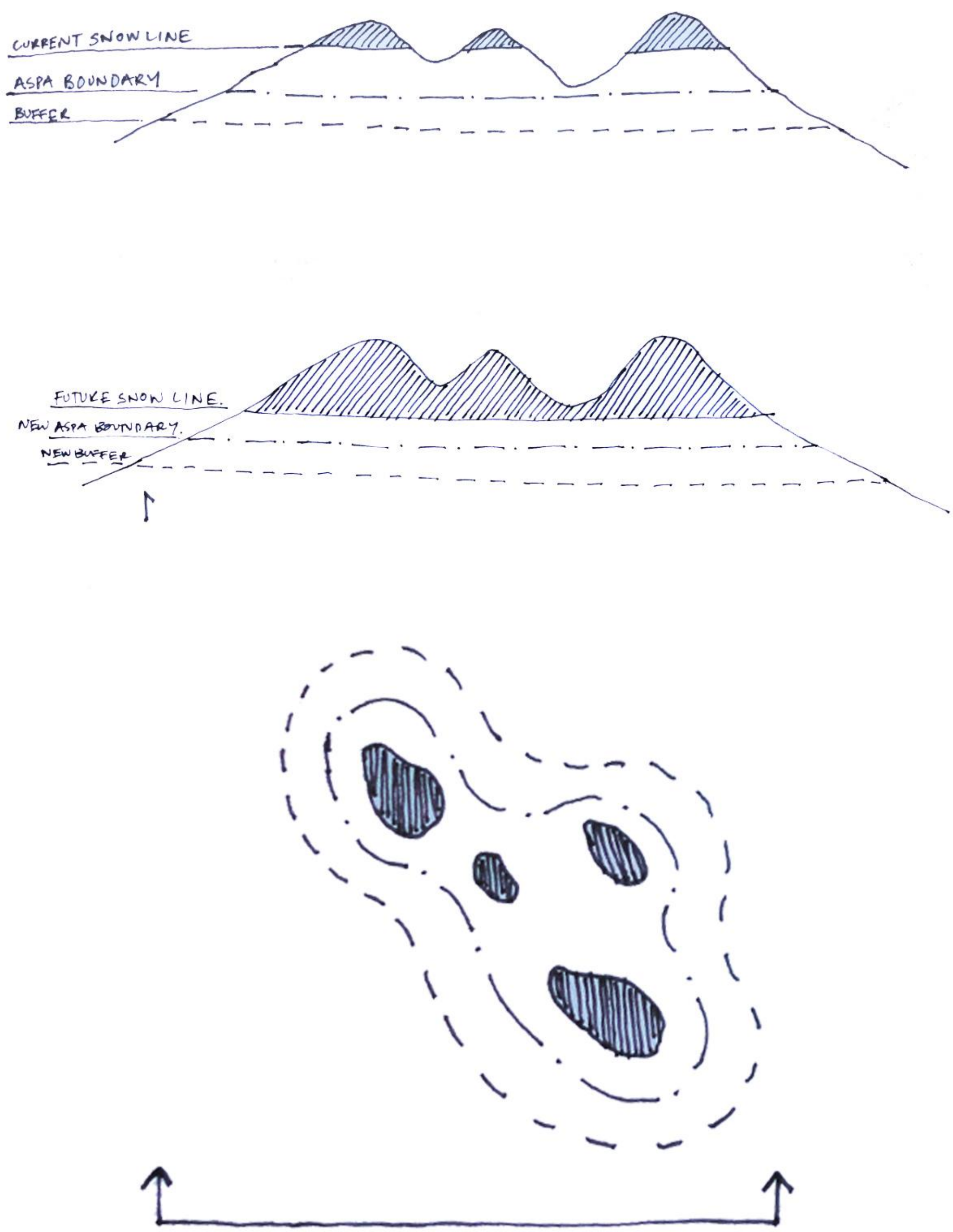

Figure 7 Proposed Elevational approach to boundary delineation for Nunatak ASPAs

This zone of protection will extend across each Nunatak range, along set lines of elevation. This also accounts for the possibility that areas between peaks, that have been snow covered for extended periods of time may be exposed in the future.

The zone of protection is intended to protect the environment from the potential detrimental effects of human activity, such as the disruption of areas by trampling. This strategy acknowledges that although an area may not currently be home to an ecosystem, it may become viable as climate changes in the future, and therefore it must be preserved to accommodate the migration of species as these changes occur.

Broad Classification 5 - Peninsula & Offshore Islands

Issues:

Intensive human activities

In this study, the West Antarctic Peninsula is classified as a region of the Antarctica that has very high vulnerability. There are currently 29 ASPAs, 2 ASMAs and numbers of cruise ship-landing sites in this region. There are virtually hundreds of different sites that have been visited in the past, out of which 30 or so receive more than 75% of all ship-borne tourists each season (Liggett, 2011). This indicates a high level of human activity on the Peninsula and surrounding islands, including scientific and commercial activities.

Regional Warming

Within the Antarctic Peninsula there are several geological environments which have the warmest average temperatures in Antarctica. These are environments A, B, E and G, which are along the west side of the Antarctic Peninsula. These are shown in Figure1. Most Antarctic vegetation is found in the Antarctic Peninsula and offshore islands region.

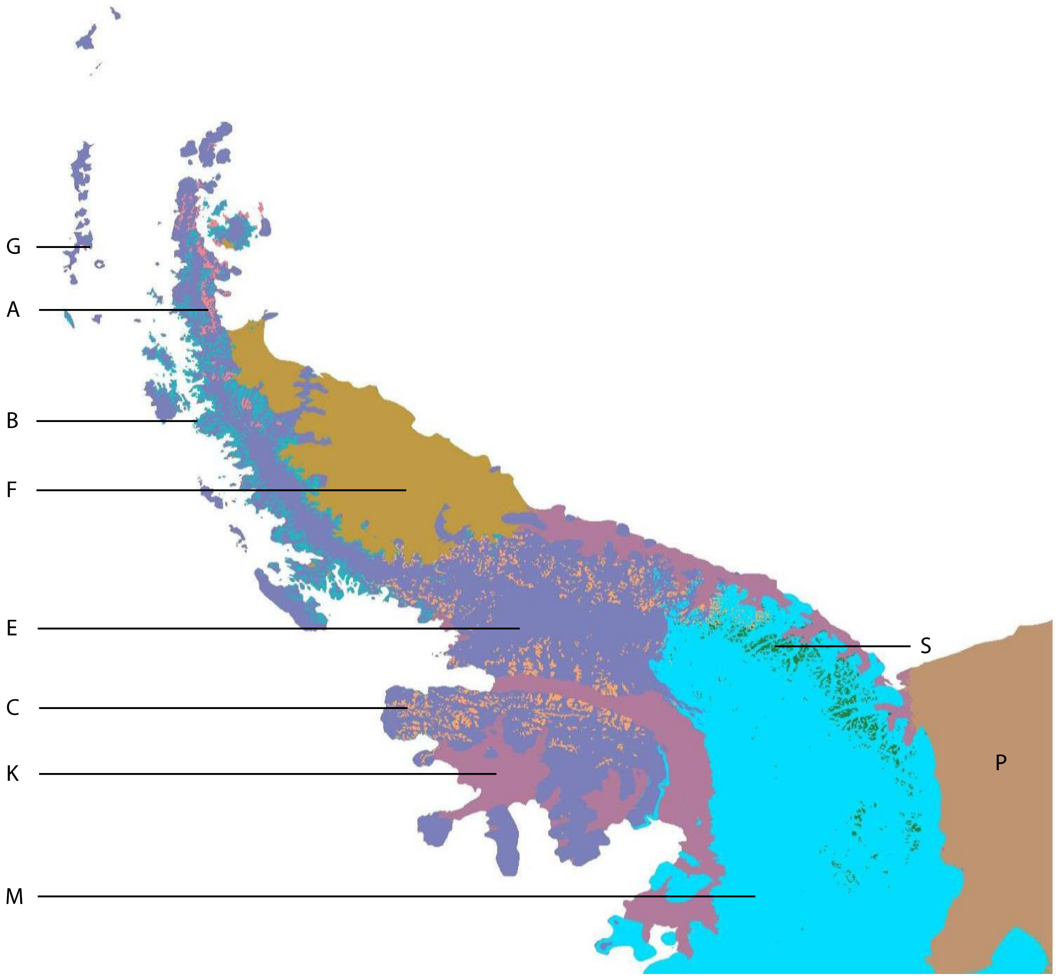

Figure 8 Antarctic Peninsula. A: Antarctic Peninsula northern geologic; B: Antarctic Peninsula mid-latitudes geologic; C: Antarctic Peninsula southern geologic; E: Antarctic Peninsula and Alexander Island main ice field and glaciers; F: Larsen Ice Shelf; G: Antarctic Peninsula offshore island geologic.

The West Antarctic Peninsula covers a small area of the entire Antarctic continent. However, it has a very complex terrestrial environment, which includes ice-free land and multiple geological units.

Differential seasonal warming rates

Rates of warming vary seasonally in the west Antarctic Peninsula region, the air temperature has warmed 2.5°C over the past 50 years, up until 2003 (Holderegger et al. 2003 cit. Oppenheimer 1998). High warming rates occur during the summer, caused by the low-frequency mode of atmospheric variability of the southern hemisphere, also known as Southern Hemisphere Annular Mode (SHAM) or Antarctic Annual Oscillation (AAO). As a result, a hotter summer may speed up the ice sheet retreat and rapid ice loss, in the marine basins beneath the East Antarctic ice sheet. On the other hand, winter has a slower warming rate compared with summer, this will potentially increase the relative humidity and may bring higher precipitation in winter (SCAR, 2009).

Increasing melt water lakes

The climate warming in the Antarctic Peninsula leads to excess melting of southern part of the ice shelf, and form an increasing number of surface melt water lakes. In these areas surface water may also act as lubrication where it penetrates between the bottom of the ice sheet and bed, and accelerate the ice sheet flow (SCAR, 2009 quote Zwally *et al.,* 2002b; Joughin *et al.,* 2008). However, it is not yet possible for scientists to predict the melting rates with high precision.

Stratospheric ozone depletion

Ozone depletion has been observed since the 1970s and it is a major source of the increasing incoming UV-B (280-320nm) in Antarctica. 17% of ozone depletion can lower plants growth rates (up to 41%) and biological material (biomass) productivity under near-ambient UV-B. UV-B radiation, also changes several chemical concentrations in plants leaves and total biomass. Total biomass includes above ground biomass and root biomass (Ruhland C. *et al.,* 2005) (Avery L. *et al.,* 2003).

Case study:

Antarctic hairgrass *(Deschampsia antarctica)*

D.anraectica is a self seeding, and has low genetic diversity (Holderegger R. *et al.,* 2003)(Wouw M. *et al..* 2008).It is one of the only two flowering plants native to the Antarctic. *D.* a*ntarctica* and is widely found in the Antarctic Peninsula from north of Signy Island to south of Léonie Islands, the history of *D. antarctic* is at least 12000 years. Similar to Antarctic Pearlwort (*Colobanthus quitensis*) *D. antarctica* has a very high freezing tolerance, it has survived the glacial advance of the Holocene (Holderegger R. *et al*., 2003). *D. antarctica* has been found on glacial forelands of Antarctic Peninsula recently, where the plant has regular contact with sea water. This indicates that *D. antarctica* has a high salinity-tolerance in it's leaves and roots, however, study has found that salt can slow down reproduction by reducing the biomass (Ruhland C. and Krna A. 2010).

The current state of Antarctic hairgrass *(Deschampsia antarctica)*

D. antarctica's total population has increased rapidly in number and size, a possible reason for the increased colonization rate and enhanced population is Antarctic Peninsula's climate warming (Holderegger R. *et al.,* 2003) (Avery L. *et al.,* 2003) (Wouw M. *et al.,* 2008) (Ruhland C. and Krna A. 2010). Increased human traffic may reduce the isolation of the Antarctic Peninsula from other terrestrial communities in the future (Wouw M. *et al.* 2008).

The total population of *D. antarctica* is increasing, however. It has a low genetic diversity (Holderegger R. *et al.,* 2003), which makes *D. antarctica* very vulnerable. At the same time the reproductive development is under stress under increasing ambient UV-B radiation caused by depletion of ozone, ambient UV-B radiation slows down the reproduction of the population (Avery L. *et al.,* 2003). At a regional scale, there is also a decreasing population due to an increasing fur seal population, which alters the chemistry in the ground, in some areas of Signy island (Wouw M. *et al.,* 2008).

Management Concepts

The purpose of management is to gain a better understanding of the effect of the changes, and whether it will have impact on Antarctic Peninsula communities. It is vital to have a clear understanding of how the Antarctic Peninsula has been colonized by terrestrial organisms in the past and what may happen in the future. To understand Antarctic Peninsula terrestrial communities means that we need have to have a correct knowledge of the geographical patterns of genetic variation of Antarctic terrestrial organisms, this would give an insight into the bio-geography of islands in the extreme environments, in another word, better management require more scientific evidence.

The current management has clear instructions on how to protect the areas and what within the areas, however, it fails to consider the changing climates and how the areas and ecosystems may change in the future. This study suggests that we keep the current management, because it is fairly complete for the current Antarctic Peninsula, which includes restrictions on entering and visiting sites by both scientists and tourists.

Above keeping the current management, one can regulate visits by the following rule:

For multiple visits, the locations need to have different environments with a temporal buffer zone in between [Fig 9].

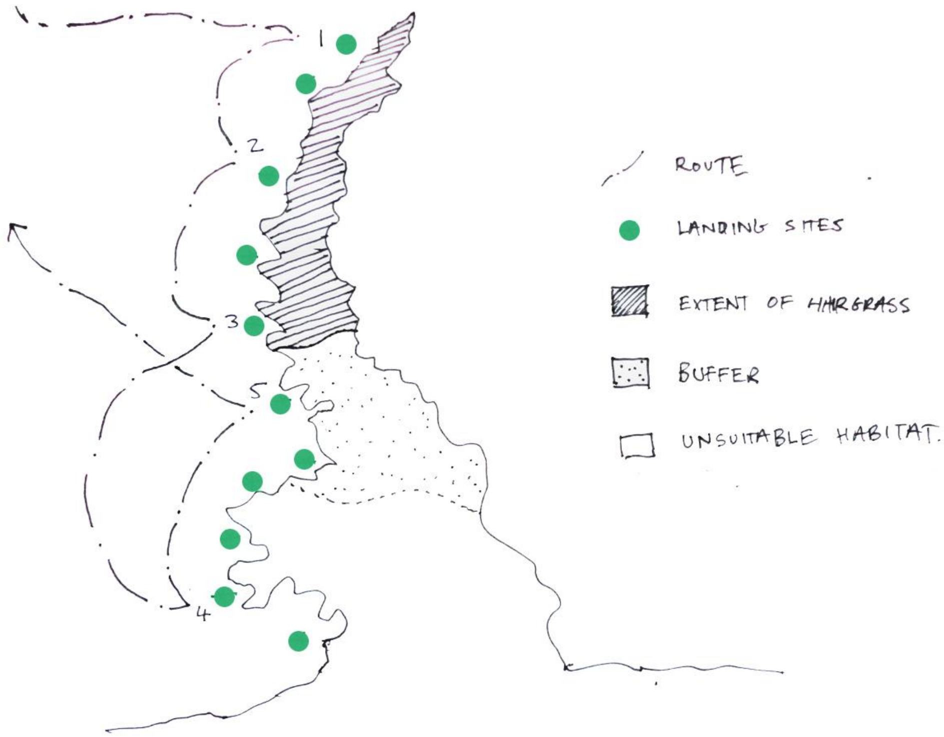

Figure 9 Temporal Buffering concept to manage the human spread of hairgrass by tourists on the Antarctic Peninsula

For example, if a visitor carries a *D. antarctica* seed from visiting an offshore island or landing sites 1, 2 or 3, and they then visit another area where is very cold and has different climate such as 4, the seed they carried is unlikely to grow in the second location. Visitors can also travel from 4 to the terrestrial environment 1, 2 or 3, the only restriction is travelling from 1 or 2 or 3 to 5. This method will not allow seeds to have the chance to grow in a similar environment.

In order to reduce competition to the native terrestrial species, we can adapt biosecurity guide lines.

Reintroducing *D. antarctica* back to Signy island may help the local ecosystem recover back to its original state, however, this method may also change the current balance in the local ecosystem.

The Antarctic Peninsula terrestrial ecosystem is very vulnerable, and the ecosystem itself has been fighting for its balance, we have to accept that the ecosystem in changing, and we cannot manage it without considering the future. We need to find a balance of the current management and the changes of the environment to produce a sustainable natural resource in the hope that this will encourage social and economical development.

Case Study:

Adelie Penguins

Adelie penguins *Pygocelis adeliae* require snow free ground on which to breed. An increase in coastal precipitation is already beginning to threaten breeding populations of Adelie penguins on the West Antarctic Peninsula. Snow presently remains on the ground at the beginning of the breeding season for a period of 2-3 weeks longer than it has historically. Such conditions are more suited to sub-antarctic penguins such as Gentoo and Chinstrap penguins. Adelie rookeries are fixed breeding locations this also presents particular challenges for the management of Adelie penguin colonies in the Antarctic Peninsula. West Antarctic Adelies are genetically distinct from those elsewhere in Antarctica making relocation of Adelie penguins to other parts of Antarctica undesirable.

Management Concepts

Given the fixed geographical location of rookeries, it is proposed that the potential for localised built interventions be explored. Technologies developed to assist with cultural preservation in Antarctica may also have applications for the preservation of Antarctica's natural heritage. Snow accumulation is an issue for heritage buildings at Cape Royds on Ross Island, this lead to the construction of vortex generators to deter the settlement of snow around huts. As a direct adoption this concept could rightly be considered crude, however the potential for adaptation of these forms and the integration of instrumentation for science and monitoring may offer other benefits [Fig 10]. Improved breeding conditions, maintaining existing breeding sites, the development of longterm monitoring and datasets and the reduced need for human visitation and disturbance at rookeries all offer positive outcomes for Adelies in the West Antarctic.

Figure 10 Localised interventions may assist reproduction and monitoring at established rookeries

Broad Classification 6 - Antarctic Marine Ecosystem

Case Study:

Antarctic Krill around the West Antarctic Peninsula

Antarctic Krill *Euphausia superba* are a key species for all 4 Antarctic Marine Ecosystems. Antarctic Krill populations have been well studied. Krill biomass is known to be coupled with seasonal flux in sea ice extent and mass. This is due to winter sea ice providing habitat for young krill through the winter, and the melt of sea ice initiating diatom blooms , which increase food availability in the spring assisting re-production (Haberman et al, 2003). A 23 year record of sea-ice extent in the Palmer Antarctic Longterm Ecological Research (Pal-LTER) area on the west of the Antarctic Peninsula reveals a sea ice extent of 5 months or more to be best for the over wintering krill population (Quentin & Ross, 2003). Surface air temperature records reveal a 5-6^{o}C increase over the last 50 years, making it the fastest warming area of the planet (Vaughn et. al., 2003). At the same time, a reduction in the duration of sea ice cover has also been observed (Smith & Stammerjohn, 2001). Krill faecal deposition also plays a vital part in the sequestration of carbon in the southern ocean (Ducklow et. al. 2006).

Ducklow et. al. (2006) proposes that krill recruitment may be a key indicator of interactions between climate change or migration and ecosystems response. However, given the growth in the krill fishery, human induced population changes confound representative assessment of krill populations. Despite longterm monitoring of krill in the west antarctic in both the Pal-LTER the American Marine Living Resources Area (AMLR) using acoustic estimate of biomass, distinguishing human induced change from climate induced change presents difficulties (Reiss, C et. al. 2008).

In response to this uncertainty CCAMLR Article II contains a fisheries management startegy which is unique. Article II combines a [1] a single species, [2] and ecosystem approach, and [3] a precautionary approach to fisheries management. In summary single species management begins by identifying target species within the fishery and setting catch quotas for these species to ensure a reproductive population. The ecosystem approach seeks to minimise the impact harvesting this species will have on the wider ocean food webs, and the precautionary approach seeks to minimise the imapact on the ecosystem by attempting to ensure impact on fish populations which are thought reversable within 20-30 years.

Methods for quantifying precautionary levels are contentious but it has been observed that uncertainty in distinguishing anthropogenic from climate induces changes in krill population is likely to result in CCAMLR setting more precautionary yields in future years. (Reiss, et.al. 2008)

Coupled with the science, in terms of managements the fact that krill based ecosystem of the Southern Ocean, the largest on the planet, is spatially and conceptually inaccessible to the international public is an issue.

Future Change

A 33% reduction in sea ice is anticipated over the next 100 years (SCAR, 2007) whilst the West Antarctic Peninsula has already seen a 40% decrease in sea-ice over the last 26 years (Comiso et.al., 1997). Given the observed relationship between sea-ice extent and krill populations in the West Peninsula, the continuation of this trend does not bode well for krill populations in the Antarctic as a whole. Both over wintering and spawning populations of krill will be reduced as sea ice duration and mass is reduced.

Compounding this is an anticipated increase on krill harvesting in the southern ocean, with the decrease in the sea ice amounting to improved access to southern waters for the expanding krill fishery.

Management Concept

Firstly, the direct integration of fisheries management with seasonal variation in sea ice could be used more extensively in the future. CCAMLR is already working towards smaller statistical areas in order to better manage fisheries to protect southern ocean mega-fauna. These smaller areas could be coupled with realtime data for sea ice extent to better integrate this controlling variable into setting of catch quotas.

Secondly, the idea that sustainability balances economy, environment and society is widely accepted in the international community. In the case of sustainable management of the krill fishery, CCAMLRs approach is advanced thouhg it is noted that all the measures contained in Article II operate on the environment-economy side of the sustainability triangle. How can sustainable management of the krill fishery be possible while this endures?

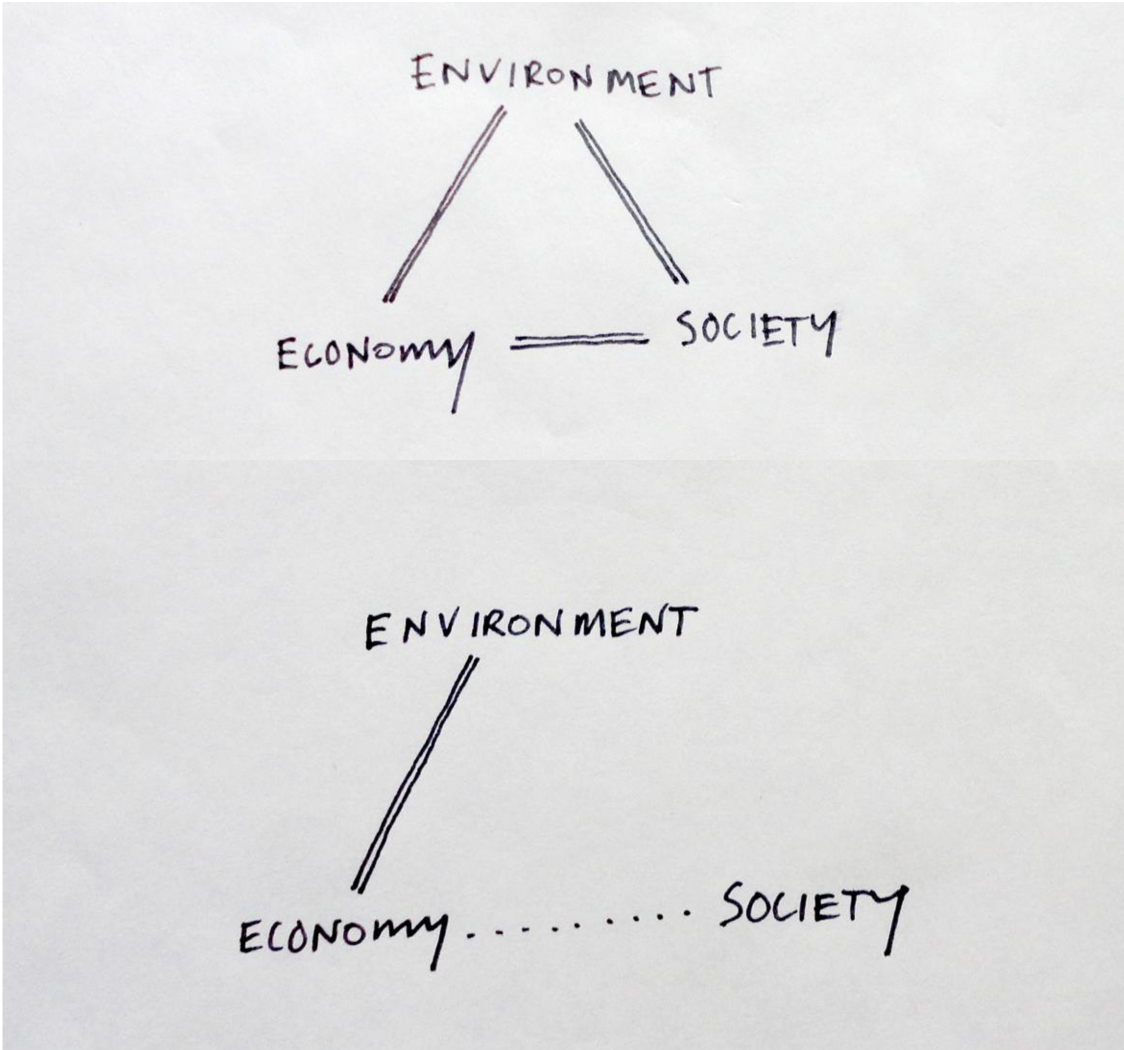

Figure 11 Sustainable management of the Southern Ocean Krill Fishery requires cultural engagement

Management strategies should seek to actively integrate the krill fishery into global culture. This take many forms with one such proposal being an international krill festival operating on either annual cycles or calibrated with el nino, la nina cycles and sea ice fluctuation.
The concept of celebrating harvest is well established in many cultures, the Yam Festival in Ghana, Harvest Moon in China, Chusok in Korea, Tet-Trung-Thu in Vietnam, Succoth in Jewish culture, Pongal, Baisakhi, Lohri, Onam in India, and Thanksgiving in the USA and Canada are all examples. Rituals such as these are not only a celebration of the years harvest, but ensure the ongoing viability of resources in the future.

In contrast, Krill, a species of central importance to the largest ecosystem on the planet, is unceremoniously extracted, processed and hidden in the global consumer stream. Cultural engagement is vital to sustainable management of the krill fishery.

Discussion

This report is conceived with the intention of making the ASPA system more adaptable, specifically so that management practices are more informed by environmental parameters. The need for more flexible boundaries is accentuated as climate changes, and ecosystem boundaries begin to shift. The current management system has no mechanism to cope with this increased transience. We have focused on developing a system based on preservation of the potential for ecosystems to occur. This presents an alternative to the current ASPA designation system where they are defined as fixed geographical units within their environment.

Ecosystems do not represent an exhaustive list of Antarctic ecosystems. However, as general concepts, the intention is that they may be applied to arrange of dfferent ecosystems.

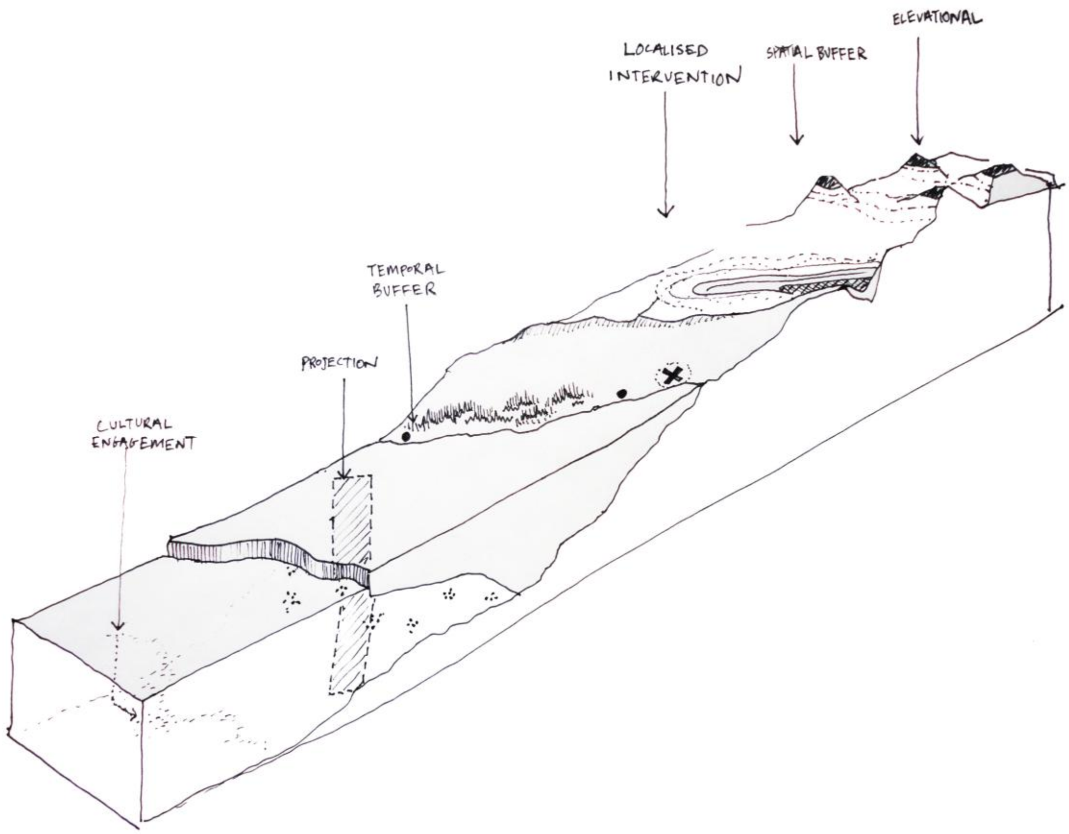

Figure 12 Managment concepts have the potential for implementation as an integrated network

Conclusions

Ecosystem management in Antarctica cannot be undertaken as a uniform approach. It needs to be informed by the spatial and temporal scales, and physical attributes of the ecosystems concerned. Strategies should be derived from both the natural and cultural context of Antarctica.

The ATS, presently accepted methods for delineating boundaries for ecosystem protection do not account for the natural migration and variation of ecosystems. Aerial projection of fixed and sometimes arbitrary boundaries is the accepted convention which will need to be challenged as climate changes. Areas where changes occur rapidly, such as ice shelves, clearly illustrate the limitations of the fixed aerial projection approach.

It is proposed that ecosystem management principles could be derived from any number of cartographic principles including longitude, latitude, network and elevational projections. In addition, acceptance and recognition of dynamic natural edges is also key to effective management.
Managing human activity as part of the ecosystem is not separate to this. Strategies such as the temporal sequencing of visitation, minimising introduction of competitor species, localised physical interventions and cultural engagement will all be important.

Integrating management across marine and terrestrial environments is also at the core of the issue. The division between the administration of management in marine and terrestrial ecosystems, whilst logistically easier to apply, does not assist in the development of an integrated and creative approach to ecosystem management.

Currently the issue of consensus decision making that underpins the ATS limits the potential for future innovations in this area. Should climate continue to change as predicted, the present system will need to be modified for the purpose of protected areas to be realised. When the environmental and political incentives to change become unavoidable, this report provides a stepping off point for that creative process.

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