Australia
State of the Environment
2016

# Antarctic environment

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## Acknowledgement of Country

The authors acknowledge the traditional owners of Country throughout Australia,
and their continuing connection to land, sea and community;
and pay respect to them and their cultures,
and to their Elders both past and present.

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## Credits

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# Contents

# Executive summary

This report mainly focuses on the environment of areas administered by Australia (the Australian Antarctic Territory, and the Territory of Heard Island and McDonald Islands), subantarctic Macquarie Island (which is part of Tasmania) and the Southern Ocean adjacent to these areas. The Antarctic region is managed cooperatively through the international agreements of the Antarctic Treaty System, in which Australia is a leading participant. Although relatively distant from other continents, Antarctica and the surrounding Southern Ocean have far-reaching effects on the rest of the globe, because they are key drivers of Earth's oceanic and atmospheric systems. In turn, again although the region is distant from permanently inhabited continents, Antarctica is under the influence of human activities just like any other continent. Human effects include direct influences—for example, the concentration of human activities in the ice-free areas inevitably affects the flora and fauna that use these limited areas as growth and breeding sites—and indirect influences, the most important of which is anthropogenic climate change.

Antarctica, the Southern Ocean and subantarctic islands are changing. The rate of change varies around the continent, but some areas—such as the Antarctic Peninsula—are changing faster than others. The most important factors contributing to physical change are warming of the ocean and the lower atmosphere, both of which are associated with increasing greenhouse gases, and cooling of the stratosphere, mainly from ozone depletion. Human activity is putting pressure on fisheries in the Southern Ocean and the ice-free areas of the continent. East Antarctica, where Australia operates, has so far changed comparatively slowly, but it, too, is changing. There is still little understanding about how various factors may interact. For example, although research has identified a link between the ozone hole and changes in atmospheric circulation over Antarctica, the response of the Southern Ocean and Antarctic sea ice to these changes is still under debate.

The rate at which the physical environment of the Antarctic region is changing appears to be faster than the rate at which organisms, especially those of a higher order, can adapt to the changes. Although many uncertainties still exist, the composition and abundance of fauna and flora are expected to alter if environmental change continues. An undesirable outcome would be that some species are lost because they are unable to adapt to changing conditions. Although a few species may benefit from the change (e.g. more breeding territory may become available as glaciers retreat), others may be outcompeted by species that can adapt to the changing ecosystems, or be replaced by species whose range is now extending from warmer climes into the Antarctic region.

Cold accommodation, Bunger Hills, Wilkes Land

# Key findings

| Key finding | Explanatory text |
| --- | --- |
| Antarctica is warming, although changes in atmospheric circulation brought about by the Antarctic ozone hole have been a temporary mitigating factor that has reduced the overall amount of warming, primarily in summer | During the past half-century, western Antarctic surface temperatures have shown general warming trends, with significant regional patterns. Cooling of the lower stratosphere because of ozone depletion in spring and early summer has helped to mitigate the amount of warming during the past 20–30 years, particularly during the summer across East Antarctica. For the remainder of the century, the effects of global climate change because of increased greenhouse gas concentrations are likely to overcome the mitigating effects of ozone depletion as the ozone layer recovers. |
| In contrast to the West Antarctic Ice Sheet, the East Antarctic Ice Sheet is not losing mass overall but may be gaining mass. In some places at the coastal margins, the ice sheet is showing variability in response to changes in ocean heat. Antarctic glacier discharge shows high variability, while glacier retreat continues on Heard Island | Although the Antarctic ice sheet is losing mass overall, this is occurring in West Antarctica and the Antarctic Peninsula. Various studies show that East Antarctica, as a whole, is close to neutral or possibly gaining mass. This aggregate conceals regional patterns of ice gain and loss in East Antarctica. In particular, coastal ice discharge from the Totten Glacier shows high variability that is related to changes in ocean heat. Recent research shows that the Totten Glacier drains a large region that rests on bedrock below sea level. This makes the ice sheet potentially vulnerable to ice retreat and ice losses, as is currently seen in parts of West Antarctica. Glacier retreat continues to be observed on Heard Island. |
| Major regional changes are occurring in Antarctic sea ice coverage | For the past 30 years, there has been a small increase in the extent of sea ice around Antarctica, but with strong regional differences. Most notable are contrasting regional changes in sea ice seasonality attributed to changing patterns of large-scale atmospheric circulation. In the western Antarctic Peninsula region, there is mounting evidence that a shortening of the ice season has affected multiple levels of the marine food web. In contrast, there is a trend towards lengthening of the annual sea ice season in the western Ross Sea sector. The situation in the East Antarctic sea ice zone is variable and complex, and is currently under investigation. |

| Key finding | Explanatory text |
| --- | --- |
| Global sea levels continue to rise, although patterns of sea level change across the Southern Ocean are variable because of regional differences in heat uptake and transport. The Southern Ocean continues to become warmer | Global sea levels are rising, but regional patterns and rates of change are variable because of particular modes of climate variability that influence heat uptake and transport. In the region from 35°S to 65°S, the upper Southern Ocean has warmed by 0.2 °C since the 1950s. This rate of warming is faster than elsewhere in the global ocean. Warmer waters enable species to extend their range southwards. These immigrating species are less specialised for the cold environment than Antarctic species, and are likely to outcompete, and perhaps replace, the local native species. This could have a significant impact, particularly on benthic (ocean floor) communities and ecosystem functioning. |
| Several factors, such as ocean acidification, increasing wind strength and changes in ocean circulation in the Southern Ocean, may affect the base of Antarctic food webs | Dissolved carbon dioxide acidifies the ocean and reduces the availability of carbonate ions that shell-making organisms require for calcification, reducing the ability of these organisms to form shells. This may affect their reproductive capabilities and recruitment. Changes in the physical environment may alter the species composition of planktonic communities, as well as the way that carbon cycles from the atmosphere through the marine ecosystems. |
| Antarctic terrestrial ecosystems are changing, especially where snowfall is replaced by rain | Retreating glaciers, higher ambient temperatures and precipitation as rain rather than snow make the terrestrial environment more accessible to plant and microbial communities. A warmer climate and increased availability of liquid water enable the populations of some species to expand and non-native species to become established. |
| Antarctic vertebrates are highly specialised to survive in the Antarctic. Population trends vary greatly among regions, even within the same species | Antarctic vertebrates encompass a variety of flying seabirds and penguins, several seal and whale species, and numerous fish. Around the Antarctic Peninsula, an apparent decrease in the abundance of Antarctic krill may have been caused by a reduction in winter sea ice coverage. This has caused a decrease in Adélie and chinstrap penguin populations. In comparison, Adélie penguin populations in East Antarctica may have increased. The reasons for this are currently unknown. |

| Key finding | Explanatory text |
|---|---|
| The environment of subantarctic islands is also changing. Most noticeable is the retreat of the glaciers at Heard Island. At Macquarie Island, the most important change had been to the natural heritage, which had suffered under the impact of introduced mammals, but a large-scale eradication program has been completed successfully | From 1947 to 2008, the glacier area on Heard Island decreased by 20 per cent. Since 2008, only relatively limited data are available for the assessment of the glaciers on the island, but further evidence of glacial retreat has been observed. Introduced vertebrates, such as cats, rats, mice and rabbits, previously caused a major deterioration of the natural heritage values of Macquarie Island. There was significant predation of native species until feral cats were eradicated in 2002. Overgrazing by European rabbits caused an increase in landslides, many of which damaged seabird colonies. A large-scale eradication program completed in 2014 successfully eradicated rabbits, rats and mice from the island. |
| The pressure of human activities on Antarctica and the Southern Ocean is increasing | The areas affected by human activities in the region continue to increase. New stations are being built, and tourism to the continent continues to grow on the Antarctic Peninsula, but is still insignificant in East Antarctica. With a growing world population, commercial fishing activities are likely to expand. Adequate resources are needed to monitor the intensity, frequency and impacts of all human activities. The Protocol on Environmental Protection to the Antarctic Treaty commits signatories to comprehensive protection of the Antarctic environment. Australia has ratified the protocol by establishing legislation to enforce procedures for reducing the impacts of Australians visiting Antarctica, and has taken practical steps to reduce the impacts of past activities, such as the clean-up of abandoned waste-disposal sites. |

# Approach

Generally, limited data are available to assess many aspects of the Antarctic environment. This is largely a consequence of the remoteness and sparse habitation of the region. Specific information is available to assess trends and changes in the physical environment. This includes palaeoclimate records from ice cores that extend back hundreds of thousands of years, synoptic weather observations generally starting in the 1950s, and satellite remote-sensing data from the late 1970s onwards. For the various components of the ecosystem, far sparser records are available. For example, data suitable for census studies of species, such as Antarctic krill and fish, are only available for recent decades. For many other species, such as baleen whales, accurate population assessments remain unavailable.

This report presents our best available assessments of the state and trends of the Antarctic environment (the area south of 60°S, the Southern Ocean and Australia's subantarctic islands), primarily as they relate to Australia's interests in the region. We have followed the methodology outlined in the *Approach* report, distilling the opinion of experts in specific fields who have been guided by the latest peer-reviewed literature. In addition, where possible, we have made use of a variety of up-to-date environmental and management data collected in support of the Australian Antarctic Program.

Overall, the material presented here is largely an update on the 2011 state of the environment (SoE) report and is primarily informed by the peer-reviewed literature that has appeared in the intervening 5 years. Consequently, almost all the assessments presented here are directly comparable with those presented in 2011.

For the physical environment, many aspects of change are occurring on multiyear or longer timescales because of the nature of physical processes associated with the Antarctic atmosphere, ice sheet and surrounding oceans. Thus, the assessed changes and trends are generally identical to those presented in SoE 2011. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change in 2014, which provided a comprehensive picture of the state of the Antarctic environment at its release, has been used as a key source of information in preparing the assessment tables in State and trends of the Antarctic environment.

In general, our assessment of the confidence rating for grade and trend is graded using the 3 levels used for SoE 2011 ('adequate', 'limited' and 'low'). At present, finer assessment using the 2 additional grades adopted in this report ('somewhat adequate' and 'very limited') cannot be confidently applied for most of the Antarctic topics considered here.

Silver leaf daisy (*Pleurophyllum hookeri*), Macquarie Island

Photo by Karen Andrew, Australian Antarctic Division, 

# Introduction

Antarctica is the southernmost continent. Including all islands and ice shelves, it covers an area of about 13.9 million square kilometres ($km^2$)—nearly twice that of Australia. The sea ice that surrounds Antarctica adds about another 19 million $km^2$ at its maximum extent in September–October (Fretwell et al. 2013), diminishing to 3 million $km^2$ in February (Parkinson & Cavalieri 2012). The annual growth and retreat of the Antarctic sea ice are one of nature's most significant large-scale annual changes. Antarctica is Earth's coldest, highest, windiest and driest continent, and its largest cold desert. Only about 21,745 $km^2$, or 0.18 per cent, of the total Antarctic land mass is ice-free (Burton-Johnson et al. 2016). Antarctica also has the deepest continental shelf and is surrounded by the largest wind-driven currents, which circulate the Southern Ocean. It is the only continent that has never had a native human population.

## Global importance of Antarctica

Although isolated from other continents, Antarctica is connected to the rest of the world through oceanic and atmospheric circulations. Antarctica and the surrounding Southern Ocean are key drivers of Earth's oceanic and atmospheric systems. A critically important feature is that about 90 per cent of Earth's ice (approximately 26.9 million cubic kilometres) (Fretwell et al. 2013) is found here, and 70 per cent of all available fresh water is locked up in the Antarctic ice sheet. If melted, this would raise sea levels by 58 metres (Fretwell et al. 2013, Vaughan et al. 2013).

Equally important is the Southern Ocean that surrounds the Antarctic continent. The International Hydrographic Organization considers the parallel of 60°S to be the northern limit of the Southern Ocean (IHO 2002); however, Australia reserves the right to extend the Southern Ocean limits to the southern shores of Australia from Cape Leeuwin in the west and South East Cape in Tasmania (IHO 2002). South of 60°S, the Southern Ocean extends across some 22 million $km^2$, averages about 3300 metres depth and reaches depths of 7000 metres; it encompasses about 6 per cent of the world's ocean volume (Eakins & Sharman 2010). The Southern Ocean is the only ocean that encircles the globe uninhibited by land masses. The Southern Ocean connects the 3 main ocean basins (Atlantic, Pacific and Indian) and creates a global circulation system that is largely driven by the Antarctic Circumpolar Current (ACC)—the world's largest current. The ACC flows from west to east around Antarctica and generates an overturning circulation that transports vast amounts of heat. The ACC also takes up a significant amount of carbon dioxide ($CO_2$) from the atmosphere (Rintoul et al. 2001).

In winter, surface waters near Antarctica freeze to form sea ice. When sea ice forms, salt is forced out of the forming ice (brine rejection), making the water below the ice more saline and therefore denser. In a few places around Antarctica, the resulting cold and salty waters are sufficiently dense to sink to the deep ocean and form Antarctic bottom water. This dense bottom water sinks and spreads northwards to supply oxygen to the deep layers of the ocean, and warmer waters flow south to replace it. The southwards flow at mid-depth also compensates for the northwards flow of lighter waters. The formation and circulation of Southern Ocean water masses provide a key link in the global 'conveyor belt' of ocean currents that controls climate by transporting heat and other properties.

For our entire planet, atmospheric pressure, humidity, air temperatures and wind patterns are interconnected and greatly influenced by processes in the Southern Ocean.

As well as playing an important role in influencing weather patterns, the Antarctic environment provides valuable information about climate change. Antarctic continental ice contains climate records extending back more than 800,000 years, which have been obtained from ice cores. Moreover, the Antarctic environment and biosphere are highly sensitive indicators of present-day environmental change. Predictions made in the 1980s and 1990s about climate change and its effects in the polar regions in the 21st century have largely been confirmed (Singh et al. 2016). The major difference between previous predictions and recent observations is that the forecast change appears to be occurring at a faster rate than originally expected—for example, significant ice loss has already been observed from glaciers and the major ice sheets of Greenland and Antarctica (Vaughan et al. 2013). In the case of Greenland and parts of West Antarctica, there is evidence that this loss is accelerating (Rignot et al. 2011, Vaughan et al. 2013, Sutterley et al. 2014). Until recently, the western Antarctic Peninsula region had been warming 2 to 3 times faster than the global average (Turner et al. 2014); 3 of the 12 ice shelves in the peninsula region have retreated significantly, and 4 have collapsed, amounting to a loss of about 18 per cent of the floating ice (Cook & Vaughan 2010). However, in East Antarctica, which has been shielded from the effects of global warming by the ozone thinning commonly known as the 'ozone hole' (Perlwitz et al. 2008), the warming is less than the global average (Turner et al. 2014). The regional differences in the responses to climate warming and variability highlight the complexity of the processes currently affecting Earth's environment.

## The natural environment

The Antarctic environment comprises diverse habitats and ecosystems that include:

- ice-covered areas
- ice-free vegetated areas and rocks
- saltwater and freshwater lakes and streams
- intertidal areas; sea ice; and mid-water, deepwater and benthic regions of the Southern Ocean.

In the terrestrial environment on the continent, species diversity is low compared with mid-latitudinal or tropical ecosystems; however, many species are abundant. Species that have made the Antarctic continent their home have evolved across very long timescales, and are now highly specialised and able to survive in the extreme conditions of the southern continent and the frigid ocean surrounding it. The most diverse vertebrate groups are flying seabirds (7 species) and penguins (2 species on the continent and 5 on subantarctic islands). Ice-breeding seals (4 species), fur seals (3 species), sea lions (1 species) and elephant seals (1 species) are also part of the Antarctic fauna. Furthermore, several species of baleen and toothed whales forage in the Southern Ocean. Some species of toothed whales appear to remain there throughout the year.

East Antarctica lacks flowering plants, and lower plants such as mosses, lichens and bryophytes live in the few ice-free areas. Algae prosper in the marine environment and in snowfields. The abundance of terrestrial invertebrates varies regionally and depends on the conditions of the local microhabitats—particularly the topography and vegetation (Nielsen et al. 2011). Many invertebrates live under rocks or in the moss beds—Antarctica's 'forests'—where moisture is available (Kennedy 1993). Species diversity is low compared with more temperate regions. The most abundant phyla are rotifers (wheel animals), nematodes (worms) and tardigrades (water bears), but mites and springtails are also found (Convey et al. 2008, Nielsen et al. 2011). The terrestrial species diversity of the region pales in comparison with the marine species. Invertebrate taxa living at the continental shelf (0–1000 metres deep) and in the deep ocean (more than 1000 metres deep) encompass more than 3500 species (Brandt et al. 2007). Sea spiders, sea urchins, marine worms, molluscs, sponges and other creatures are highly diverse, with a large percentage of endemic species (Brandt et al. 2007, Rapp et al. 2011).

An international survey of the Southern Ocean, the Census of Antarctic Marine Life of 2007–08, compiled a biogeographical atlas that provides maps of the distribution of at least 6400 benthic species, highlighting the extraordinary biodiversity of the Southern Ocean (Roberts 2013). Many of these species were newly discovered during the census, and questions still need to be answered about their roles in the ecosystem and the reasons for the variability in their distribution (Kaiser et al. 2013). Antarctic fish are often endemic and are dominated by notothenioids (icefish), which make up more than half of the known 320 fish species in the Southern Ocean (Eastman 2005). Marine microbes are highly abundant and constitute most of the biomass in the Southern Ocean. They play a crucial role in nutrient cycling (Hutchins et al. 2009, Pearce et al. 2010).

The species composition on the subantarctic islands is different from that on or near the continent. The fauna of Heard Island and McDonald Islands includes 3 species of penguin not found on the Antarctic continent and 15 species of flying seabirds, including 2 species of albatross, several petrels, skuas and sheathbills. Three different seal species also frequent the island or breed there (BirdLife International 2016a). The vegetation on Heard Island and McDonald Islands covers the ice-free areas and includes a variety of vascular plants (12 species), mosses (44 species), lichens (34 species) and liverworts (17 species) (Hughes 1987, Bergstrom et al. 2002). Heard Island and McDonald Islands are a listed World Heritage Area because of their unique wilderness, which provides examples of biological and physical processes that occur in an environment largely undisturbed by humans. Because the islands support various threatened and endangered seabird species, the International Union for Conservation of Nature (IUCN) has also declared the region an Important Bird Area.

Macquarie Island is home to an estimated 3.5 million seabirds, comprising 13 different species. These include wandering albatross (*Diomedea exulans*), grey-headed albatross (*Thalassarche chrysostoma*), a variety of small petrels and 4 species of penguins. In 2011, the IUCN nominated Macquarie Island as an Important Bird Area because of the presence of various threatened and endangered seabird species (BirdLife International 2016b). In terms of vegetation, Macquarie Island supports 45 species of vascular plants and 91 species of moss, as well as many lichens and liverworts (Selkirk et al. 1990). Macquarie Island is listed as a World Heritage Area because of the unique opportunity it provides to study exposed oceanic crust, and its wild natural beauty.

Although generally rich in nutrients such as nitrogen and phosphorous, the productivity of the Southern Ocean is not as high as might be expected because of low levels of iron (an essential micronutrient) and low light levels (because of persistent cloud cover and reduced daylight hours during winter).

Wandering albatross (*Diomedea exulans*)

Photo by Michael Double, Australian Antarctic Division, 

## Antarctic governance

The Antarctic Treaty and a set of related international agreements, known collectively as the Antarctic Treaty System, provide the framework for governance of the Antarctic region.

### Antarctic Treaty

The Antarctic Treaty was signed in December 1959 and entered into force in 1961. From the 12 original parties (including Australia) in 1959, membership of the treaty has now grown to 53 countries. The Antarctic Treaty area—the area south of 60°S—comprises 10 per cent of our planet's total surface area. Australia and 6 other nations claim territory in Antarctica. While the Antarctic Treaty is in place, differences of opinion regarding the status of territorial claims are effectively set to one side, and the Antarctic is available to be used by any nation for peaceful and scientific purposes. Russia, China, India, the United States and France–Italy have permanently occupied stations in the Australian Antarctic Territory (AAT) (Figure ANT1). In 2015, Belarus began construction of a station within the AAT near Russia's Molodyozhnaya Station.

Australia was instrumental in the negotiations leading to the treaty and, together with France, instigated the negotiations that resulted in the Protocol on Environmental Protection to the Antarctic Treaty (1991), known as the Madrid Protocol. The Madrid Protocol establishes the internationally agreed framework for comprehensive protection of the Antarctic environment, and designates Antarctica as a 'natural reserve, devoted to peace and science'. The Madrid Protocol established the Committee for Environmental Protection as an expert advisory body to provide advice and formulate environmental recommendations in respect of the protocol to meetings of Antarctic Treaty members. Activities subject to the protocol must be assessed for their environmental impacts. Activities must also be planned and conducted in a manner that ensures protection of the Antarctic environment, and its dependent and associated ecosystems.

Each signatory state is required to pass enabling legislation to give effect to the environmental protection measures of the protocol relating to activities of their national programs and citizens while in Antarctica. Australia has done this through the *Antarctic Treaty (Environment Protection) Act 1980*.

The provisions of the Antarctic Treaty and the Madrid Protocol do not apply to Australia's subantarctic islands. Administrative control and government responsibilities for Heard Island and McDonald Islands were handed from the British to the Australian Government in 1947. The islands are an external territory of Australia and are managed on behalf of the government by the Australian Antarctic Division (AAD). Macquarie Island and nearby islets are part of Tasmania, and are managed by the Tasmanian Department of Primary Industries, Parks, Water and Environment.

Australia works closely with fellow Antarctic Treaty parties to ensure the effective governance of the region, to undertake important scientific research, and to conserve and protect Antarctica's unique environment.

### Convention on the Conservation of Antarctic Marine Living Resources

The conservation of Antarctic marine living resources is subject to the regulations imposed under the Convention on the Conservation of Antarctic Marine Living Resources. This convention came into force in 1982 as part of the Antarctic Treaty System. Article 1 of the convention defines its area of operation as 'the area south of 60° South latitude and the area between that latitude and the Antarctic Convergence which form part of the Antarctic marine ecosystem' (UN 1980).

The convention was established because of a growing concern among the Antarctic Treaty parties that an increase in krill catches in the Southern Ocean could have a serious effect on populations of krill and other marine life—particularly birds, seals and fish, all of which depend predominantly on krill for food. Antarctic krill (*Euphausia superba*) was first fished in the 1960s at low levels (4 tonnes in 1961–62 and 306 tonnes in 1964–65) as an exploratory fishery (Miller & Agnew 2000). Commercial exploitation began only in the late 1970s and early 1980s, when around 500,000 tonnes of Antarctic krill were caught each year (Nicol et al. 2011).

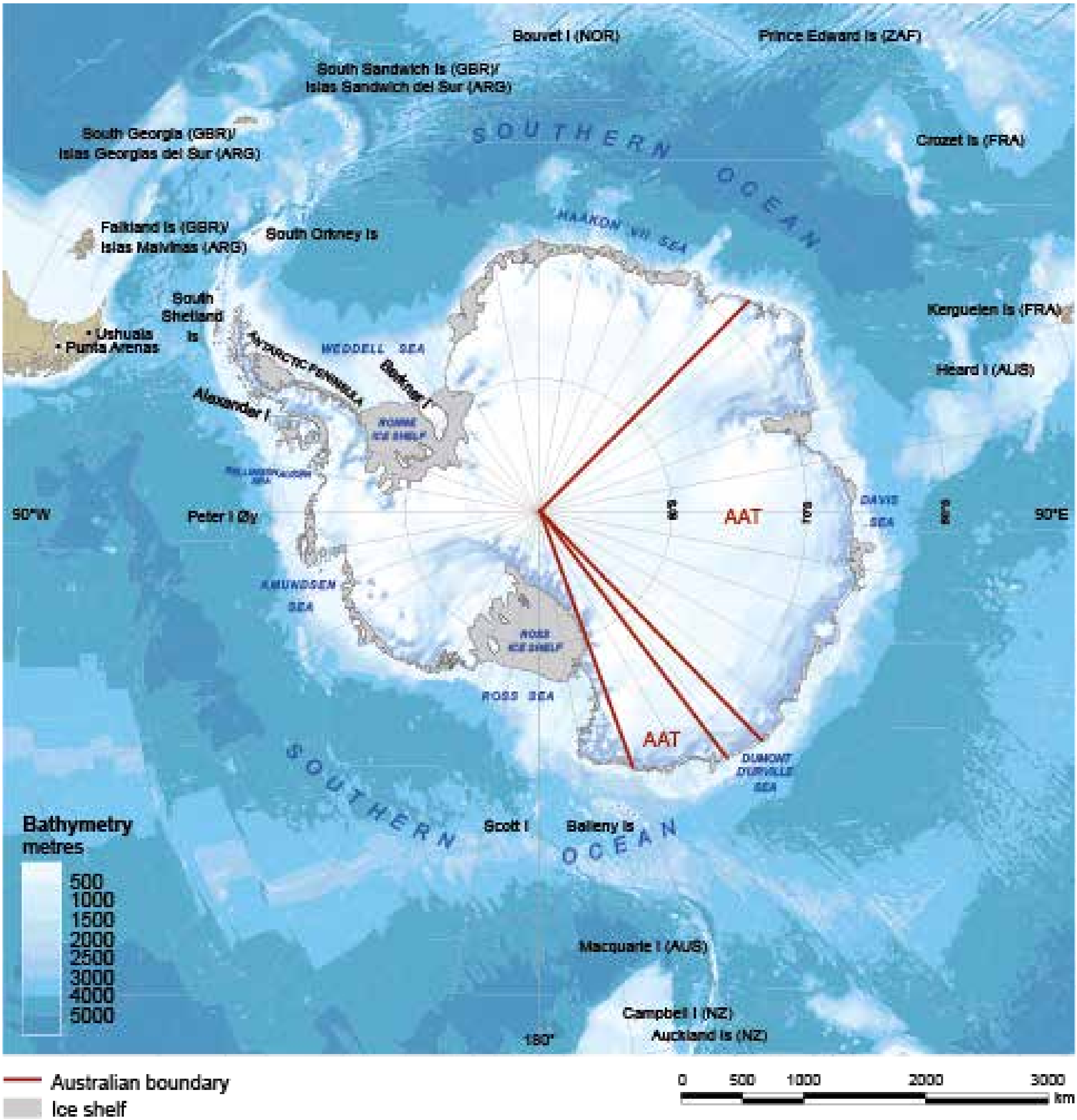
The convention is implemented through the international Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR comprises 25 member states; a further 11 countries have agreed to the terms of the convention. The objective of the convention is the conservation of Antarctic marine living resources. CCAMLR has implemented an ecosystem-based management system to ensure that not only are the fisheries sustainable, but that the needs of dependent predators and the ecosystem are given due consideration. This sets CCAMLR apart from regional fishery management organisations, which focus largely on the management and production of harvested species, and often deal with a single species. CCAMLR considers the needs of krill-dependent predators and sets catch limits to ensure that their needs are met. Several krill-dependent predators were selected as indicators of the health of the Southern Ocean ecosystem, and the CCAMLR Ecosystem Monitoring Program was developed. Its aim is 'to detect and record significant changes in critical components of the ecosystem to serve as a basis for the conservation of Antarctic marine living resources' (CCAMLR 1984). Indicator species include Adélie penguins (*Pygoscelis adeliae*) and crabeater seals (*Lobodon carcinophagus*). The Convention on the Conservation of Antarctic Marine Living Resources was the first international convention whose fisheries management strategy was based on the ecosystem approach (Arnaudo 2005).

CCAMLR now considers and adopts a range of conservation measures, including those that protect the general marine environment, species and communities, and those that manage commercial fishing activities. The precautionary approach adopted by CCAMLR requires that conservation and management measures are established, so that populations of harvested species do not decrease below levels that ensure stable recruitment. CCAMLR also encourages national programs operating in Antarctica to undertake fisheries-related research aimed at maintaining species stocks at levels that maintain recruitment into populations of target species, but also provide for the needs of dependent species (Constable 2002).

CCAMLR has successfully implemented the ecosystem approach to management in new, exploratory and established fisheries under its control. Fishing in the Southern Ocean in CCAMLR sectors 58.4.1 and 58.4.2 (East Antarctica) has remained well below set catch limits, since no fisheries operate there. However, catch limits are still set for the East Antarctic sectors should a fishery reopen there. Patagonian toothfish (*Dissostichus eleginoides*) and icefish are currently harvested in Australian subantarctic waters, and precautionary catch limits apply in accordance with CCAMLR's conservation measures.

## Australian Antarctic Territory

The AAT (Figure ANT1) comprises an area of approximately 5.9 million $km^2$, and its coastline extends more than 11,200 kilometres (excluding offshore islands). Only 1110 kilometres, or 10 per cent, of the coastline is exposed rock—the rest is ice. Some parts of the rock coastline are very steep, such as the Scullin Monolith, and only a few areas offer the opportunity for establishing scientific research stations on ice-free rock. The locations of Australian facilities, and areas where regular research and support operations take place are comparatively small. However, they are concentrated in coastal ice-free areas that are more susceptible to impacts arising from human activities.




Source: Adapted from a map provided by the Australian Antarctic Data Centre

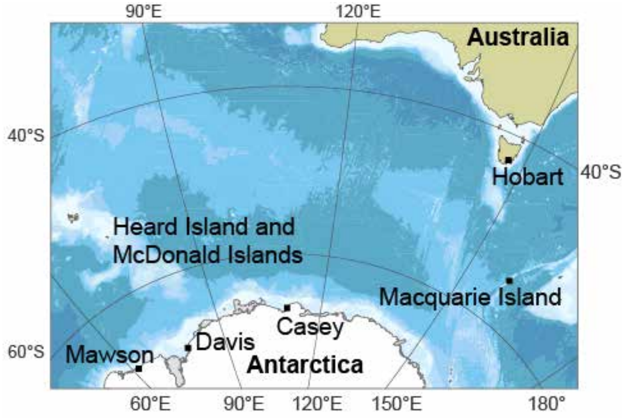
**Figure ANT1** Antarctica and the Australian Antarctic Territory

Australia has strong and longstanding national interests in Antarctica. These interests determine the underlying policy settings that frame Australia's engagement in Antarctica. The *Australian Antarctic strategy and 20-year action plan* (Australian Government 2016), launched in April 2016, outlines Australia's national interests in Antarctica, which are to:

- maintain Antarctica's freedom from strategic or political confrontation
- preserve Australia's sovereignty over the AAT, including our sovereign rights over adjacent offshore areas
- support a strong and effective Antarctic Treaty System
- conduct world-class scientific research consistent with national priorities
- protect the Antarctic environment, having regard to its special qualities and effects on our region
- be informed about, and able to influence, developments in a region geographically proximate to Antarctica
- foster economic opportunities arising from Antarctica and the Southern Ocean, consistent with our Antarctic Treaty System obligations, including the ban on mining and oil drilling.

The AAT is administered by the AAD of the Australian Government Department of the Environment and Energy. Australia maintains a permanent presence in Antarctica through 3 continuously occupied continental stations, as well as temporary field stations. Australia also has a permanent research station on Macquarie Island (Figure ANT2).

Scientific research is conducted in diverse areas of Antarctic science on land and at sea. The goals and priorities of the scientific work are set out in the *Australian Antarctic science strategic plan 2011–12 to 2020–21* (AAD 2011). The activities and outcomes of the scientific work are enhanced through Australia's engagement with the Scientific Committee on Antarctic Research (SCAR) and the Council of Managers of National Antarctic Programs (COMNAP). SCAR is a body of the International Council for Science that is charged with the initiation, promotion and coordination of scientific research in Antarctica and the Southern Ocean. COMNAP is the international association that brings together national Antarctic programs to develop and promote best practice in managing the support of scientific research in Antarctica.




Sources: Map provided by the Australian Antarctic Data Centre; additional data from Intergovernmental Oceanographic Commission et al. (2003). Antarctic Digital Database version 5, © Scientific Committee on Antarctic Research 1993–2006

**Figure ANT2** **Subantarctic and East Antarctic operational area of the Australian Antarctic Division**

## Antarctic environment: 2011–16 in context

Since 2011, the Antarctic environment has continued to respond to global pressures from human activity. As is the case in other regions of the globe, long-term trends in characteristics of the Antarctic physical environment are emerging against a backdrop of intrinsic variability that operates on various spatial and temporal scales. At any particular location, the intrinsic variability is dictated over hours to several days by meteorological processes, while various modes of the climate system—most notably the Southern Annular Mode, the El Niño–Southern Oscillation and the Pacific Decadal Oscillation—influence the Antarctic region across seasonal to decadal timescales. In general, in situ measurements of the physical environment in the Antarctic region continue to be relatively restricted in spatial and temporal extent compared with elsewhere.

Antarctica is generally warming, continuing the trend apparent during the latter half of the 20th century, although regional and temporal variations in long-term climate behaviour are apparent (Turner et al. 2014). Although some areas of the Antarctic Peninsula and West Antarctica rapidly warmed in the late 20th century, recent temperature trends on the Antarctic Peninsula are less marked and show greater consistency with the natural variability of the climate system (Turner et al. 2016). Coastal East Antarctica is generally warming, although the trend is weaker than in West Antarctica, and in some regions and seasons shows evidence of cooling (Turner et al. 2014).

Further indications of improvement in stratospheric ozone levels above Antarctica in spring and summer are emerging, although meteorological factors continue to significantly influence the year-to-year severity of the ozone hole (Solomon et al. 2016). For example, estimated effective levels of ozone depleting substances in the Antarctic stratosphere decreased from approximately 93 per cent to 89 per cent of their peak value in 2000 in the past 5 years (an improvement of 4 per cent). Although continued ozone improvement is expected because of the Montreal Protocol on Substances that Deplete the Ozone Layer, the Antarctic ozone hole will continue to have an important influence on Southern Hemisphere summer climate in the coming 2–3 decades, primarily by helping to maintain the changes in the westerly winds that developed over the Southern Ocean towards the end of the 20th century (Eyring et al. 2013).

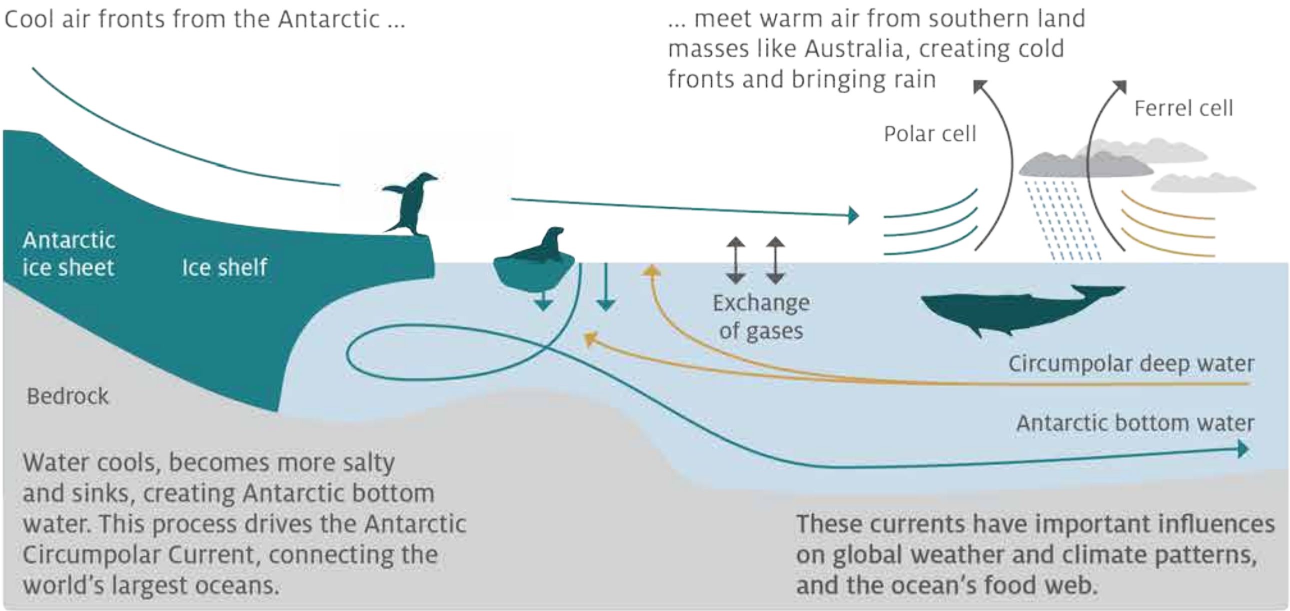
The Southern Ocean is changing in ways that are likely to affect regional and global climate, and marine productivity (Rhein et al. 2013). Ocean temperatures around the Antarctic continent have increased more rapidly and to greater depth than the global average in recent decades (Roemmich et al. 2015). This warming has been linked to glacier retreat and ice-shelf disintegration in West Antarctica (Miles et al. 2013), and indications of increased basal melt of the Antarctic ice sheet (Schodlok et al. 2016). The extent of sea ice around Antarctica has shown a small overall annual increase in recent decades, particularly in the Ross and Weddell seas, which is linked to climate variability in the Pacific Ocean (Meehl et al. 2016). There have been, however, significant regional decreases in the Amundsen and the Bellingshausen seas (Hobbs et al. 2016a).

Changes to the marine environment, including ocean acidification, are having a significant impact on keystone organisms such as krill. Krill embryos are likely to be negatively affected by increasing ocean acidification, which may significantly reduce hatching success (Kawaguchi et al. 2013). Since krill is near the base of the food web, these changes may have profound effects throughout Antarctic ecosystems, particularly on dependent predators such as seabirds, seals and whales.

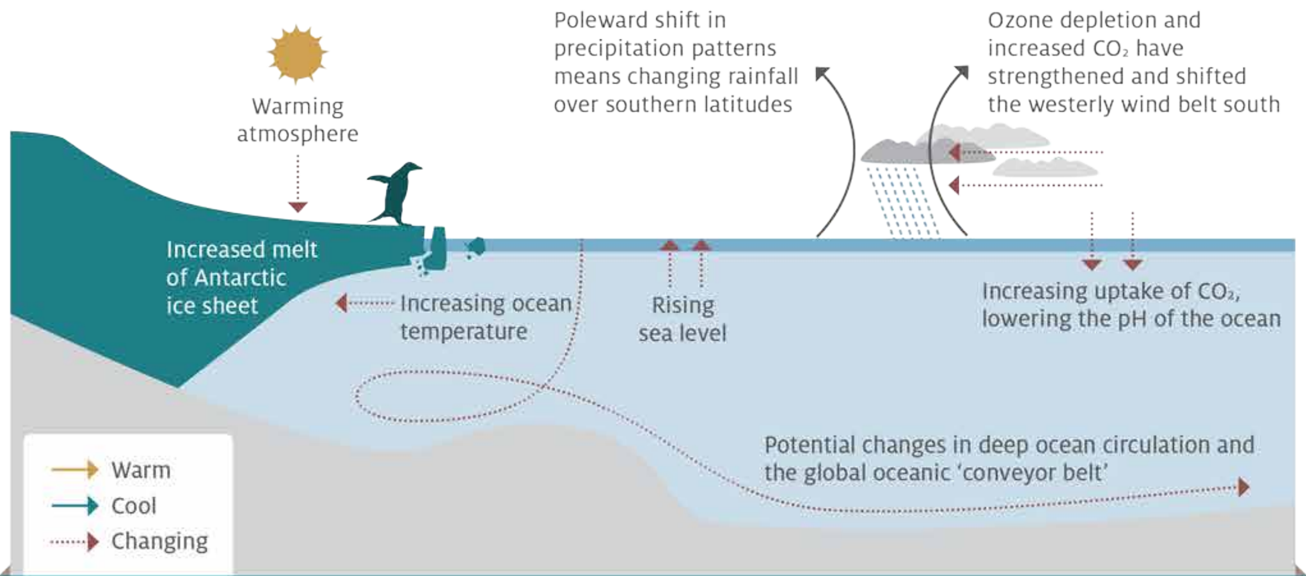
Overall, the quality of the East Antarctic environment has not significantly changed since 2011, and Australia has continued to demonstrate a strong commitment to Antarctic research and policy development for global benefit. However, various pressures from global climate change continue to influence Antarctica. Arguably, the most significant ongoing risks to society from these changes are posed by Antarctica's increasing contribution to sea level rise from ice-sheet melting, and the potential for reduced productivity and diversity of the Southern Ocean ecosystem because of increasing ocean acidification.

# The Antarctic region, an important driver of global climate, is showing changes

## World ocean and atmospheric currents feel the effects of Antarctica.




## However, climate patterns in parts of Antarctica are responding to human influences.




**Changes in Antarctica and the Southern Ocean are likely to affect ocean currents and atmospheric circulation patterns in regions across the globe. These processes are interconnected and complex, and scientists are still trying to understand the full magnitude of these changes and what impacts they will have for us.**

# Pressures
## affecting the Antarctic environment

### At a glance

The climate of Antarctica is changing. Compared with conditions prevailing in the 1950s, parts of West Antarctica—particularly the Antarctic Peninsula region—have warmed. In East Antarctica, where Australia operates, temperatures have also increased, but to a lesser extent. Across Antarctica, many environmental observations show modest rates of change and large year-to-year variability, which limits the ability to ascribe significance to trends in most cases. However, changes have been observed, including increased maximum sea ice extent, strengthened westerly winds, altered ocean properties and thinning of some ice shelves, in addition to specific seasonal and regional trends in temperatures. These environmental changes—and our new understanding of the physical environment, bedrock, ice thickness and ocean–ice boundaries—suggest that further change is likely, with associated impacts on marine and terrestrial ecosystems. In some regions, changes mirroring those already under way in West Antarctica are possible, with potentially profound global impacts.

Globally, extreme weather events such as heatwaves, storm surges and increased precipitation are expected to increase in frequency and intensity as the planet warms. In certain regions at the periphery of Antarctica, rain is now occasionally falling where historically it only ever used to snow. These events are changing the Antarctic environment and may affect the biodiversity that has developed under a specific moisture regime. Climate change is also driving ocean acidification, which will affect many Antarctic marine species, including crucial species at the base of the food web.

Human activities are still increasing; new stations are being constructed, often in rare ice-free areas. Tourism is a major activity around the Antarctic Peninsula. Disturbance of habitat and wildlife, introduction of invasive plants and other alien organisms, and pollution are all risks linked to human presence on the continent. Marine debris, particularly plastics, is an increasing pressure on Antarctic species, causing mortality and morbidity through entanglement and ingestion. The debris comes both from human presence on the continent and human pollution throughout the rest of the planet, which makes its way to Antarctic regions. Worldwide demand for fishery products means that fishing and other legal or illegal extraction of resources are pressures on the Antarctic environment and its species.

Subantarctic islands are changing rapidly as rainfall patterns are changing, and glaciers at Heard Island are retreating and thinning. Although eradication efforts have successfully reduced the impact of introduced species on some islands, the changing climate is likely to pave the way for more invaders.

This section presents information on matters that affect the Antarctic environment and describes the current state of the environment. The focus is on the AAT, because this is where Australia's activities are centred, although certain trends in the environment may relate to East Antarctica in general, or Antarctica as a whole. Also discussed are Australia's subantarctic islands—Macquarie Island, and Heard Island and McDonald Islands—and the Southern Ocean.

Discussing every aspect of the Antarctic environment comprehensively is beyond the scope of this section. Instead, this section reports on several selected indicators, some of which have long-term (more than 1 decade) data that offer the best representation of current change in high-priority areas. The discussion identifies and considers environmental variables that are currently subject to pressures that are likely to be influential in the foreseeable future. We summarise indicators discussed in recently published scientific literature, and offer information about operational indicators that are relevant to running the Australian Antarctic Program. Although only a limited number of sites are monitored regularly in the AAT, some results are representative of other areas in East Antarctica with similar ecological characteristics. Where appropriate, comparisons are made with events occurring in West Antarctica, where environmental change is proceeding at a faster rate than in the eastern part of the continent.

## Human influences on Antarctica

As detailed in the *Drivers* report, the key drivers of environmental change are population and economic growth. Antarctica, as the only continent without a native human population, has been subjected to less pressure from human activities than other continents. However, the southern continent, and its surrounding seas and islands have not escaped the effects of these activities. The establishment of permanent stations affects the local environment, and pollution elsewhere on our planet finds its way to Antarctica. For example, human-made chlorofluorocarbon gases have damaged the vital natural sunscreen provided by ozone in the Antarctic stratosphere, human-made $CO_2$ has increased the acidity of the Southern Ocean, and traces of pollutants such as dichlorodiphenyltrichloroethane (DDT) had already found their way into the Antarctic ecosystem by the 1960s (Sladen et al. 1966). Several vertebrate populations were hunted to near extinction in the past, and current economic activities such as fishing and tourism have all had an impact. With an increasing number of stations built on the continent, and more ships and aircraft visiting Antarctica than ever before, pollution with hydrocarbons (e.g. fuel and oil) through leakage and spills is a real risk, particularly for benthic communities (Polmear et al. 2015).

Arguably, the clearest example of large-scale human influence in the Antarctic region is the springtime ozone hole that began forming over Antarctica during the late 1970s (see Box ANT1). The ozone hole has significantly influenced the climate of the Antarctic region, and has caused episodes of unprecedentedly high levels of ultraviolet radiation at Earth's surface (WMO 2014). As a result of international controls pertaining to ozone-depleting substances, the ozone hole is expected to be largely repaired by the middle of the 21st century, and its effects on solar radiation will dissipate.

Meanwhile, a much more potent and longer-lasting agent of change in the Antarctic region is the continuing anthropogenic emissions of greenhouse gases—in particular, $CO_2$. The Southern Ocean is absorbing vast quantities of $CO_2$. This offsets part of the emissions; however, it is also leading to a change in the ocean's chemistry, called ocean acidification. For the next 40 years, organisms that occupy high-latitude oceans and that evolved during thousands of years under comparatively stable conditions are expected to be vulnerable to these changed conditions. The physiology and energy requirements of organisms, such as pteropods and molluscs, may be negatively affected (Seibel et al. 2012). Long-term changes in the carbon chemistry of the oceans can reduce the growth rate of the larvae of some fish species, and affect their respiration and behaviour (Frommel et al. 2012). Fish in early life stages lack the ability to self-regulate their internal pH (level of acidity), and tissues can be damaged as the environmental $CO_2$ concentration increases. However, other species may be resilient to these changes in terms of their physiology. Krill populations are already under pressure through increasing ocean temperatures and changes in sea ice cover; the combined effects of these pressures and an increase in ocean acidification could significantly compromise krill recruitment within a century (Kawaguchi et al. 2013).

Increased atmospheric $CO_2$ is also contributing to climate change by warming the lower atmosphere (Myhre et al. 2013). In the Antarctic region, the most significant warming has occurred on the Antarctic Peninsula. From 1951 to 2011, surface temperatures increased by 0.54 °C per decade at Faraday–Vernadsky Station (Turner et al. 2014), whereas the global temperature increase averaged 0.12 °C per decade from 1951 to 2012 (Hartmann et al. 2013). This warming has caused the ice shelves to collapse in the peninsula region (Scambos et al. 2003) and glaciers to retreat in some areas of West Antarctica (Cook et al. 2005). The warming has also decreased the extent of sea ice in the Bellingshausen Sea (Thomson & Solomon 2002).

Shoreline with sediment-laden sea ice and melt puddles

The average near-surface temperatures across the entire continent have been estimated to have increased by 0.11 ± 0.08 °C per decade from 1958 to 2012 (Nicolas & Bromwich 2014). Greater overall warming is observed in West Antarctica than in East Antarctica. Although the continent is showing an overall warming, some regions have exhibited cooling trends, particularly in autumn (Nicolas & Bromwich 2014, Turner et al. 2016). Increasing air and ocean temperatures cause changes in snowfall patterns (Bromwich et al. 2011), which in turn affect the quality, extent and durability of sea ice. For example, near Davis research station, a long-term monitoring study of sea ice detected a delay in the time when the maximum thickness is reached by the nearshore or 'fast' ice, and attributed this trend to the warmer winters in recent years (Heil 2006).

Assessing the overall impact that climate change will have on the physical systems of Antarctica is difficult. A lack of data exists for large parts of the continent, and timeseries tend to be too short or are available for only a small number of locations. The processes driving weather patterns and underlying climate change are complex, because they can operate on different temporal and spatial scales, and either increase or counteract each other. Some connections—for example, between atmospheric and oceanic phenomena—are still poorly understood.

Similarly, although we know that it is highly likely that climate change will alter ecosystems, the processes involved are complex and not fully understood (Constable et al. 2014, Larsen et al. 2014). Some biological models have explored the consequences of climate change for individual species, but ecosystem models are still in development (Murphy et al. 2012). Predicting how organisms will respond individually or collectively to climate change and other human-induced pressures is a major challenge for current research. We do not know which species may be able to adapt to the changing environment through genetic responses. Some organisms may even benefit from the effects of climate change, at least in the short term. For example, more ice-free areas offer potential habitat for plants and animals. However, the long-term consequences are hard to predict and will depend on the degree to which the atmosphere warms.

The restoration of ozone levels during the next several decades will also have a significant effect on the region. This will generally return ultraviolet exposure to near or even below pre–ozone hole levels (WMO 2014), to the advantage of many species, particularly in the Antarctic Peninsula region. However, during the repair phase, weakening of the temperature gradients produced in the Antarctic stratosphere by the ozone hole will allow the effects of greenhouse gas increases to more strongly influence the Antarctic climate—further increasing Antarctic temperatures—particularly in East Antarctica during summer.

## Pressures on the marine environment

The water chemistry of the Southern Ocean appears to be changing at a faster rate than previously estimated, particularly in the deep ocean layers (Hauri et al. 2016). In the cold Southern Ocean, $CO_2$ is being sequestered (absorbed) at a higher rate than in subtropical waters. Increases in $CO_2$ cause ocean acidification through a series of chemical reactions that reduce the availability of biologically important minerals, such as calcium carbonate. This reduction makes it difficult for shell-building organisms to extract the calcium they need from the ocean.

Changes in the physical ocean environment are likely to affect the ocean's primary production (the development of new organic matter at the bottom of the food web), which influences the survival of higher-order predators. However, the degree and nature of the effects of climate change on various levels of production, and on ocean circulation and chemistry are still unclear. These uncertainties limit the degree to which we can predict the effects of changes in the physical environment and biological production, as well as the rate and direction of change and the relative importance of various pressures.

### Marine species

Wildlife populations have been exposed to change in their environment throughout the history of our planet. Some extreme events led to mass extinctions. However, other natural changes—for example, changes in atmospheric $CO_2$—have taken place slowly for centuries or longer, enabling certain vertebrate species to evolve adaptive traits (Würsig et al. 2002). In contrast, current climate change is occurring at an unprecedented rate, leaving many species vulnerable because their capacity to adapt operates much more slowly than the rate of climate change. Also, the changes are not constant, but often vary with region, and may differ in their timing and scale.

Species differ significantly in their ability to adapt because of differences in their physiology, generation time, longevity, reproductive output and success, and more. It is difficult to predict with certainty how species will react to changes in their environment, or to changes in interspecies interactions. Birds, for example, tend to breed most successfully when their food supply is abundant at a certain time of year. If food becomes less available at key times (e.g. onset of breeding, fledging or weaning of young), the survival of the species can be affected, particularly when this change in availability occurs in the long term. Sudden changes in habitat promoted by extreme events may, in some cases, advantage a population. For example, a study of Adélie penguins in the Ross Sea suggests that this species can be advantaged by reductions in sea ice cover (Lescroel et al. 2014). In contrast, extensive sea ice concentration greatly reduced the breeding success of several flying seabird species (Barbraud et al. 2015). In general, inherent differences between species, plus a lack of understanding about how various environmental factors may interact, currently make it difficult to predict the fate of particular species and populations with certainty (Würsig et al. 2002).

With the level of climate change predicted under a business-as-usual scenario, organisms are likely to encounter significant changes to their environment, which may alter species composition and abundance in various regions. Organisms can react to their changing environments in 3 main ways:

- Species shift to areas where the conditions are similar to those they encountered previously and where adaptations are not required. Movement of species on the Antarctic Peninsula is possible: as the northern parts become warmer, affected species may move further south. However, the size of the Antarctic continent and access to food limit how far they can go. In the southern Indian Ocean, wildlife populations breeding on the subantarctic islands have far fewer options to move south, because there is no intermediate location between the islands and the Antarctic continent. Thus, if they were to shift their distribution, they may have to endure colder conditions than they have so far experienced.
- Species adapt to live under warmer and perhaps more marginal conditions at their current breeding locations. This might require a shift in their behaviour and/or physiology to allow them to adjust—for example, the timing of their breeding season, the growth rate of their offspring or even the age of first breeding. Some of these changes would require a change in their genetic makeup. Which strategy species ultimately choose depends on their degree of adaptability, as well as the rates of change of the various parameters (Lagos et al. 2015).
- If species fail to move or to adapt to their altering environment, they will become extinct (Learmonth et al. 2006). This would be an undesirable outcome because biodiversity would be reduced. Some species are clearly more threatened by environmental changes than others.

A further threat to marine organisms is the occurrence of plastic in their environment. Plastic debris has been polluting Earth's oceans for decades and has even been detected in the sediments of the deep ocean (Van Cauwenberghe et al. 2013). The total amount of debris afloat is difficult to estimate, but beach surveys on subantarctic islands—for example, Macquarie Island—have indicated that monthly accumulation rates of plastics are increasing (Eriksson et al. 2013). Entanglement in, and ingestion of, plastics have long been recognised as serious hazards to wildlife, but the extent to which they occur is largely unknown and requires further investigation (Bravo Rebolledo & Franeker 2015). A technical report recently published by the Secretariat of the Convention on Biological Diversity demonstrated that 80 per cent of wildlife encounters with marine debris involved macroplastics (pieces of plastic more than 5 millimetres in diameter) and 11 per cent involved microplastics (pieces of plastic less than 5 millimetres in diameter) (Secretariat of the Convention on Biological Diversity 2012). Macroplastics can harm, and often kill, wildlife. But the effects of microplastics tend to be less obvious. Because microplastics are very small, they are bioavailable (i.e. they can be ingested), mainly by marine invertebrates. Thus, microplastics enter the food web near its base and can be transferred through the web by secondary ingestion by higher organisms (Seltenrich 2015). Microplastics can leach toxins and can concentrate certain persistent organic pollutants (POPs) (Wright et al. 2013). In seabirds in the north

Pacific Ocean, chemicals originating from plastic particles appear to have been transferred into the birds' tissues (Tanaka et al. 2013). The potential impacts of transfer of microplastics and their accumulation requires further study.

POPs and heavy metals are among the tens of thousands of pollutants that have reached the world's oceans. Some POPs have reached the Southern Ocean through long-range transportation through the atmosphere (Galbán-Malagón et al. 2013), but Antarctic stations are also likely sources (Wild et al. 2014). Heavy metal contamination can also occur because of human activity on stations. For example, mercury, lead and other metals (probably originating from paint) were found in the tissues of Antarctic clams (*Laternula elliptica*) (Vodopivez et al. 2015). Like microplastics, heavy metals and POPs can enter the food web. For example, 33 different POPs were detected in the blood of wandering albatrosses from Crozet Island in the southern Indian Ocean (Goutte et al. 2013, Carravieri et al. 2014). A variety of POPs were also found in organisms as diverse as krill, snow petrels (*Pagodroma nivea*), benthic organisms and fish off the coast of Adélie Land, East Antarctica (Goutte et al. 2013).

Ocean acidification is likely to have severe biological impacts within decades, and could dramatically affect the structure and function of marine ecosystems (Feely et al. 2004, Doney et al. 2009a, Hutchins et al. 2009, Orr et al. 2009, Dupont et al. 2010, Ericson et al. 2010). Such changes would have profound effects on ecosystem services, including the productivity of fisheries. These changes are most pronounced in the polar regions, where the acidity of the water is changing twice as fast as in the warmer tropical and subtropical regions.

Antarctic invertebrate communities form a significant part of the marine food web. They drive geobiochemical cycles and detoxify the marine environment. The various species of invertebrates will be affected differently by ocean acidification. Experimental work on temperate marine organisms has demonstrated a wide variety of responses, ranging from potentially positive effects, such as increased metabolic rates in autotrophs (organisms that produce their own food from inorganic sources), to negative effects, such as decreased growth rates in sea urchins (Hendriks et al. 2010).

Ocean acidification affects the life stages of organisms in different ways (Dupont et al. 2010). For example, fertilisation of the Antarctic nemertean (ribbon) worm (*Parborlasia corrugatus*) may not be affected by higher acidity, and experimental work showed that egg development appeared resilient when the pH of sea water (which is normally alkaline) was reduced to neutral (Ericson et al. 2010). However, abnormalities occurred at a later stage (blastula stage) of the embryos' development (Ericson et al. 2010). Although the pH changes that produced the abnormalities are not predicted to occur by 2100, they are expected if the oceans continue to acidify beyond 2100 (Ericson et al. 2010). Other factors, such as temperature and nutrient availability, also play a part.

Another factor potentially influencing microbe communities is increased ultraviolet B (UVB) radiation because of ozone depletion (UNEP 2016). Different species appear to respond differently to UVB stress. In the Southern Ocean, UVB penetrates to a depth of approximately 12 metres (Tedetti & Sempere 2006). Thus, plankton communities in shallow waters are subject to higher UVB radiation than those in deeper waters. Debate still exists about whether this exposure may lower primary production in the Southern Ocean (Moreau et al. 2016). Under increasing UVB radiation, the microbial species composition has shifted towards more UVB-resistant species, causing changes in the composition of microbial communities and production. This may influence the food availability of organisms at higher trophic (food web) levels. Furthermore, under experimental conditions, the concentration of phytoplankton and their cell sizes decreased when they were exposed to high UVB stress (Davidson & Belbin 2002). In the Southern Ocean, phytoplankton is largely protected from radiation by a layer of snow or ice, even where that layer is thin. As sea surface temperatures rise, early melting of the ice will expose phytoplankton to higher levels of solar radiation for longer periods (Hader et al. 2007).

The benthic invertebrate communities of Antarctica, especially those living outside the intertidal zone—for example, in the high Antarctic—exist in a very stable environment where temperatures fluctuate as little as 1.5 °C throughout the year (Peck 2005). These stenothermal environments (those with a narrow temperature range) came into existence about

4–5 million years ago as the waters surrounding Antarctica cooled (Pörtner et al. 2007). It is difficult to predict how warming of the ocean may affect organisms adapted to live in a very narrow temperature range. Many invertebrates die or cannot perform crucial biological activities when temperatures are raised 5–10 °C (Pörtner et al. 2007). However, these results are based on experiments during which temperatures are increased rather quickly compared with rates of change expected in nature. The more gradually environmental change occurs, the better are the chances for at least some species to adapt to the changing conditions.

Penguins off the coast of Antarctica

Photo by Nicholas Brown, © Geoscience Australia, all rights reserved

## Assessment summary 1

### Pressures affecting Antarctic marine species

| Component | Summary | Assessment grade (Very high impact / High impact / Low impact / Very low impact) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Increases in ocean carbon dioxide | The responses vary among species, and range from increases in metabolic rates (positive effects) to decreases in growth rates (negative effects) | Low impact — | ◒ | ◒ | ◆ |
| Ocean acidification | Concentrations of nutrients and rates of calcification will decrease, causing changes in microbial composition, production and nutritional value | Low impact ↙ | ◒ | ◒ | ◆ |
| Ultraviolet B radiation | Interspecies differences in response, but can reduce production, slow growth, limit survival and change species composition. In conjunction with ocean acidification, an increase in UVB radiation will potentially alter microbe assemblages | Low impact — | ● | ● | ◆ |
| Sea surface temperature | Surface warming may increase stratification, increase exposure to UVB radiation, reduce surface nutrient supply and change interactions among key species, causing changes in microbial composition and production. A latitudinal shift in productivity is predicted. There is also increased potential for the invasion of non-native species | Low impact ↙ | ◒ | ◒ | ◆ |
| Sea ice extent | Sea ice extent is highly variable and regional differences exist. Decreases in sea ice may reduce microbial food available to grazers (e.g. krill), but extensive sea ice can have adverse effects on the breeding success of seabirds | Not assessed | ○ | ○ | X |
| Sea ice thickness | Thinning alters the light regime; higher light intensities may reduce productivity of light-sensitive species. Changes in seasonality may lead to mismatch for zooplankton and higher consumers | Not assessed | ○ | ○ | ◆ |

## Assessment summary 1 (continued)

| Component | Summary | Assessment grade (Very high impact / High impact / Low impact / Very low impact) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Marine plastics | Currents along the frontal zones increase the risk of exposure to marine debris for seabirds. Microplastics are of particular concern and may be more widespread in the Southern Ocean than expected. Deposition of marine debris, particularly plastics, can lead to ingestion by, and entanglement of, seabirds and seals. Negative impacts on chicks are also possible, because ingested debris may leach harmful chemicals | Low impact, Deteriorating | Limited | Limited | X |
| Marine pollution | Persistent organic pollutants and inorganic pollutants from local and external sources exist; some are expected to increase and may have direct and indirect toxic effects on Antarctic organisms<br>Near the stations, the impact is localised and comes mainly from old tip sites | Low impact, Unclear | Adequate | Adequate | Comparable |

UVB = ultraviolet B

For additional information and an accessible version of the assessment summary, see SoE Digital.

**Recent trends**

- Improving
- Deteriorating
- Stable
- ? Unclear

**Grades**

- **Very low impact:** Communities are not affected by changes, and operate at maximal reproductive capacity
- **Low impact:** Few communities are affected and operate below maximal reproductive capacity; structure and function of system/community are not impaired
- **High impact:** Some communities are affected and operate well below maximal reproductive capacity; structure and function of system/community are impaired
- **Very high impact:** Affected communities are barely functional

**Confidence**

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

## Commercial fisheries

The largest commercial fishery in the Southern Ocean is for Antarctic krill. The krill fishery is managed by CCAMLR and sets precautionary catch limits for statistical areas in the Southern Ocean. The convention area is divided into 3 statistical areas, and subareas and divisions, which allow catch data and other information to be reported for individual krill stocks. The krill fishery is currently concentrated in the South Atlantic Ocean (statistical area 48), where CCAMLR has set a precautionary limit of 5.6 million tonnes. However, in recent years, no more than 300,000 tonnes were extracted (Nicol & Foster 2016). No krill fishery currently exists in East Antarctica, although krill fishing did take place from 1974 to 1995. There is interest in the East Antarctic krill fishery, and CCAMLR may approve proposals for harvesting in coming years. Although precautionary catch limits are currently set for large statistical areas, this does not take account of potential fishery impacts on ecosystems at smaller scales. Therefore, CCAMLR has set trigger limits that cannot be exceeded until a more elaborate management strategy is established.

Annual krill catch in areas other than East Antarctica has been increasing in recent years. Three times in the 2010–15 fishing seasons, one of the statistical subareas (subarea 48.1) was closed to krill fishing before the end of the fishing season because the catch reached annual trigger limits. In 1996 and 2006, the AAD conducted 2 major marine science voyages (BROKE in 1996, BROKE-West in 2005–06) to examine the distribution and abundance of krill in East Antarctic waters, and found quantities that could sustain commercial activities (Nicol et al. 2010). CCAMLR used the results of these surveys to set precautionary catch limits on the krill fishery off most of East Antarctica (80°E to 150°E).

Krill fisheries may face challenges, because krill are vulnerable to environmental changes, particularly climate change (Kawaguchi et al. 2013). Furthermore, the development of new technologies and the arrival of new entrants into the fishery must be managed carefully (Nicol & Foster 2016).

Australian fishing efforts for Patagonian toothfish and, to a lesser extent, mackerel icefish (*Champsocephalus gunnari*) are concentrated around the subantarctic Heard Island and McDonald Islands, and Macquarie Island. Both regions are surrounded by substantial marine reserves. Commercial fishers operate throughout the year around Heard Island and McDonald Islands, and fishing activities are regulated by the Australian Fisheries Management Authority (AFMA), consistent with CCAMLR conservation measures. The fishery around Macquarie Island is also managed by AFMA because it falls outside the CCAMLR area, although CCAMLR-like procedures are adopted. Licensed vessels in the subantarctic fisheries show a very high degree of compliance with licence conditions. Catch limits, based on the best scientific information available, are adopted through the CCAMLR process, and Australia undertakes regular fish stock assessments for the regions. By tightly regulating fishing permits, seabird bycatch has been virtually eliminated in these regions.

In the Indian Ocean, illegal, unreported and unregulated (IUU) fishing has been a significant problem in the high seas off Antarctica and outside the Australian exclusive economic zone at Heard Island and McDonald Islands. Bottom longline and gillnet fishers have exploited toothfish on the continental slope and submarine banks. In the absence of actual catch rates, it is difficult to determine how many fish are caught by IUU vessels. Since 2009–10, CCAMLR has not estimated IUU fishing, noting that all known IUU vessels were gillnetters. Gillnets are banned by CCAMLR. Many fish caught are damaged by sea lice before they are landed, making it difficult to estimate exactly how many fish were taken out of the ocean. Furthermore, lost gillnets continue to float through the ocean, and catch and destroy fish (‘ghost fishing’), so that the actual numbers of fish taken from the ecosystems are much larger than those officially reported.

The 2015 calendar year was a particularly successful one in countering IUU fishing in the Southern Ocean. The IUU fleet in the southern Indian Ocean found it increasingly difficult to operate following a collaborative effort by Australia and France, other CCAMLR members, and port states where IUU-caught toothfish were taken to be unloaded. Australia successfully boarded 3 IUU fishing vessels in the high-seas areas to verify the nationality of vessels under Article 110 of the United Nations Convention on the Law of the Sea. Information obtained from such operations has led to subsequent actions by port states and CCAMLR member countries whose nationals have been engaged in IUU fishing. The International Criminal Police Organization (INTERPOL), and several CCAMLR member countries and port states have successfully prosecuted, fined and imposed jail terms on perpetrators. For most of 2015, all remaining IUU vessels known to be fishing in the region were either sunk or impounded. Since then, for the first time in nearly 20 years, it was unlikely that IUU fishing was occurring off East Antarctica.

Although fishing and other legal or illegal extraction of resources are themselves pressures on the Antarctic environment and its species, several pressures also affect the fisheries. These include the results of climate change, as discussed above (particularly ocean acidification), and other anthropogenic factors, such as pollution.

Killer whale (*Orcinus orca*) and white-chinned petrel (*Procellaria aequinoctialis*)
Photo by Dave Harvey, Australian Antarctic Division, all rights reserved

## Assessment summary 2
### Pressures affecting Antarctic fisheries

| Component | Summary | Assessment grade: Very high impact | Assessment grade: High impact | Assessment grade: Low impact | Assessment grade: Very low impact | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|---|---|---|
| Extraction of biotic resources—krill | Currently, krill catches are below the catch limits set by CCAMLR. However, in the South Atlantic, the krill fishery is expanding. Environmental changes will negatively impact krill, which could make this species vulnerable | | | ? | | | | |
| Extraction of biotic resources—finfish | The Australian EEZ off Heard Island and McDonald Islands, and Macquarie Island supports fisheries for toothfish and icefish that have a high level of independent monitoring. Government and independent bodies have assessed them as ecologically sustainable | | | — | | | | X |
| Illegal, unreported and unregulated fishing | IUU fishing for toothfish remains a serious threat in the Southern Ocean; impact is difficult to ascertain with accuracy, but it threatens the sustainability of harvested and dependent species<br>Recent multilateral initiatives have led to the cessation of IUU activities off East Antarctica | | ↗ | | | | | |
| Ocean acidification | Some marine organisms are already affected by ocean acidification, including through reduced calcification of shells and exoskeletons. Current impact is probably low, but is expected to lead to measurable changes in the Southern Ocean ecosystem and change in species composition in the longer term | | | ↙ | | | | |

CCAMLR = Commission for the Conservation of Antarctic Marine Living Resources; EEZ = exclusive economic zone; IUU = illegal, unreported and unregulated
For additional information and an accessible version of the assessment summary, see SoE Digital.

## Assessment summary 2 (continued)

| Recent trends | Grades | Confidence | Comparability |
|---|---|---|---|
| Improving | **Very low impact:** There are few short-term, reversible impacts from this factor | **Adequate:** Adequate high-quality evidence **and** high level of consensus | **Comparable:** Grade and trend are comparable to the previous assessment |
| Deteriorating | **Low impact:** There are transitory impacts from this factor, but they are locally restricted | **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus | **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment |
| Stable | **High impact:** There are significant impacts from this factor that may become irreversible in future and become effective regionally | **Limited:** Limited evidence **or** limited consensus | **Not comparable:** Grade and trend are not comparable to the previous assessment |
| Unclear | **Very high impact:** There are predicted significant impacts from this factor that are irreversible, and impact is regional | **Very limited:** Limited evidence **and** limited consensus | X **Not previously assessed** |
| | | **Low:** Evidence and consensus too low to make an assessment | |

## Pressures on the terrestrial environment

The pressures on the Antarctic terrestrial environment operating on a global scale include anthropogenic climate change, such as atmospheric warming and changes to water regimes. Local pressures include the introduction of non-native species and impact from human activities, particularly on stations and their immediate surroundings.

### Climate change

Climate change impacts in Antarctica and the subantarctic include changes in trends in climate parameters (e.g. air temperature, precipitation, wind speed), and increased frequency and impact of extreme or pulse events (Nielsen et al. 2011). The impacts of both trends and extremes can be regionally and species specific. Changes to local environments can start follow-on degradation, such as erosion driven by alteration of surface properties (Levy et al. 2013). Flooding from an extreme summer warming event in 2002 altered species abundances in nematode communities in the McMurdo Dry Valleys (4800 $km^2$ of ice-free valleys west of McMurdo Sound) (Nielsen et al. 2011). The lichen *Usnea antarctica* is likely to be vulnerable to regional environmental change. Climate simulation experiments showed that this slow-growing lichen suffers a negative carbon balance because of an increase in respiration rates in winter and a decrease in photosynthetic activity in summer. However, mosses and microarthropods showed no signs of negative impact under the experimental conditions (Bokhorst et al. 2015).

### Introduction of non-native species

The introduction of non-native species has significantly altered the landscape, composition of ecosystems and species interactions on many subantarctic islands that are not under Australian jurisdiction (Frenot et al. 2005). Studies of the flora at the French subantarctic Kerguelen Islands date back to 1874 when 3 introduced plants were collected (Frenot et al. 2005). Large-scale surveys, mainly in the 1970s and 1980s, discovered a total of 168 introduced plant species on Possession, Kerguelen and Amsterdam islands. During a survey in 2000, 118 of these were still present. On some islands, the introduced species are well established and outnumber the native species. For example, at the Kerguelen Islands, 68 introduced plant species were present in 2000 compared with only 14 native species (Frenot et al. 2005). In addition, there are 30 known introduced invertebrate species.

The northern part of the Antarctic Peninsula is the only Antarctic region with naturally occurring flowering (vascular) plants: Antarctic hairgrass (*Deschampsia antarctica*) and Antarctic pearlwort (*Colobanthus quitensis*). However, in recent years, several species of non-native vascular plants have been found there, and they appear to be spreading. Furthermore, non-native plants have recently been rediscovered in areas from where they had been removed. The warming of the peninsula has allowed such biological invasions and establishment of non-natives. They displace the native plants and are deemed to be a serious threat to the integrity of the ecosystem (Molina-Montenegro et al. 2015).

At Macquarie Island, 5 non-native vascular plants have become established since the island's discovery. Two plant species were successfully eradicated, but the remaining 3 are still thriving. Disturbed sites, such as walking tracks, are particularly suited to colonisation by annual meadow grass (*Poa annua*), a small grass that can outcompete some native species. Research is currently under way to evaluate the distribution and impact of *P. annua* to find ways to eradicate this invasive species in the near future (Williams et al. 2013). On Macquarie Island, there are also 28 introduced invertebrate species. Research has suggested that the presence of some introduced invertebrates has a negative impact on the richness and density of native invertebrate species (Terauds et al. 2011).

Macquarie Island's flora suffered severe degradation through overgrazing by rabbits (*Oryctolagus cuniculus*), resulting in erosion and landslides (PWS 2014). For seabirds, introduced cats (*Felis catus*), rats (*Rattus* spp.) and rabbits posed the most significant conservation problems at Macquarie Island. The mammals directly affected seabirds through predation of eggs, chicks and adults; and rabbits damaged the vegetation, leading to erosion, increased exposure to natural predators and loss of breeding habitat (Baker et al. 2002). Following successful eradication of cats on the island in 2000, a comprehensive eradication program for rabbits, rats and mice (*Mus* spp.) started in 2010 and was completed successfully in 2014. The elimination of cats, rabbits and rodents has had a positive effect on plant and seabird communities (see Box ANT1).

### Box ANT1 Successful eradication of alien mammals and environmental recovery on Macquarie Island

Feral cats (*Felis catus*) had been present on Macquarie Island since the 19th century. They preyed on small, unattended chicks of many seabird species, as well as rabbits and rodents (Rounsevell & Brothers 1984). From 1975 to 1984, a program was in place to keep the cat population under control, but the numbers of burrowing seabirds continued to decrease. Hence, from 1998 to 2000, an intensive cat eradication program was conducted and, in June 2000, the last cat on the island was destroyed (PWS 2015).

From 2000 to 2006, rabbit numbers increased dramatically on Macquarie Island (Terauds et al. 2014) after the cats had been eradicated (Bergstrom et al. 2009, Robinson & Copson 2014). In 1978, the Tasmanian Parks and Wildlife Service estimated that some 150,000 rabbits inhabited Macquarie Island, and introduced myxomatosis to reduce the rabbit population.

However, from 1999 to 2003, the number of rabbits increased, and it became clear that myxomatosis was no longer as effective as it had been when it was introduced. The increasing rabbit population caused widespread vegetation damage and destruction through overgrazing. The vegetation cover was so overgrazed that the substratum became eroded. Many coastal slopes were transformed from lush, waist-high vegetation to grazed lawns or bare ground; these were increasingly prone to landslips from high-rainfall events and seismic activity, which killed flying seabirds and penguins. Seabird colonies also lost the protection provided by vegetation and lost habitat at their breeding grounds. Some vegetation types, such as the prickly shield fern (*Polystichum vestitum*), were also threatened (Bergstrom et al. 2009), and remaining patches were fenced to maintain existing populations.

In 2006, an eradication program for rabbits, rats and mice on Macquarie Island was developed (PWS 2007). It cost approximately $20 million over 7 years, and was jointly funded by the Tasmanian and Australian governments.

The field phase of the eradication of rabbits and rodents started in June 2010 when helicopters dropped bait pellets containing brodifacoum (an anticoagulant poison), targeting rabbits, rats and mice across the island. However, because of inclement weather, only 8 per cent of the island's area could be baited, and it was decided to continue the project in the 2011 winter (Springer 2016).

Some nontarget species, most likely scavenging species such as skuas and giant petrels, were expected to possibly be affected by the eradication efforts. By 9 February 2011, 947 dead birds had been found, including 298 northern giant petrels (*Macronectes halli*; approximately 8 per cent of the breeding population on the island), 16 southern giant petrels (*M. giganteus*; 0.3 per cent), and 226 subantarctic skuas (*Catharacta antarctica*; 11 per cent). The actual number of bird mortalities is likely to have been higher, because not all areas of Macquarie Island could be intensively searched, and an unknown number of individuals may have died at sea.

Additionally, 4 southern giant petrels (1 bird banded at Macquarie Island) were found dead in the New Zealand subantarctic area and tested positive for brodifacoum.

An overgrazed area at the boardwalk at Sandy Bay, which led to destruction of tussock grass (*Poa foliosa*) fields

## Box ANT1 (continued)

Further, although only 10 northern giant petrel carcases were examined, 9 were males, probably because of their more coastal-oriented foraging (females tend to be more pelagic), exacerbating the impact on the breeding population. The primary cause of bird deaths was brodifacoum poisoning resulting from the secondary ingestion of poisoned carcases of bird and target species, the accessibility of these carcases, and the scavenging behaviour of the bird species. Because brodifacoum has a particularly long half-life in a carcase, it remains active months after an animal dies. Deaths of kelp gulls and black gulls may have been caused by both primary and secondary poisoning.

The 2010 operations were reviewed (PWS 2014). To reduce the impact of the eradication program on nontarget species, several changes were made, including increasing the efforts to systematically search for, and remove, poisoned target and bird carcases.

Some 10 weeks before the second aerial baiting phase started, rabbit haemorrhagic disease virus was released on the island, which reduced the rabbit population by about 80–90 per cent (Springer & Carmichael 2012). From May to July 2011, 2 island-wide bait drops were completed. Intense hunting pressure was exerted on the remaining rabbits immediately after the baiting phase to prevent the population from increasing again. In July, the rabbit-hunting teams arrived on the island with 12 specially trained dogs to follow up on the ground and eliminate rabbits that had survived the baiting.

Hunters and their dogs working above Hurd Point searching for rabbits

Photo by Steven Horn, Australian Antarctic Division, all rights reserved

Joker the springer spaniel next to a king penguin while taking a break in the search for rabbits

Photo by Lauren Koehler, Australian Antarctic Division, all rights reserved

For 4 years, field teams used a range of techniques, including shooting, fumigating burrows and trapping, to ensure that all rabbits were removed. In April 2013, additional teams were landed, including 3 rodent-detecting dogs (Springer 2016). Teams carried GPS equipment to ensure complete coverage of the island. Collectively, the teams tracked 92,000 kilometres from August 2011 to March 2014.

In 2014, the operation was declared a success, and the island is now recognised as being free from introduced vertebrate pests (Springer 2016). Vegetation recovery has been rapid in most areas in the absence of rabbits (Shaw et al. 2011), and small burrowing birds are already increasing in numbers because of widespread vegetation recovery and the absence of rats.

Quarantine and monitoring of Macquarie Island continue, and should ensure that the island remains free from non-native mammals. Several long-term collaborative projects are under way to monitor and report on the post-eradication recovery of island ecosystems.

**Box ANT1 (continued)**

Regrowth of the native tussock grass at Sandy Bay
Photo by Tasmanian Parks and Wildlife Service, 

The McDonald Islands in the southern Indian Ocean may be the only islands in the subantarctic that are free from introduced species. Nearby Heard Island has 2 known introduced plants: annual meadow grass and a perennial herb (*Leptinella plumosa*). It also has 3 introduced invertebrate species: the earthworm *Dendrodrilus rubidus*, the mite *Tyrophagus putrescentiae* and Californian wingless thrips (*Apterothrips apteris*) (AAD & Director of National Parks 2005). No introduced vertebrates exist on Heard Island.

The pressures of climate change and introduced species may combine (Convey 2005, 2010). New species that become established in a warming environment tend to be more competitive than native species because of better dispersal mechanisms or a lack of predators, or because they occupy niches that previously did not exist (Chown et al. 2012). Under such circumstances, food webs and ecosystem functioning could be altered dramatically (Convey & Lebouvier 2009).

## Human activities

Tourism is particularly concentrated on the Antarctic Peninsula, which was visited by about 42,800 travellers and support staff in the 2015–16 season. Although there is limited evidence-based assessment of human disturbance of wildlife, a recent meta-analysis of available data found statistically significant negative effects on physiological and population responses at a variety of visit sites in the Antarctic and subantarctic (Coetzee & Chown 2016).

Pollution of the Antarctic environment occurs mainly at the centres of human activity, such as stations. For example, alkaline particles can become airborne and drift downwind during building operations that require concrete. Damage to lichens caused by this airborne pollution lead to bleaching about 90 metres from the site (Adamson & Seppelt 1990). Airborne pollutants, such as POPs, have been found in the atmosphere above Antarctica, albeit at lower levels than in the Arctic (Vecchiato et al. 2015).

Station personnel (including researchers) tend to disturb wildlife more near stations than in remote areas.

## Assessment summary 3

### Pressures affecting the Antarctic terrestrial environment

| Component | Summary | Assessment grade: Very high impact | Assessment grade: High impact | Assessment grade: Low impact | Assessment grade: Very low impact | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|---|---|---|
| Changes in ambient temperature | Populations of some native plants are expanding rapidly on subantarctic islands where ice-free areas are increasing. Composition of plant assemblages may change as non-native species become established | | ? | | | ● | ● | ◆ |
| Changes in water availability | In some areas of East Antarctica, there is evidence of long-term drying, and moss beds appear to have contracted to areas with reliable water supply | | ? | | | ● | ● | ◆ |
| Changes in wind patterns | In East Antarctica, moss growth is retarded because of changes in wind patterns related to ozone depletion | | ? | | | ● | ● | ◆ |
| Introduction of non-native species and pathogens | Invasive species can have a devastating effect on endemic species and communities. *Poa annua*, a small grass, is spreading and outcompetes native plant species. The eradication program of cats, rabbits, rats and mice at Macquarie Island has been completed successfully and has had a positive effect on plant communities (see State and trends of the Antarctic environment)<br>Further warming of the atmosphere may help pathogens and non-native species to become established | | ? | | | ◒ | ◒ | ◆ |
| Erosion | More ice-free areas are likely to suffer from erosion, especially on subantarctic islands | | ? | | | ◒ | ◒ | ◆ |
| Pollution | Deposition of solid and liquid wastes can affect both terrestrial and marine communities<br>Impacts tend to be localised, but pollutants also come from nonlocal sources and are likely to contaminate much larger regions | | ↙ | | | ◒ | ◒ | ◆ |

## Assessment summary 3 (continued)

| Component | Summary | Assessment grade (Very high impact / High impact / Low impact / Very low impact) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Marine debris | Deposition of marine debris, particularly plastics, can lead to ingestion by, and entanglement of, seabirds and seals. Negative impacts on chicks are also possible, because ingested debris may leach harmful chemicals | High impact, Deteriorating | Adequate | Adequate | Not previously assessed |
| Wildlife disturbance | Increased visitation puts pressure on wildlife populations. With increasing demands to see wildlife, more areas may be visited more often and by more people<br>More research activities may also increase wildlife disturbance<br>New technology such as drones may disturb wildlife | Low impact, Unclear | Limited | Limited | Comparable |
| Physical disturbance and habitat loss | Many human activities significantly alter the natural environment. Visitation can negatively affect habitat—for example, through trampling | Low impact, Stable | Adequate | Adequate | Comparable |

For additional information and an accessible version of the assessment summary, see SoE Digital.

**Recent trends**

- ↗ Improving
- ↙ Deteriorating
- — Stable
- ? Unclear

**Grades**

- **Very low impact:** There are few short-term, reversible impacts from this factor
- **Low impact:** There are transitory impacts from this factor, but they are locally restricted
- **High impact:** There are significant impacts from this factor (may be cumulative); impacts are region specific and may become irreversible in future
- **Very high impact:** There are predicted significant impacts from this factor that are irreversible; impact is region specific

**Confidence**

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

## Pressures on Antarctic historic heritage

The Mawson's Huts Historic Site at Cape Denison in the AAT is Australia's oldest and arguably most significant historic heritage site in Antarctica. At the time of their construction, more than 100 years ago, the huts were built to last only a few years. It was never anticipated that they would still be standing a century later and considered a valuable part of Australia's Antarctic heritage.

The building materials are vulnerable to deterioration, and the natural elements—wind, weather, frost, ice and melt water—threaten the integrity of the buildings and structures. Corrosion, fungal growth, wind and snow loads, exposure to ultraviolet radiation, the freeze–thaw cycle, and high relative humidity inside the main hut also affect the conservation of structures and artefacts (Lazer 2006).

The Mawson's Huts Historic Site Management Plan provides guidance for the protection and conservation of the site buildings and artefacts. The AAD works closely with the Mawson's Huts Foundation to determine conservation priorities and methods to appropriately manage the site.

On the subantarctic islands, artefacts associated with 19th century sealing activities remain. The maritime climate promotes corrosion of metal artefacts, and wooden items are abraded by windborne sand and salt particles. Disturbance by wildlife, land erosion and slippage are also potential problems (Vincent & Grinbergs 2002, Clark 2003, Vincent 2004), as are erosion and exposure of artefacts, and volcanic and seismic activities. Seismic activity has been identified as a specific threat to structures on Macquarie Island, although most of the research expedition buildings have been built to withstand tremors (Lazer 2006).

Heard Island is a long way from continental Australia, and caring for the components of historic heritage on the island is an enormous challenge. The cultural heritage of Heard Island is therefore conserved through a process of managed decay. This is a pragmatic management option, which acknowledges the practical impossibility of conserving all elements of the cultural environment in a remote area where access is extremely limited (Vincent & Grinbergs 2002, Lazer 2006). Permitted visits are very infrequent and tend to be restricted to the short summer. The management plan states that heritage values, such as buildings, are in a greatly deteriorated state and have been in such a state for a long time, and are permitted to disintegrate under the influences of weather and climate. However, the exposed asbestos requires management, because it poses a threat to the natural environmental and a safety risk for people visiting the site. There are several sealers' graves in the south-eastern part of the island, not far from a large king penguin (*Aptenodytes patagonicus*) colony. The vegetation cover is dense, and continues to engulf and cover the old graves.

A specific risk to Heard Island is the changing coastline. For example, wooden oil barrels that were left by sealers at Oil Barrel Point have disappeared steadily during the past few decades as they have eroded out of the beach cliff (Lazer & McGowan 1990). Less than a quarter of those recorded in the 1980s are still in place.

The AAD liaises closely with vessel operators known to be interested in visiting the island to advise them of authorisation requirements. Given Heard Island's remote location, however, it is possible that some unauthorised visits could occur and that activities that would otherwise require a permit, such as entering the Heritage Zone or collecting materials from the island, could be done without the Australian Government being aware.

## Assessment summary 4
### Pressures affecting Antarctic historic heritage

| Component | Summary | Assessment grade (Very high impact / High impact / Low impact / Very low impact) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Melt water | Fine snow particles penetrate and fill the buildings, and cause structural damage and damage to artefacts | High impact ↙ | ● | ● | ◆ |
| Wind | Wind can limit conservation work and destroy weakened structures | High impact ↙ | ● | ● | ◆ |
| Climate change | Increased wind strength and storm frequency puts pressure on structures | High impact ↙ | ● | ● | ◆ |
| Coastal erosion | Dynamic coastline changes at Heard Island and McDonald Islands threaten some artefacts | High impact ↙ | ● | ● | ◆ |
| Fauna and flora | Wildlife, such as elephant seals, can exert considerable impact when they move across sites<br>Overgrowth by plants on subantarctic islands can obscure items, such as the headstones of graves on Heard Island and McDonald Islands | High impact ↙ | ● | ● | ◆ |
| Unauthorised collection of biological and geological material, and artefacts | Could occur at Heard Island; unauthorised visits possibly occur | Not assessed | ○ | ○ | X |

For additional information and an accessible version of the assessment summary, see SoE Digital.

## Assessment summary 4 (continued)

**Recent trends**

- ↗ Improving
- ↙ Deteriorating
- — Stable
- ? Unclear

**Grades**

- **Very low impact:** Component is hardly impacted by factor and requires no further conservation efforts
- **Low impact:** Factor impacts on part of the component, which may require further conservation efforts
- **High impact:** Factor has a moderate impact on the component, which requires further conservation efforts
- **Very high impact:** Factor impacts component significantly and limits further conservation efforts

**Confidence**

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

# State and trends
## of the Antarctic environment

### At a glance

The physical and chemical components of the Antarctic environment are changing. The Antarctic surface and lower atmosphere are warming, with the strongest temperature increases in the Antarctic Peninsula region and West Antarctica. Part of the warming is because of global temperature increases that are accompanying the rise in atmospheric greenhouse gas concentrations. Antarctic temperature changes are also being influenced by shifts in atmospheric circulation as a result of stratosphere cooling through ozone depletion and increasing levels of carbon dioxide, and variability in the heat content of the oceans. Most notably, there is strong evidence that stratospheric ozone depletion associated with the Antarctic ozone hole has mitigated the warming of much of Antarctica during the summers of the past 2–3 decades. There is increasing evidence that the ozone layer is starting to recover as a direct consequence of international controls on the use of human-made ozone-depleting substances.

The complex Antarctic food web is based on vast numbers of marine microorganisms, including bacteria, phytoplankton and zooplankton. Changes to the marine environment, including ocean acidification, will have a significant impact on these organisms. Since these organisms are at the base of the food web, such changes will have profound effects throughout the Antarctic ecosystems.

Few data are available about the status of Antarctic vertebrates, which encompass a variety of flying seabirds and penguins, several seals and whales, and numerous fish. The distribution and abundance of humpback whales are probably the best known of any whale species. Recent surveys indicate that some stocks are increasing to a point that their delisting as a threatened species under Australian legislation has been proposed. There is some evidence that the breeding distribution of Adélie penguins has expanded during the past decade; however, the size of emperor penguin colonies may have declined. Similarly, although several fur seal populations appear to be increasing, the numbers of southern elephant seals at Macquarie Island are declining. Climate change and warming conditions are also supporting the movement of non-native species into the region, where they may outcompete native species. Introduced plants, such as annual meadow grass (*Poa annua*), are thriving on Australia's subantarctic islands.

Many subantarctic islands also carry the legacy of introduced vertebrates, such as rabbits or pigs that were released during the sealing years onto the islands as food sources. A notable step has been taken in the past few years to redress the damage cause by introduced species in the subantarctic through the successful eradication of rabbits, rats and mice on Macquarie Island.

Australia's 4 permanently occupied research stations of Casey, Davis, Mawson and Macquarie Island are strictly controlled, with guidelines on vehicle operations, waste and emissions. Australia is also managing and remediating several contaminated sites that are a legacy of past practices. This section presents information on the state of the major components of the Antarctic environment, and the assessment of trends in key indicators. Because of the wide spatial scale of key physical and ecological processes, we consider the whole of the Antarctic and Southern Ocean region. However, where possible, we focus on East Antarctica and Australia's subantarctic islands.


Emperor penguins (*Aptenodytes forsteri*) and RSV *Aurora Australis*
Photo by Patti Virtue, Australian Antarctic Division, all rights reserved

## The physical environment

The physical environment includes both the nonliving factors that characterise an ecosystem (e.g. weather patterns, ice coverage, the atmosphere) and the processes that drive them (e.g. weathering of rocks, anthropogenic emissions that deplete ozone in the atmosphere).

### The atmosphere—climate and weather patterns

Antarctica is a major driver of global weather and climate, and influences the large-scale patterns of circulation at all layers in the atmosphere. Interactions between the atmosphere, ice and ocean in the Antarctic region set up patterns of variability across the Southern Hemisphere that, ultimately, influence the weather and climate of Australia. Physical processes in the Antarctic atmosphere form part of the engine that globally transports greenhouse gases, human-made chlorofluorocarbon gases, other pollutants and volcanic dust. Consequently, remote sources of human-made and natural pollution have pathways to Antarctica.

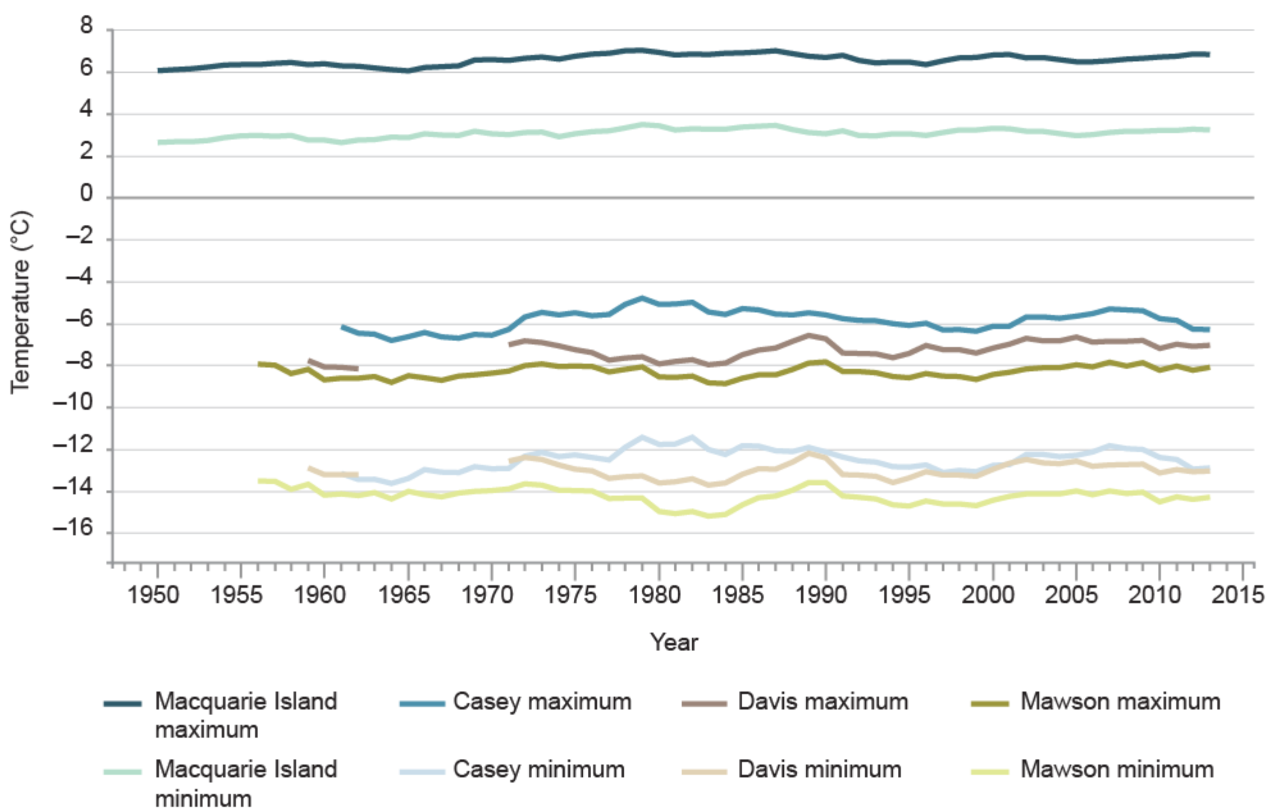
The climate of our polar regions and their dominant weather patterns are a result of the shape and rotation of the planet. Largely because of the spherical shape of Earth, the poles receive less solar energy than the equator. The interior of Antarctica—where the ice sheet is 2–4 kilometres thick and, hence, high above sea level—remains very cold throughout the year, because it is generally well shielded from the warmer air masses found at mid-latitudes. In contrast, the equatorial regions, where seasonal change is barely apparent, remain warm all year round. The latitudinal temperature difference between the equator and Antarctica creates a pressure gradient that Earth's rotation acts on, to create a belt of cyclonic weather systems between 40°S and 70°S. The clockwise rotation of cyclones (as seen from satellite imagery) transports heat from the equator towards the Antarctic continent (Gitelman et al. 1997). The high altitude of the Antarctic ice sheet (averaging around 2200 metres) allows the air above the continent to cool significantly, becoming much denser than the air at the coast. This results in strong gravity-driven katabatic (downslope) winds in the coastal regions, where they are particularly prevalent during winter. The outflow from the katabatic winds influences the southward extent of the cyclonic weather systems that continually move across the Southern Ocean.

Although the earliest substantial Antarctic weather instrumental records extend back to the beginning of the 20th century (to 1904 for the South Orkney Islands), the bulk of records suitable for surface climate analysis started to become available in the late 1940s. During the 1960s, regular 'upper air' measurements—which profile conditions in the troposphere (Earth's surface to 10 kilometres high) and lower stratosphere (10–30 kilometres) using radiosonde balloons—began at several sites in the Antarctic region. The advent of polar-orbiting weather satellites in the late 1970s greatly improved the spatial, temporal and vertical remote sensing of the Antarctic region.

The Australian Bureau of Meteorology gathers year-round detailed weather information at Australia's Antarctic and subantarctic stations. The Australian sites contribute to the Antarctic Observing Network of the World Meteorological Organization (WMO 2016a), which—in November 2015—comprised 113 stations. In 2015, Australia's Davis and Macquarie Island research stations became candidate members of the Global Climate Observing System Reference Upper Air Network, which is designed to maintain long-term climate records (WMO 2016b). In addition to the records gathered at staffed sites, weather data are collected by automatic weather stations at more than 100 locations across Antarctica (Lazzara et al. 2012), and by drifting buoys, balloons, and various satellite and ground-based remote-sensing techniques (AAD 2008).

Although there is significant interannual variability in Antarctic weather because of various large-scale atmospheric and oceanic processes associated with the global movement of heat, trends are apparent in the recent historical record. During the past half-century, the Antarctic surface has warmed. Work by Nicolas and Bromwich (2014) provides a best estimate of 0.11 ± 0.08 °C per decade averaged across the continent. This warming is most significant in the western and northern parts of the Antarctic Peninsula, and in parts of the West Antarctic Ice Sheet (Turner et al. 2009, 2014; Hartmann et al. 2013). At the Faraday–Vernadsky Station on the western side of the Antarctic Peninsula, an annual trend of +0.54 °C per decade from 1951 to 2011 has been observed, which is the most significant trend in the peninsula region (Turner et al. 2014). Winter temperatures at this site exhibited a stronger trend of +1.01 °C per decade from 1950 to 2011 (Turner et al. 2014). West Antarctica warmed on average by approximately +0.22 °C per decade from 1958 to 2012, with the winter and spring seasons showing the strongest warming trends (Steig et al. 2009, Nicolas & Bromwich 2014). Byrd Station in West Antarctica appears to show the most rapid warming of any site on Earth, with a warming of +2.4 ± 1.2 °C per decade from 1958 to 2010 (Bromwich et al. 2013). Coastal East Antarctica is generally warming, although the trend is weaker than in West Antarctica, and some regions and seasons show evidence of cooling (SCAR 2009, Steig et al. 2009). For example, a statistically significant cooling trend has been observed at the high plateau at the South Pole.

At Australia's Casey, Davis and Mawson Antarctic research stations, the long-term annual maximum and minimum temperatures have varied regionally (Figure ANT3). Mawson and Davis, which are separated by approximately 640 kilometres, show similar trends, whereas Casey, some 1390 kilometres east of Davis, exhibited a warming during the 1970s while the other stations cooled. Part of the variability in the temperatures at these stations over interannual and longer timescales can be attributed to changes in the Southern Annular Mode, particularly in summer. In the case of Macquarie Island, the long-term trend is of warming, which is most significant in summer (Box ANT2).




Source: Monthly average temperature data from Climate Data Online, Bureau of Meteorology. The record for Casey comprises measurements at Wilkes (February 1960 – January 1969), Casey Tunnel (February 1969 – December 1988) and the present Casey Station (from January 1989)

Figure ANT3 Annual average daily maximum and minimum temperatures, smoothed with a 5-year running mean, for Australia's Casey (1961), Davis (from 1959) and Mawson (from 1956) Antarctic research stations, and subantarctic Macquarie Island (from 1950)

Although greenhouse gas changes are likely contributing to the warming of Antarctica (Hartmann et al. 2013), regional influences have been attributed to changes in the Southern Annular Mode (Marshall et al. 2006; Box ANT2), which is, in turn, influenced by stratospheric ozone depletion and greenhouse gas changes (Box ANT3). Additionally, regional climate variability in Antarctica is influenced by connections to the tropical oceans, particularly through the El Niño–Southern Oscillation, Indian Ocean Dipole and Interdecadal Pacific Oscillation climate modes, and from variability in the tropical North Atlantic (Li et al. 2014, Turner et al. 2014, Turney et al. 2015). At present, it is unclear how these tropical connections are responding to global climate change (Hartmann et al. 2013).

In the upper atmospheric layers, balloon and satellite measurements indicate that the Antarctic lower troposphere (surface to 5 kilometres) has warmed during the past 50 years (SCAR 2010), while the lower stratosphere (10–30 kilometres) has cooled (Randel et al. 2009, WMO 2014). These temperature changes are likely to be because of the effects of increased greenhouse gas concentrations in the atmosphere and, particularly in the case of the stratosphere, decreases in ozone concentrations (Turner et al. 2014, WMO 2014). In the Antarctic mesosphere (50–95 kilometres), temperatures are expected to decrease in response to increasing $CO_2$ levels (which is opposite to the situation in the troposphere). Above Davis, temperatures in the upper mesosphere near 87 kilometres exhibited a long-term cooling of –1.2 ± 0.9 °C per decade from 1995 to 2010 (after accounting for influences from the solar activity cycle). The cooling is more pronounced in spring; this is possibly associated with changes in atmospheric structure associated with the ozone hole (French & Klekociuk 2011).

## Box ANT2 Variability and trends in East Antarctic temperatures and the Southern Annular Mode

The Southern Annular Mode (SAM) is the principal driver of atmospheric variability at southern high and mid-latitudes on the timescale of weeks to months (Turner et al. 2014). The SAM manifests as a see-sawing of pressure levels between high and mid-latitudes, and operates on seasonal and interannual timescales around the entire Southern Hemisphere. It is defined to be in a positive state when Antarctic surface pressures are below average, which is accompanied by a southwards shift of the belt of strong westerly winds across the Southern Ocean. The negative state has above average pressures and a northwards wind shift.

Since the 1960s, the SAM has shown a statistically significant positive trend during austral summer (December–February) and autumn (March–May). This results in a general decrease in surface air pressure around the Antarctic coast, and an increase in pressure at southern mid-latitudes during these seasons (Marshall 2003). The trend has deepened the meteorological feature known as the Amundsen Sea Low, which has contributed to warming of the Antarctic Peninsula (and, to a lesser extent, West Antarctica) and to a reduction of sea ice in these regions. Additionally, changes in the SAM have led to fewer but more intense cyclonic weather systems in the Antarctic coastal region (60°S–70°S), except in the region of the Bellingshausen–Amundsen seas (SCAR 2009).

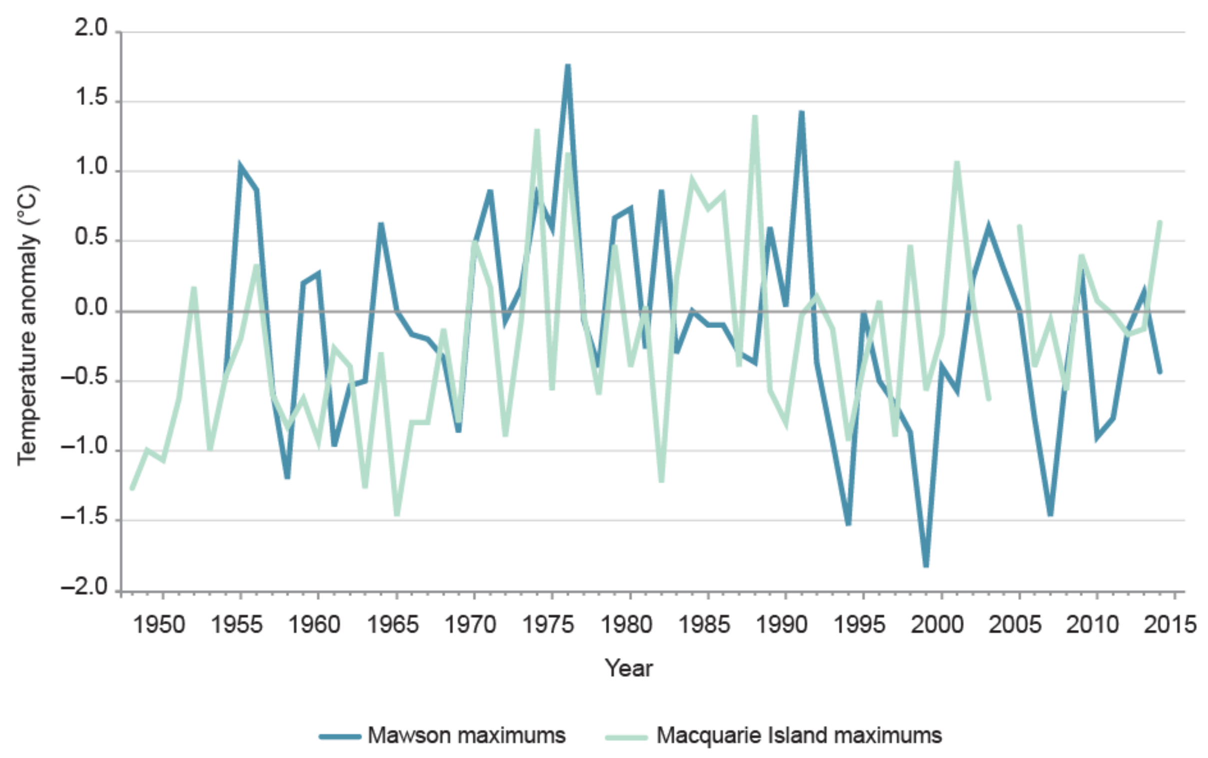
Broadscale changes in atmospheric circulation brought about by the readjustment of the vertical and horizontal temperature gradients in the atmosphere drive year-to-year changes in the strength of the SAM. The trends in the SAM during summer and autumn have been linked to depletion of stratospheric ozone because of the Antarctic ozone hole (which has promoted stratospheric cooling) (Marshall et al. 2004) and, to a lesser extent, increasing greenhouse gases (which promote warming of the troposphere and cooling of the stratosphere). Additional variability in the SAM has been linked to natural modes of variability in ocean temperatures (Marshall & Connolley 2006).

The observed trends in the SAM (towards lower Antarctic surface pressures) have promoted cooling of the Antarctic region by reducing the inflow of heat from lower latitudes (because of an associated strengthening of the circumpolar westerly winds) and reducing the downwards heat transport near the surface (Nicolas & Bromwich 2014). By accounting for the effect of the SAM on Antarctic surface temperatures, a residual warming that is attributed to greenhouse gas increases has been identified (Gillett et al. 2008).

## Box ANT2 (continued)

As shown in Figure ANT4, the summer temperature anomaly at Macquarie Island based on the 1971–2000 average exhibits multiyear variability. Generally, the period since the early 1970s has been warmer than the first 2 decades of the record. At Mawson, the summer temperature anomaly has been generally cooler since the mid-1990s compared with the earlier record.

In the case of Mawson and several other sites in East Antarctica, a general pattern of anticorrelation has been observed between the strength of the SAM and near-surface temperatures (Marshall 2007). In comparison, the SAM–temperature relationship is much weaker at Macquarie Island. For Mawson, around 25 per cent of the variance in the summer and winter temperature anomaly is explained by the SAM–temperature correlation, at least in 20 year intervals up to 2004 (Marshall 2007). The strength of this relationship indicates that, although seasonal temperatures in a given year can be influenced by the SAM, other sources of variability can play a more important role. Recent work by Marshall et al. (2013) suggests that the SAM–temperature relationship in East Antarctica reversed during the 2000s as a result of emerging internal climate variability associated with ocean–atmosphere interactions. Overall, continued collection of long-term, high-quality climate data in the Antarctic region is required to more fully interpret current trends.




Source: Monthly average temperature data from Climate Data Online, Bureau of Meteorology

Figure ANT4 Summer (December–February) average temperature anomaly of daily maximum temperatures (annual average of the monthly mean daily maximum temperature deseasonalised by the summer mean for 1971–2000) for Mawson and Macquarie Island

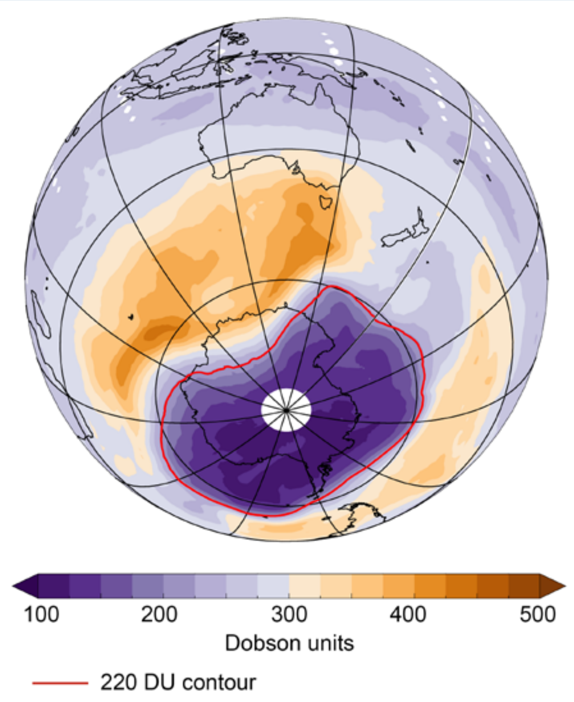
## Box ANT3 The Antarctic ozone hole

The Antarctic ozone hole is an anomalous reduction in the amount of ozone in the lower stratosphere (12–20 kilometres in altitude) above Antarctica, which has taken place each spring since around 1980 (WMO 2014). This phenomenon has led to an increase in damaging ultraviolet radiation reaching the surface of Earth (Bais et al. 2015) and a cooling of the stratosphere (Solomon et al. 2015).

The ozone hole is caused by chemical processes involving human-made halon gases, particularly chlorofluorocarbons (CFCs). Such chemical processes are promoted by the extreme cold and special circulation conditions in the Antarctic stratosphere during winter. Antarctic ozone destruction begins in August, reaches a peak from late September to early October (when up to approximately 70 per cent of the ozone column is destroyed in a region covering about twice the surface area of Antarctica; Figure ANT5), and usually ends in late November. Similar chemical processes also cause significant ozone destruction over the Arctic between December and March of some years, and contribute to a small, but important, overall reduction in global stratospheric ozone levels.

In 1987, the Montreal Protocol was signed to improve the health of the ozone layer by restricting the use of CFCs and other ozone depleting substances. This treaty has since been ratified by 197 parties and has led to a gradual reduction in equivalent effective stratospheric chlorine (EESC; Figure ANT6), which is an estimate of the effective quantity of halogens in the atmosphere. This estimate is used to quantify the amount of stratospheric ozone loss that can be explained by the level of human-made halogens. The levels of CFCs peaked in the mid-1990s; since then, the use of these chemicals has been greatly reduced. Based on modelling of the expected evolution in EESC levels, the Antarctic ozone hole is expected to be repaired during the latter part of the 21st century (Butchart et al. 2010, WMO 2014). Recent observations provide evidence that stratospheric ozone levels are improving (Solomon et al. 2016).

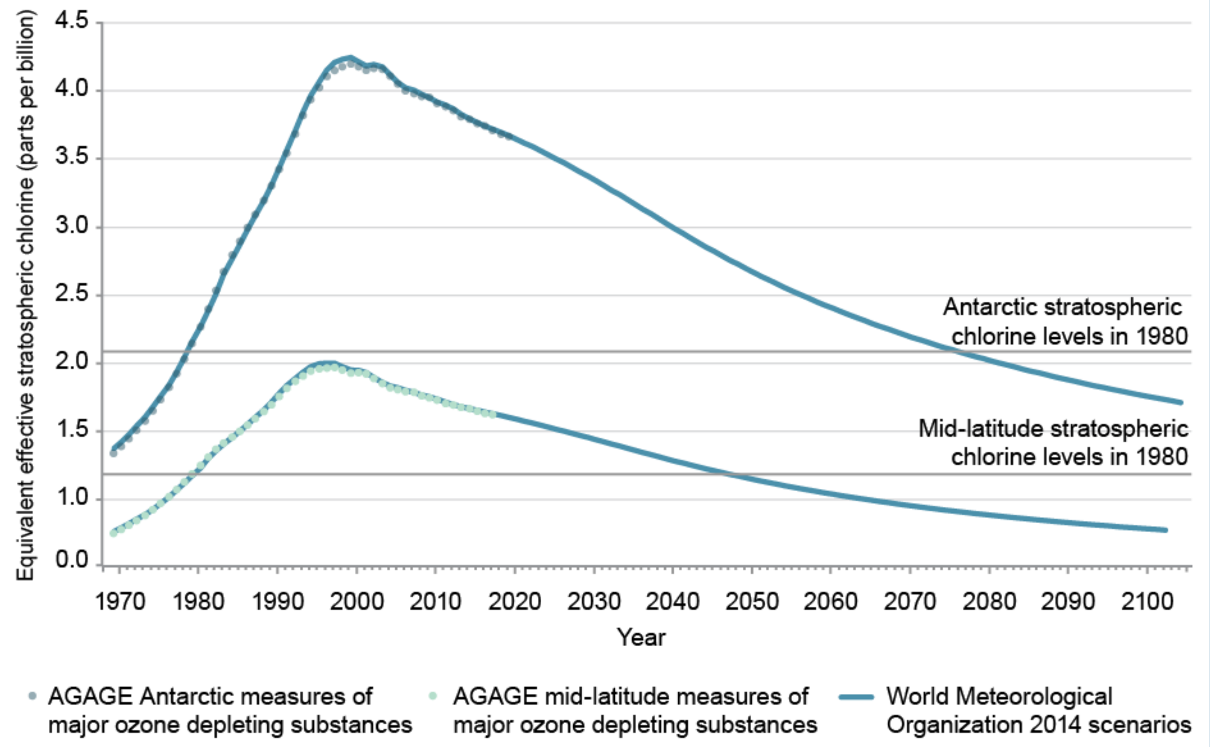
The recent behaviour of ozone levels above the British Halley Research Station, which has the longest available Antarctic record, is shown in Figure ANT7. Ozone levels fluctuate significantly from year to year because of the influence of meteorological factors. Several measures of the severity of Antarctic ozone loss indicate that the ozone hole has not increased in size since 2006 (Klekociuk et al. 2015). After accounting for year-to-year variability, Antarctic ozone has increased by approximately 5 per cent since 2000. Although this increase is consistent with the expected decrease in EESC levels (Figure ANT6), it cannot be definitely attributed to the change in EESC levels (WMO 2014).




DU = dobson unit (thickness of the ozone layer measured in 0.01 millimetre steps at standard temperature and pressure)
Note: On 24 September 2006, the area of the ozone hole within the 220 DU contour was the largest observed in any year of observations.
Source: Data from NASA Goddard Spaceflight Center Code 613.3; visualisation by Paul Krummel, CSIRO Oceans and Atmosphere

**Figure ANT5** Map of the total-column amount of ozone in the atmosphere on 24 September 2006, as measured by the Ozone Monitoring Instrument on the Aura polar-orbiting satellite

## Box ANT3 (continued)



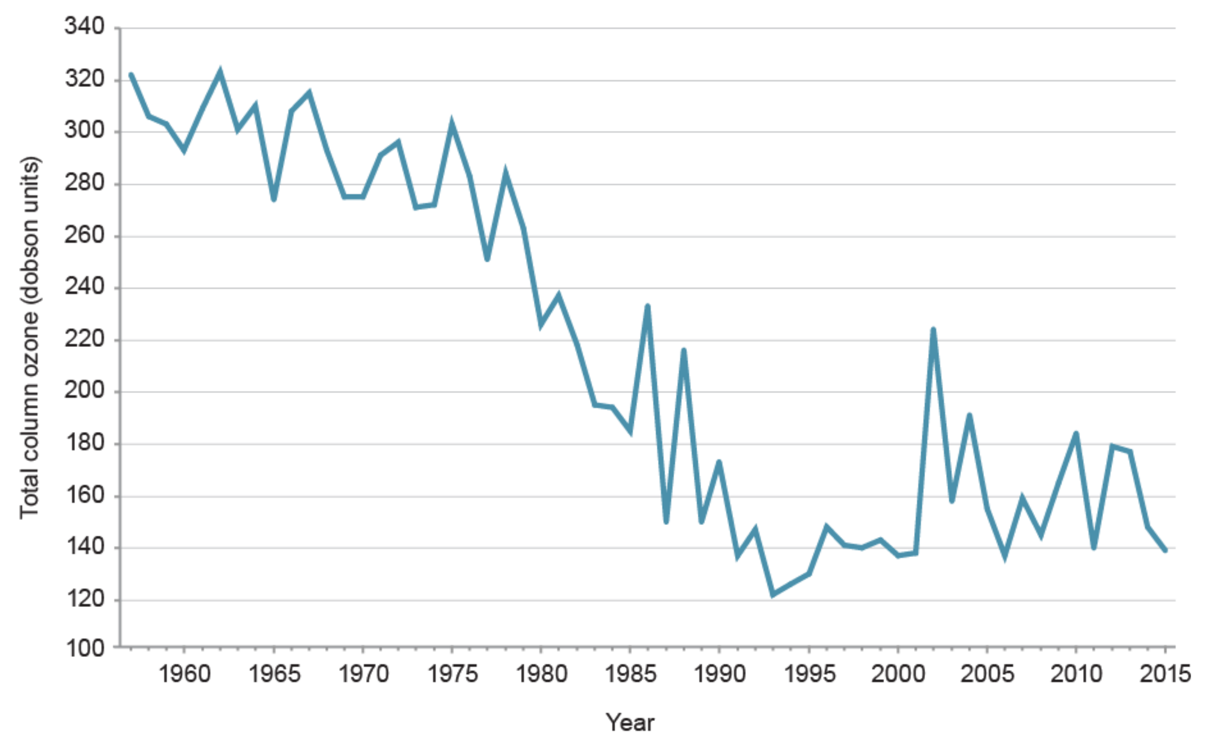

AGAGE = Advanced Global Atmospheric Gases Experiment
Source: Paul Krummel, CSIRO Oceans and Atmosphere; updated from Klekociuk et al. (2014)

**Figure ANT6** Equivalent effective stratospheric chlorine for the Antarctic and Southern Hemisphere mid-latitudes derived from AGAGE global measurements of all major ozone depleting substances and World Meteorological Organization 2014 scenarios

Stratospheric cooling associated with the ozone hole, and ozone depletion in general, has led to an overall polewards shift of the Antarctic jet stream (strong westerly winds 7–12 kilometres above Earth's surface), primarily in summer, in turn influencing the route of storms in the high to mid-latitudes and the SAM (see Box ANT2). The wind changes have been linked to regional changes in precipitation (Kang et al. 2011), changes in sea ice around Antarctica (SCAR 2009), warming of the Southern Ocean (SCAR 2009), a local decrease in the ocean sink of carbon dioxide (WMO 2014) and influences on the circulation in the mesosphere (Smith et al. 2010).

Throughout the remainder of the 21st century, the changes on the Antarctic surface brought about by the ozone hole are expected to gradually decrease (WMO 2014). However, the stratospheric effects of greenhouse gas increases will tend to cancel out the effects of ozone recovery, and the jet stream may stay at its current latitude. The interactions of these two competing circumstances are not yet fully understood, and much will depend on the speed of the ozone recovery and the rate of increase of greenhouse gases (McLandress et al. 2011, Polvani et al. 2011, Previdi & Polvani 2014).

**Box ANT3 (continued)**




Source: Data courtesy of Jonathan Shanklin, British Antarctic Survey

Figure ANT7 October monthly average total-column ozone values for Halley Research Station, 1957–2015

Sørsdal Glacier, Vestfold Hills, East Antarctica

Photo by David Barringhaus, 

## Assessment summary 5
### State and trends of the Antarctic atmosphere

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Surface temperature | Long-term measurements exist only at a limited number of sites (primarily since 1957). Satellite remote-sensing measurements primarily began in the late 1970s<br>Annual average temperatures have generally increased throughout Antarctica since 1957, with the most marked warming occurring in the Antarctic Peninsula region and West Antarctica | ↙ | ● | ● | ◆ |
| Tropospheric temperature (surface to tropopause; 0–10 km above ground in polar regions) | Satellite and radiosonde measurements are available; the most extensive and reliable data have been available since the late 1970s<br>A general warming trend, linked to human factors, is taking place in the lower troposphere; the trend decreases towards the tropopause | ↙ | ● | ● | ◆ |
| Stratospheric temperature (tropopause to stratopause; 10–50 km in polar regions) | Satellite and radiosonde measurements are available; the most extensive and reliable data have been available since the late 1970s<br>A general cooling trend is most significant across the Antarctic continent in spring and summer because of the annual formation of the ozone hole | ↙ | ● | ● | ◆ |
| Mesospheric temperature (stratopause to mesopause; 50–85 km in polar regions) | Limited satellite and ground-based remote-sensing data are available; however, there is some evidence of decreasing temperatures, but modes of variability make interpretation complex | ? | ◒ | ◒ | ◆ |
| Greenhouse gas concentrations (troposphere) | Few tropospheric measurement sites exist in Antarctica and the subantarctic, but increases in carbon dioxide and methane linked to human factors are apparent | ↙ | ● | ● | ◆ |

## Assessment summary 5 (continued)

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Stratospheric ozone concentration | There are possible signs of recovery (increased concentration of ozone) in spring and summer above Antarctica, but there is also significant interannual variability because of meteorological factors<br>Stronger signs of ozone recovery are expected during the next 1–2 decades | Good, Improving | Adequate | Adequate | Comparable |
| Effective equivalent stratospheric chlorine (EESC) | Improvement (i.e. decrease) in ozone depleting substances (ODSs) is expected in the troposphere<br>Estimates of EESC in the stratosphere are based on the level of tropospheric ODSs, combined with transport modelling | Good, Improving | Adequate | Adequate | Comparable |

For additional information and an accessible version of the assessment summary, see SoE Digital.

**Recent trends**

- Improving
- Deteriorating
- Stable
- Unclear

**Grades**

- **Very good:** Component is unaffected by pressures
- **Good:** Component is affected by pressures and likely to recover in future
- **Poor:** Component is affected by pressures and trends are likely to continue
- **Very poor:** Component is affected by pressures and unlikely to recover in future

**Confidence**

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

## The cryosphere—Antarctic ice sheet and glaciers

The Antarctic ice sheet consists of 3 topographically different regions:

- the Antarctic Peninsula, which reaches further north than any other area in Antarctica
- the West Antarctic Ice Sheet
- the East Antarctic Ice Sheet, which is by far the largest component, extending from about 30°W to about 165°E.

The ice mass budget of the Antarctic continental ice sheet is the balance between mass gained from snowfall, and mass lost by melt from the ice shelves and formation (discharge) of icebergs at the coast. The net mass balance is complex to assess, because changes in snowfall and iceberg discharge vary by region. Abrupt changes have been observed in some coastal regions, including the rapid disintegration of floating ice shelves. This has raised questions about the potential for rapid ice discharge from Antarctica into the sea. Changes in global sea levels and in the freshwater input to the Southern Ocean are the major environmental consequences of changes in the Antarctic ice sheet. There are also possible flow-on effects on global ocean circulation and marine ecosystems.

Methods for measuring ice mass changes for Antarctica fall into 3 main categories:

- The mass budget method uses measured snowfall (input), combined with losses across the periphery (from measured velocity and thickness—output), to compute gains or losses over time.
- A second method monitors surface elevation changes to determine losses (lowering elevation) or gains (rising elevation) and infer mass changes.
- A third method uses satellite measurements of gravitational pull as the instruments pass over the ice to 'weigh' the ice sheet directly.

Each method has advantages and disadvantages, and relies on different data sources. Consequently, the magnitudes of estimates vary; however, most studies now broadly agree within their error estimates.

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (Vaughan et al. 2013) provides a synthesis of several studies and methods. For Antarctica, the loss of mass totalled around 2 gigatonnes (Gt) from 1991 to the end of 2011 (Figure ANT8). It is worthwhile noting that 360 Gt of ice mass converts to around 1 millimetre of sea level rise.

The average loss of ice in 2002–11 was 147 (72–221) Gt per year (Gt/y). This is an increase from a loss of 30 Gt/y in 1992–2001. The average loss during the 2 decades was 88 ± 35 Gt/y, which is consistent with an independent assessment combining several detection methods that found a loss of 71 ± 53 Gt/y during the same period (Shepherd et al. 2012). Shepherd et al. (2012) give a regional separation showing:

- West Antarctic loss of 65 ± 26 Gt/y
- Antarctic Peninsula loss of 20 ± 14 Gt/y
- East Antarctica gain (within errors) of 14 ± 43 Gt/y.

Studies since IPCC AR5 (McMillan et al. 2014, Harig & Simons 2015) give varied results from a range of methods, underscoring considerable remaining uncertainties, including those driven by the impact of interannual variability on studies with limited temporal scope (Gorodetskaya et al. 2014, Paolo et al. 2015).

The broad picture remains one of overall ice loss from Antarctica, dominated by the West Antarctic Ice Sheet and the Antarctic Peninsula, with accelerating losses likely regionally in West Antarctica (Sutterley et al. 2014, Harig & Simons 2015). The situation for the East Antarctic Ice Sheet is more ambiguous, ranging from close to balance to potentially gaining considerable net mass (King et al. 2012, Harig & Simons 2015). However, even mass gains are not uniform, and some parts of the sheet are likely to lose mass.

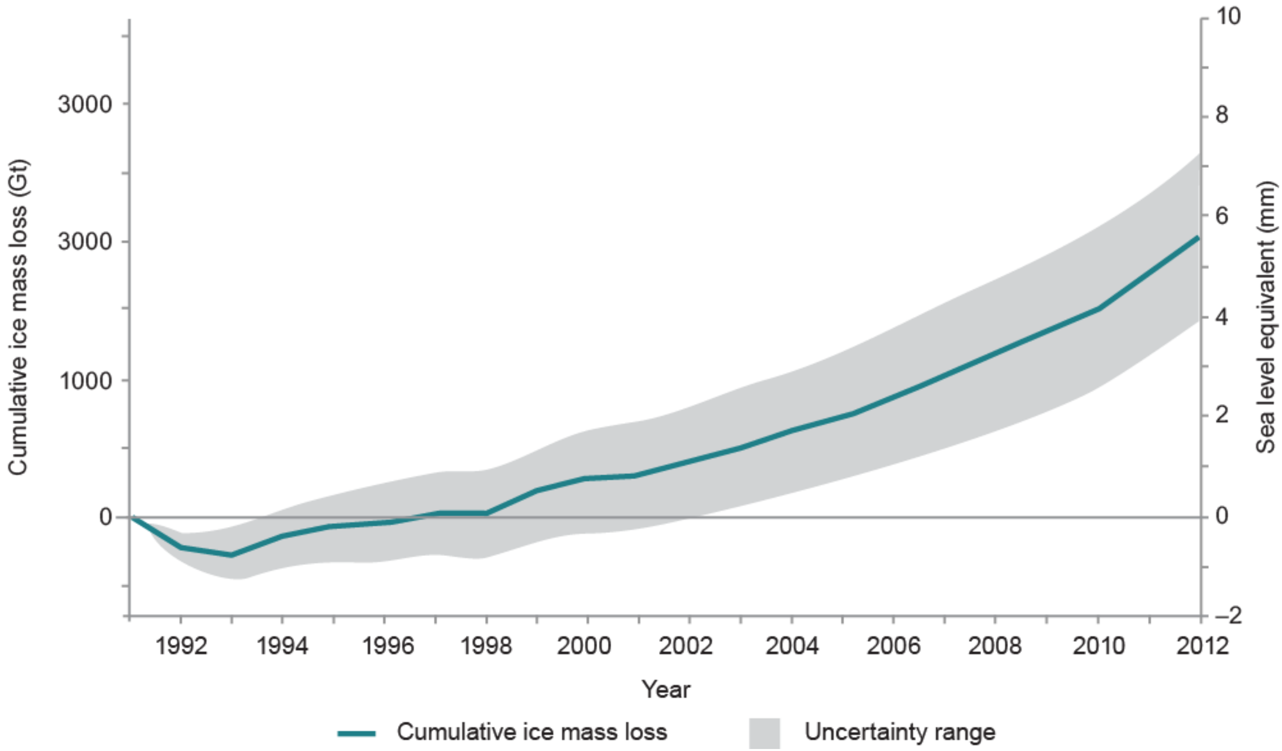
Change is also seen in the ice shelves that fringe the continent. Ice shelves consist of floating ice where the continental ice discharges to the ocean. More than 80 per cent of the continental ice drains through such floating ice (Pritchard et al. 2012), which impedes the flow of ice discharge from the grounded ice behind. Although removal of floating ice has no direct impact on sea level, the removal of ice shelves allows for accelerated discharge from the continent, with a consequent impact on sea level.

Several studies analysing satellite measurements of the surface height of ice shelves have established that a large percentage of Antarctica's ice shelves are thinning (Pritchard et al. 2012), with large interannual variability (Paolo et al. 2015). The total Antarctic ice-shelf volume for 2003 to the end of 2011 decreased on average by 310 ± 74 cubic kilometres per year. This compares with just 25 ± 64 cubic kilometres per year for 1994–2002. The dominant driver of ice-shelf thinning in most cases is believed to be increased ocean melting (Pritchard et al. 2012, Dutrieux et al. 2014). However, atmospheric processes may also be important, particularly for lower-latitude ice shelves in rapidly warming regions such as the Antarctic Peninsula (Cook & Vaughan 2010).

The largest ice-shelf thinning is currently seen in West Antarctica, with more modest changes in East Antarctica. For 1994–2002, the volume of the East Antarctic ice shelf increased by 148 ± 45 cubic kilometres per year. This reversed for 2003–11, with a volume loss of 56 ± 37 cubic kilometres per year. West Antarctica showed accelerating loss for the 18 years to the end of 2011 (Paolo et al. 2015).

In some regions, ice-shelf thinning and loss carry additional significance for future mass loss because of potential instability of the ice sheet. In areas where ice is grounded below sea level on a bed that deepens inland, initial ice retreat, once triggered, can lead to accelerated discharge and further retreat, which is irreversible (Schoof 2007). Some studies indicate that this process is already under way in regions of West Antarctica (Rignot et al. 2014), and reflects the connection between ice-shelf and ice-sheet losses in West Antarctica.

Although this process is yet to be seen in East Antarctica, recent work mapping the bed beneath the East Antarctic Ice Sheet reveals extensive areas grounded below sea level that may be similarly vulnerable to loss (Roberts et al. 2011, Young et al. 2011, Fretwell et al. 2013). In East Antarctica, 2 regions have been identified where future large-scale retreat could




Gt = gigatonne; mm = millimetre
Source: Adapted from Figure 4.16 of Vaughan et al. (2013)

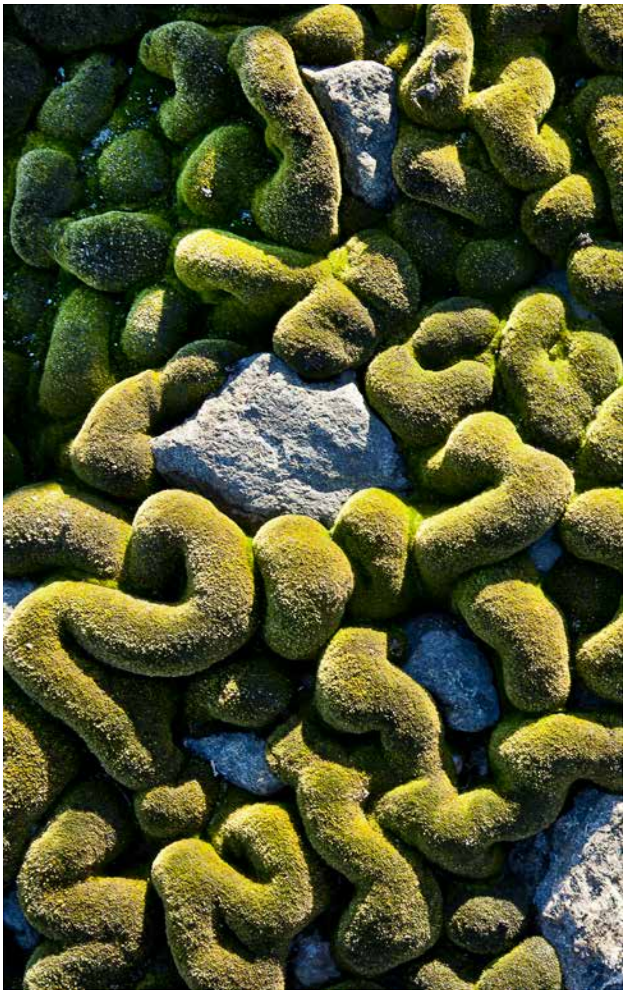
**Figure ANT8** Annual average estimated cumulative ice mass loss and sea level equivalent, 1992–2012 occur. The Wilkes Subglacial Basin and the Aurora Subglacial Basin each cover extensive areas of ice grounded more than a kilometre below sea level. Ice thinning and loss in the margins of these regions have the potential to lead to large-scale retreat on centennial timescales (Golledge et al. 2015, Pollard et al. 2015).

The Totten Glacier ice shelf and Moscow University ice shelf are of interest because they drain a large region of the interior (the largest by volume in East Antarctica), which includes large areas grounded below sea level that could be subject to unstable retreat (Greenbaum et al. 2015). The changes to the East Antarctic ice shelf noted above (Paolo et al. 2015) are modest, and do not yet indicate that processes of loss seen in West Antarctica are under way. Studies indicate that large interannual and decadal variability in the Totten Glacier ice shelf is a response to increases in ocean temperature (Gwyther et al. 2014). Further detailed investigation of the bed beneath Totten Glacier is required to establish potential future response and vulnerability, but recent work suggests that large-scale ice retreat in East Antarctica has occurred in the past (Mackintosh et al. 2014).

The influences of climate change on Antarctica are also illustrated by events in the Antarctic Peninsula region. The Antarctic Peninsula has experienced one of the highest regional temperature increases on the planet (2.8 °C in 50 years). Several floating ice shelves in that region have recently collapsed abruptly—for example, the Larsen B ice shelf collapsed in March 2002, and the Wilkins ice shelf started to disintegrate in March 2008 (Steig et al. 2009, Humbert et al. 2010). By 2009, the Antarctic Peninsula had lost about 28,100 km$^2$ from the 152,200 km$^2$ of ice shelves present in the 1950s (Cook & Vaughan 2010). With the buttressing effect of grounded ice shelves gone, glaciers adjacent to the collapsing ice shelves now flow around 3 to 4 times faster into the ocean (Scambos et al. 2003, Rignot 2008). This increase in the discharge of grounded ice from the ice sheet to the ocean is contributing to sea level rise.

Glaciers on Heard Island are continuing to retreat. There have been 5 complete aerial inventories of Heard Island glaciers since 1947. In the 1940s, the island had a total glaciated area of 288 km$^2$ (Ruddell 2006). This decreased to 256 km$^2$ in the late 1980s (Ruddell 2006)—an 11 per cent loss. By the late 2000s, the glaciated area had decreased further to 231 km$^2$ (Harris 2009, Lucieer et al. 2009).

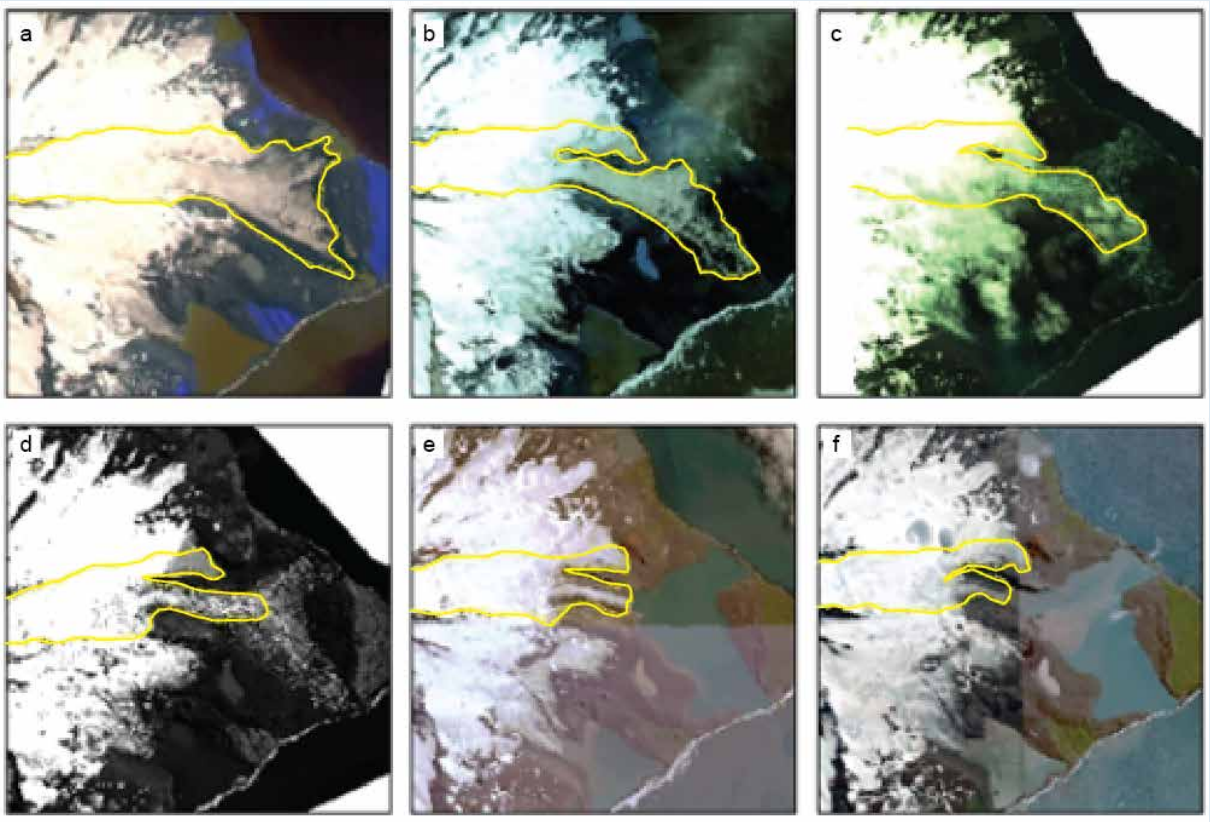
Physiographic and orographic effects on Heard Island have resulted in the glaciers on the leeward (eastern) and windward (western) side reacting differently to changes in the climate. The most recent surveys indicate that the glaciers on the leeward side of the island continue to retreat at a more rapid rate than those on the windward side. Brown Glacier, on the eastern side of the island, decreased from approximately 6.2 km$^2$ in 1947 to 4.4 km$^2$ in 2004—a 29 per cent loss in area (Thost & Truffer 2008). Recent studies have shown that the area of Brown Glacier decreased to 3.6 km$^2$ in 2008 (Harris 2009, Lucieer et al. 2009), and had decreased even more by 2014 (Donoghue 2016). The nearby Stephenson Glacier has also shown recent ice loss (Box ANT4).



Moss bed near Mawson Station

## Box ANT4 Retreat of Stephenson Glacier on Heard Island

A series of satellite images has highlighted the dramatic retreat of Stephenson Glacier on the eastern side of Heard Island from 1947 to 2014 (Figure ANT9). Comparing aerial surveys in 1947 with 1988 SPOT satellite imagery shows that Stephenson Glacier decreased by 4.6 square kilometres ($km^2$; 18 per cent) between 1947 and 1988. By 1997, it had lost a further 2.1 $km^2$ (10 per cent), which opened up a 6.5 $km^2$ lagoon (Ruddell 2006). By 2000, there was a further retreat of 0.1 kilometres (Ruddell 2006). This shrinkage was not steady—the northern margin experienced a dramatic acceleration (to about 100 metres per year) in retreat from 1987 to 2000 (Kiernan & McConnell 2002). Retreat continued and, in 2006, a waterway opened between the 2 proglacial lagoons (lagoons formed during the retreat of a melting glacier) that had formed near the terminus of Stephenson Glacier. Between 2006 and the early 2010s, the retreat continued. The waterway increased in size (to 8.7 $km^2$ in 2012 and 9.3 $km^2$ in 2014), and the glacier area decreased by 1 $km^2$ between 2012 (10.9 $km^2$) and 2014 (9.9 $km^2$) (Donoghue 2016).




Note: The yellow glacier outlines are estimates and are for illustration of change only.
Source: SPOT imagery courtesy of the Australian Antarctic Data Centre; © Centre National d'Etudes Spatiales, 1988, all rights reserved. DigitalGlobe 2003, 2006 and 2008 imagery courtesy of the Australian Antarctic Data Centre; © DigitalGlobe, all rights reserved. DigitialGlobe 2012 and 2014 imagery © DigitalGlobe

**Figure ANT9** Satellite imagery from Heard Island illustrating the retreat of Stephenson Glacier and the opening of Stephenson Lagoon between 1988 and 2014: (a) 9 January 1988 SPOT image; (b) 17 January 2003 Quickbird image; (c) 30 January 2006 Quickbird image; (d) 23 March 2008 Worldview-1 image; (e) 2 February 2012 GeoEye-1 image; (f) 6 February 2014 GeoEye-1 image

## The cryosphere—sea ice

Sea ice is the frozen surface of the ocean. It covers, on average, approximately 3 million km$^2$ of the Southern Ocean each summer and about 18.5 million km$^2$ each winter (or 0.8–5.2 per cent of the global ocean's surface area) (Comiso 2010). This cover forms a crucially important component of the global cryosphere and climate system. Sea ice and its snow cover insulate the ocean from heat loss to the atmosphere and significantly raise the ocean surface albedo (reflectivity). Thus, incoming solar radiation is effectively reflected. Sea ice also provides a barrier to the exchange of momentum and gases, such as $CO_2$ and water vapour, between the ocean and the atmosphere. Moreover, brine (salty) water rejected by growing sea ice modifies the ocean density structure, which plays a key role in driving global ocean circulation (see Global importance of Antarctica).

Sea ice also dominates the seasonal physical and chemical dynamics of the high-latitude Southern Ocean, and plays a crucial role in marine ecosystem structure and function. Plants and animals at all trophic levels are highly dependent on sea ice for a variety of reasons. For example, in shallow waters, sea ice controls the amount of light that is available to photosynthesising organisms (Clark et al. 2015a), while marine mammals and seabirds use it as a habitat (Ainley et al. 2003). The pulse of fresh water into the ocean from its seasonal melt is a major driver of intense algal blooms around the high-latitude Southern Ocean each late spring to summer.

Any substantial changes in sea ice coverage and properties therefore have wide-ranging and lasting climatic, meteorological, physical, ecological and human impacts.

Given its close association with patterns of atmospheric and oceanic temperature and circulation, sea ice is a sensitive passive indicator of climate change and climate variability. It is also a key modulator of such change and variability through complex feedback processes within the atmosphere, termed the ocean–sea ice interaction system.

Sea ice itself is made up of 2 main components. The most extensive is 'pack ice', which is made up of individual pieces called 'floes', and is in constant motion in response to winds and ocean currents. The other main component is 'fast ice', which forms as a narrow band of stationary sea ice (up to about 150 kilometres wide) that is confined to coastal margins, where it is held in place by grounded icebergs and/or in sheltered embayments.

The ratio of fast ice to overall sea ice changes with season. In summer, the percentage of fast ice can be higher than in winter and the proportion of pack ice is significantly reduced. Variability in the extent of fast ice is higher in summer than in winter (Fraser et al. 2012). Narrow fast ice is of key significance as a stabilising influence on the floating ice sheets in certain locations (Massom et al. 2010) and is an important habitat for many organisms (Massom & Stammerjohn 2010). For Antarctic operations, sea ice can create significant shipping and logistical challenges. For example, sea ice can be an aid or impediment to station resupply in the AAT, depending on its extent, duration and thickness.

Sea ice in the Arctic and Southern oceans has different characteristics, based on differences in the geographical settings and the processes affecting them. During the past few decades, the sea ice in the 2 oceans has displayed dissimilar changes with time. Whereas sea ice in the Arctic Ocean is largely enclosed by land masses, Antarctic sea ice surrounds the continent. It is largely unconstrained and highly dynamic because it is exposed to Southern Ocean wind and waves.

Based on satellite data extending back to 1979, annual sea ice extent in the Arctic decreased by 3.8 ± 0.3 per cent (or 0.48 million km$^2$) per decade from 1979 to 2012 (Vaughan et al. 2013), with particularly rapid loss in summer (about 30 per cent has been lost during the summers since the late 1970s) (Stroeve et al. 2012). This change has wide-ranging climatic and ecological consequences. In contrast and during the same period, there has been a small but significant net increase in the overall Antarctic sea ice extent of 1.5 ± 0.2 per cent (or about 0.17 million km$^2$) per decade (see Box ANT4 for a discussion of recent annual records). Note that this slight net increase is the sum of strong regional differences—that is, substantial decreases in the Bellingshausen–Amundsen seas sector and a larger increase in the Ross Sea, which dominate the overall trend (Comiso et al. 2011, Parkinson & Cavalieri 2012, Hobbs et al. 2016a). Proxy information from ice-core and historical whaling records suggests that Antarctic sea ice coverage declined significantly in the decades before the late 1950s to early 1960s (Curran et al. 2003, Hobbs et al. 2016b).

Contrasting regional patterns of change are also apparent in the seasonality (annual duration) of Antarctic sea ice coverage. In the north-eastern and western Antarctic Peninsula, and southern Bellingshausen Sea region, later ice advance and earlier retreat led to a shortening of annual sea ice duration by 100 ± 31 days (a trend of –3.1 ± 1.0 days per year) from 1979–80 to 2010–11 (Stammerjohn et al. 2012). These changes have had impacts on the marine ecosystem, particularly on phytoplankton communities (Montes-Hugo et al. 2009). The opposite is true in the western Ross Sea, where the ice season has lengthened substantially—by 79 ± 12 days (at 2.5 ± 0.4 days per year) (Stammerjohn et al. 2012).

Across East Antarctica (within the AAT), a small increasing trend in sea ice extent (Cavalieri & Parkinson 2012) is accompanied by patterns of change in sea ice annual duration that are generally of a lower magnitude and zonally complex (Hobbs et al. 2016a). From 1979–80 to 2009–10, the annual sea ice duration changed by ±1–2 days per year in some regions of the AAT (Massom et al. 2013a).

Looking to the near-coastal region, the current satellite-derived timeseries of fast ice extent from 2000 to 2008 (Fraser et al. 2012) is too short to support a statement about long-term trends. However, significant changes have been observed during this short period, with a 4.1 ± 0.4 per cent increase each year in the Indian Ocean sector (20°E to 90°E) and a decrease of 0.4 ± 0.4 per cent each year in the sector from 90°E to 160°E. Greater persistence of more extensive coastal fast ice across the Indian Ocean sector from 2004 (Fraser et al. 2012) had a major impact on logistical operations around the resupply of both Mawson Station and the Japanese Syowa Station.

Based on satellite and submarine records, there is high confidence that the average Arctic winter sea ice thickness decreased between 1980 and 2008 (Stocker et al. 2013). In contrast, there is inadequate information to assess whether large-scale sea ice thickness and volume are changing around Antarctica (Vaughan et al. 2013). IPCC AR5 stated that anthropogenic influences are very likely to have contributed to Arctic sea ice loss since 1979 (Stocker et al. 2013). There is current uncertainty as to whether the smaller overall increase in Antarctic sea ice extent is meaningful as an indicator of climate change, because the extent varies so much from year to year and with location around the continent (Stocker et al. 2013) (see Box ANT5). Moreover:

> *There is low confidence in the scientific understanding of the small observed increase in Antarctic sea ice extent due to the incomplete and competing scientific explanations for the causes of change and low confidence in estimates of natural internal variability in that region.* (Stocker et al. 2013)

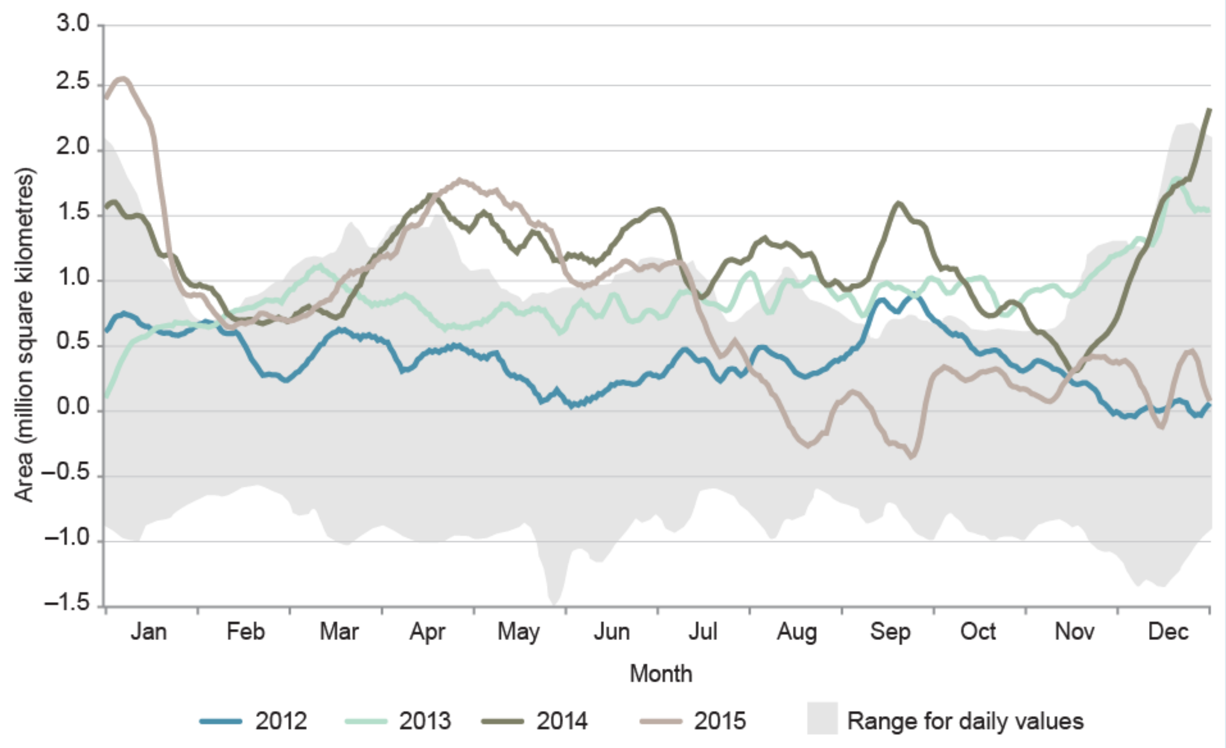
Research published in 2012 found that changing wind speed and patterns, and associated sea ice drift accounted for some of the increase in overall sea ice extent in the Antarctic and its regional contrasts (Holland & Kwok 2012). These wind variations are associated with changes in atmospheric pressure patterns around Antarctica, which have been linked to sea surface temperature anomalies in the tropical Pacific Ocean (Yuan & Martinson 2001, Turner et al. 2009) and North Atlantic Ocean (Li et al. 2014). These findings imply that the recent overall slight growth of Antarctic sea ice coverage is consistent with an Earth that is generally warming (King 2014). Other studies also provide evidence that Antarctic sea ice thickness and volume are changing because of climate change, and suggest reasons, such as the:

- changing patterns of ocean circulation and heat content around Antarctica (Martinson 2012)
- decreasing salinity in the upper ocean because of increased ice-shelf basal melt (Bintanja et al. 2013) and snowfall (Liu & Curry 2010)
- feedback mechanisms involving increased upper-ocean heat storage in spring–summer, because it delays subsequent sea ice advance in autumn (Stammerjohn et al. 2012).

## Box ANT5 Antarctic sea ice extent, 2012–15

In 2012, 2013 and 2014, the overall Antarctic sea ice extent reached well above the long-term average (since 1979 when satellite observations began) of 18.5 × $10^6$ square kilometres ($km^2$). In fact, each of these years set new successive daily records for the greatest ice extent since 1979 (Figure ANT10) (Massom et al. 2013a,b, 2014, 2015). The mechanisms responsible for each of these anomalous extents were, however, quite different, and their examination underlines the complexity of sea ice formation and decay.

In 2012, the net Antarctic sea ice extent remained close to, or slightly above, average for much of the year until late summer. During August and September, strong winds caused a rapid expansion of the ice edge and pushed the ice extent to a new record high. In 2013, different mechanisms appear to have been involved in achieving the subsequent record extent; the early advance of sea ice in the western Ross Sea sector was associated with colder than average sea surface temperatures (SSTs) originating in that region. When it reached lower latitudes, this cold SST anomaly tongue turned eastwards in the Antarctic Circumpolar Current, and wrapped around the northern edge of the sea ice to aid its further expansion as the year progressed. Colder than average SSTs off the ice edge in the Weddell Sea delayed sea ice retreat in late 2013 and drove early advance during 2014. Indeed, greater than average sea ice extent in the Weddell Sea was the main contributor to the well above average net Antarctic sea ice extent in early 2014. As the 2014 season progressed, sea ice expansion pushed further to the east, so that much of the Indian Ocean sector experienced well above average ice coverage for the rest of 2014.




Note: The shaded banding represents the range of daily values for 1981–2010.
Source: National Snow and Ice Data Centre data, analysed by P Reid, Bureau of Meteorology

**Figure ANT10** Five-day running average of daily sea ice extent anomaly (compared with the 1981–2010 average) for the Southern Hemisphere, 2012–15

## Box ANT5 (continued)

During mid-2014, wind-driven ice advance in the western Pacific Ocean and Ross Sea also contributed to the record sea ice extent in 2014. It is currently unknown whether the patterns of sea ice expansion and decay in 1 year influenced the pattern of extent in the following year.

These 3 years of successive record-breaking sea ice extents were followed by an equally interesting year in 2015. For much of early 2015, daily sea ice extents were well above average (Figure ANT10), but there was a dramatic slowing of ice expansion in June. This coincided with the development of a strong El Niño event in the tropical Pacific Ocean, which transported warmer than average waters westwards. El Niño–Southern Oscillation (ENSO) events influence large-scale variability in atmospheric patterns at polar southern latitudes, which in turn determine where sea ice expands more or less rapidly (Yuan 2004). Because 2012–14 was not significantly influenced by the ENSO, more localised (high-latitude) processes tended to dominate the growth and retreat of sea ice at that time. However, with the development of an El Niño in 2015, there was a rapid transition to a different atmospheric synoptic pattern and associated ice growth conditions. In the subsequent months of 2015, as the sea ice distribution responded to these new growth conditions, net sea ice retreated to close to average extents.

Young sea ice along ice margin

Photo by Glenn Jacobson, Australian Antarctic Division, all rights reserved

## Assessment summary 6
### State and trends of the Antarctic cryosphere

| Component | Summary | Assessment grade: Very poor | Poor | Good | Very good | Confidence: In grade | In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|---|---|---|
| Sea ice extent | From November 1978 to December 2012 across the Antarctic, overall, a 1.5 ± 0.3% increase per decade is seen, but there are regionally varying trends (both positive and negative) that are season dependent<br>More certainty exists about the observations than about the environmental consequences. However, proxy information from ice-core and historical whaling records suggests that sea ice coverage declined significantly in the decades before the late 1950s to early 1960s | | | ? | | ● | ● | ◆ |
| Sea ice seasonality | Major and opposing trends are seen in different areas. In the western Antarctic Peninsula and north-western Weddell Sea, later annual advancing of sea ice edge and earlier retreat mean that the sea ice season is shortening, with deleterious effects on ecosystems. Sea ice advance appears more sensitive to climate variability than sea ice retreat. Conversely, the season is longer in the western Ross Sea. The trend patterns across East Antarctica are more complex | | ↙ | | | ● | ● | ◆ |
| Fast ice (sea ice adjacent to land) | Insufficient information exists to determine whether the extent or seasonality of fast ice is changing (current satellite-derived timeseries is too short, and limited to East Antarctica for 2000–08). From 2000 to 2008, there were different responses in the Indian Ocean and western Pacific sectors | Not assessed | | | | ○ | ○ | ◆ |
| Pack ice (ice floes of varying sizes and density characteristics) | Changes to the characteristics of pack ice are likely to have a cascading impact through the ecosystem. At present, there is great uncertainty in large-scale estimates of the thickness distributions of sea ice and its snow cover. Research continues to derive these key quantities from satellite data | | ↙ | | | ◒ | ◒ | ◆ |

# Assessment summary 6 (continued)

| Component | Summary | Assessment grade (Very poor, Poor, Good, Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
| --- | --- | --- | --- | --- | --- |
| East Antarctic Ice Sheet | Overall, mass balance for the East Antarctic Ice Sheet is neutral to positive, unlike the West Antarctic Ice Sheet, which is clearly losing mass. Ice changes at some locations on the coastal margin show significant variability in response to changes in ocean heat and potential vulnerability to irreversible retreat in the long term. The present state of knowledge does not allow us to fully assess state and trend | Not assessed | [Low] | [Low] | X |
| Heard Island and McDonald Islands, and other subantarctic glaciers | Most Heard Island and McDonald Islands glaciers have retreated since 1947: total glacier area decreased from 288 $km^2$ in 1947 to 231 $km^2$ in 2008<br>Rising temperatures and newly exposed terrain led to changes in the distribution of flora | [Poor; Deteriorating] | [Limited] | [Adequate] | [Comparable] |

For additional information and an accessible version of the assessment summary, see SoE Digital.

**Recent trends**

- Improving
- Deteriorating
- Stable
- Unclear

**Grades**

- **Very good:** There are no significant changes in physical or chemical processes
- **Good:** There are some significant changes in physical or chemical processes in some areas, but these are not to the extent that they are significantly affecting ecosystem functions
- **Poor:** There are substantial changes in physical or chemical processes, and these are significantly affecting ecosystem functions in some areas
- **Very poor:** There are substantial changes in physical or chemical processes across a wide area of the region as a result of human activities, and ecosystem functions are seriously affected in much of the region

**Confidence**

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

## The Southern Ocean

The Southern Ocean is changing in ways that are likely to affect regional and global climate, and marine productivity (Rhein et al. 2013). The Southern Ocean has warmed more rapidly and to a greater depth than the global ocean average in recent decades (Böning et al. 2008, Gille 2008, Schmidtko & Johnson 2012, Roemmich et al. 2015), although the warming is less than that observed in the Arctic Ocean (Armour et al. 2016). Most of the Southern Ocean has also freshened, reflecting an increase in precipitation and, possibly, Antarctic ice melt (Böning et al. 2008, Helm et al. 2010). In recent decades, Antarctic bottom water (see Global importance of Antarctica) has warmed, freshened and decreased in volume (Rintoul 2007; Purkey & Johnson 2010, 2012, 2013; van Wijk & Rintoul 2014). Sea ice formation and melting are important drivers of shallow overturning, and changes in sea ice extent may play a role in future changes in circulation near the continent (Bindoff & Hobbs 2016). Increased ocean heat transport has caused Antarctic ice shelves and glaciers to thin and retreat, particularly in West Antarctica, where an irreversible retreat may now be under way (Stan et al. 2012, Joughin et al. 2014, Rignot et al. 2014). The ozone depletion and increase in atmospheric greenhouse gases caused by human activities have resulted in changes in wind patterns, and caused many of the changes observed in the Southern Ocean (Turner et al. 2014).

Global sea levels are rising, primarily because of oceanic uptake of heat, and run-off from melting ice caps and glaciers (Church et al. 2013). The rate of change of sea level has been regionally and globally variable in recent decades because of influences from natural climate variability, particularly the El Niño–Southern Oscillation and the 1991 eruption of the Mount Pinatubo volcano, but is expected to increase because of continuing global warming (Fasullo et al. 2016). From 1993 to 2012, most of the Southern Ocean increased in height, with parts of the Pacific sector showing a modest fall—these changes are consistent with observed changes in ocean heat content (Church et al. 2013).

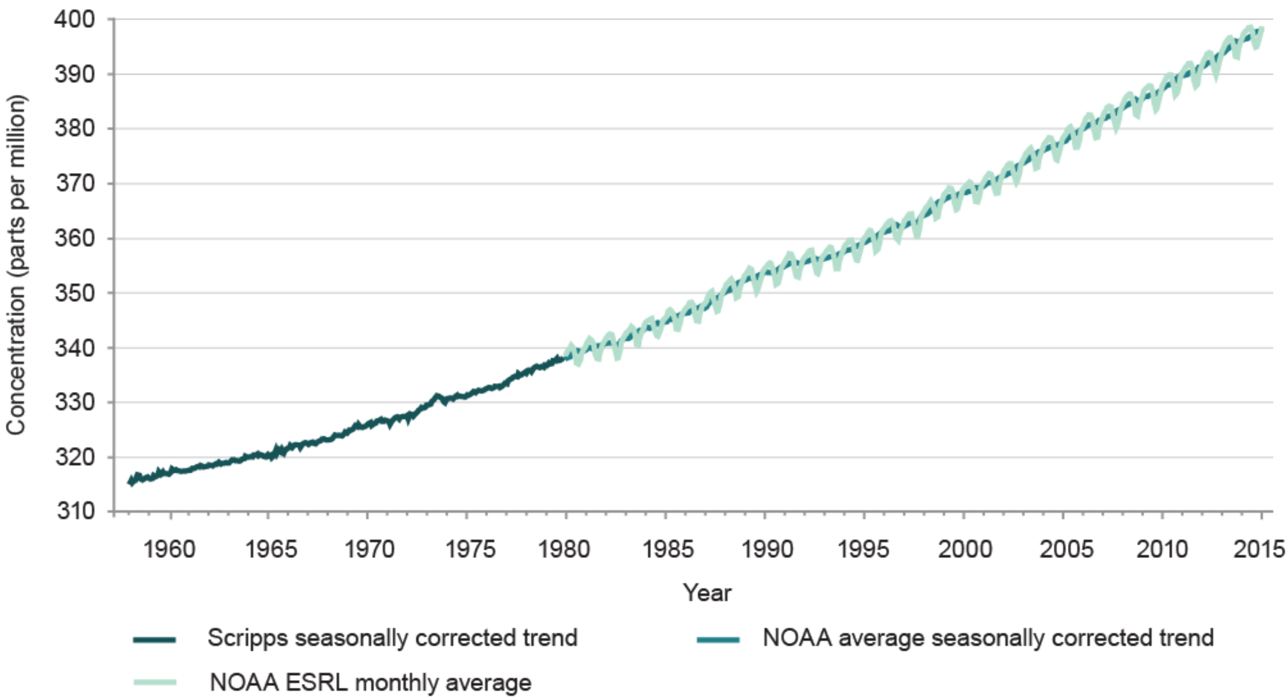
The Southern Ocean is one of the world's largest sinks for atmospheric $CO_2$. Approximately 25–30 per cent of the anthropogenic $CO_2$ released to the atmosphere has been taken up by the world's oceans, some 40 per cent of which has been taken up by cold Southern Ocean waters that lie south of 40°S (Sabine et al. 2004, Doney et al. 2009a, Takahashi T et al. 2009).

Although this ocean uptake reduces the accumulation of $CO_2$ in the atmosphere, it also causes ocean acidification (see Human influences on Antarctica). Atmospheric $CO_2$ levels are currently higher than they have been for at least the past 25 million years (Dolman et al. 2008) and reached approximately 397 parts per million in 2014 (Le Quéré et al. 2015; Figure ANT11). From 2005 to 2014, the rate of global $CO_2$ emissions from fossil fuels and industry grew by 2.2 per cent per year, compared with 3.2 per cent per year for 2000–09 and 1 per cent per year for 1990–99 (Le Quéré et al. 2015). Of the approximately 9 Gt of $CO_2$ emitted each year from 2005 to 2014 (Le Quéré et al. 2015):

- around 33 per cent was taken up by land (mainly from forest growth)
- around 29 per cent was taken up by the oceans
- the remainder contributed to the increase in atmospheric $CO_2$.

Compared with pre-industrial times (before the 1700s), when $CO_2$ levels were around 280 parts per million, the pH of the Southern Ocean has dropped from pH 8.2 to pH 8.1, indicating increased acidity (Howard et al. 2009). Thus, although the ocean is still alkaline, it is becoming more acidic. This increase is linked to the dramatic rate of increase of $CO_2$ in the atmosphere; the rate is 100 times greater than during any other time in the past 650,000 years (Howard et al. 2009).

Ocean acidification is likely to affect the efficiency of the Southern Ocean as a sink for atmospheric $CO_2$, and will also have profound impacts on species and ecosystems (Doney et al. 2009a).




NOAA ESRL = National Oceanic and Atmospheric Administration Earth System Research Laboratory
Note: The deseasonalised global average levels from 2 measurement networks (Scripps Institution of Oceanography and NOAA) are shown by the coloured solid lines. The mean seasonal cycle measured from 1980 by the NOAA network is shown by the light blue line.
Source: Le Quéré et al. (2015)

**Figure ANT11** Monthly average surface atmospheric carbon dioxide concentrations, 1958–2015

# Assessment summary 7

## State and trends of the Southern Ocean

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Ocean temperature | The Southern Ocean has warmed in recent decades; warming is strongest in the upper ocean | Good ↙ | ● | ● | ◆ |
| Ocean acidity | Polar pH levels are changing twice as fast as tropical ones. Pre-industrial acidity has dropped from pH 8.2 to pH 8.1 | Good ↙ | ● | ● | ◆ |
| Ocean salinity | The salinity of the Southern Ocean has reduced in recent decades | Good ↙ | ● | ● | ◆ |
| Southern Ocean circulation and structure | Changes in wind forcing caused by human activities (ozone depletion and increased greenhouse gases) have driven a polewards shift of Southern Ocean currents, contributing to warming. Antarctic bottom water has warmed, freshened and decreased in volume, and this has likely influenced large-scale circulation. Changes in patterns in sea ice formation and melting may influence shallow overturning near the continent | Good ↙ | ● | ● | ◇ |
| Sea level | Global sea levels are rising because of uptake of heat by the oceans, and run-off from ice caps and glaciers. The rate of sea level change shows regional and global variation with time because of particular aspects of climate variability | Good ↙ | ● | ● | ◇ |

For additional information and an accessible version of the assessment summary, see SoE Digital.

## Assessment summary 7 (continued)

**Recent trends**

- ↗ Improving
- ↙ Deteriorating
- — Stable
- ? Unclear

**Grades**

- **Very good:** There are no significant changes in physical and/or chemical processes as a result of human activities
- **Good:** There are some significant changes in physical and/or chemical processes as a result of human activities
- **Poor:** There are substantial changes in physical and/or chemical processes as a result of human activities that significantly affect ecosystem functions in some areas
- **Very poor:** There are substantial changes in physical and/or chemical processes as a result of human activities that significantly affect ecosystems functions in much of the region

**Confidence**

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

# The living environment

Given its extreme conditions, the Antarctic has a surprising diversity of ecosystems. Antarctica is the coldest, windiest, driest and highest continent. Only about 0.18 per cent of the continent is ice-free. Since plants, the invertebrates associated with them and most seabirds require bare rock as growth or breeding habitats, the ice-free areas are important for their survival. The limited availability of ice-free areas means that many species are often found breeding close to each other.

Because Antarctica and the Southern Ocean are distinct in their physical properties from other parts of the world, they have many endemic species. For example, 100 per cent of the nematodes, 50 per cent of the lichens and more than 30 per cent of the terrestrial invertebrates on the Antarctic continent are found nowhere else (Pugh & Convey 2008), and the dominant fish species in the Southern Ocean are endemic to the region (Cheng et al. 2003).

## Marine environments

The climate of the Southern Ocean and its circulation play a central part in the global carbon cycle (IPCC 2013). The Antarctic marine ecosystem, comprising the area south of the Antarctic Polar Frontal Zone, is a productive area that many species—such as seals, whales and seabirds—depend on. It also supports valuable commercial fisheries. Antarctic krill is the keystone species in the Antarctic marine ecosystem (Kawaguchi & Nicol 2014). It is expected that krill, together with other creatures at the lower trophic levels, will experience the greatest effects of a warming ocean (Constable et al. 2016). Although metabolic rates of such animals may initially increase, if warming continues, this effect is likely to be reversed and lead to a decrease in production because of a lack of available nutrients or increased predation by higher trophic levels. Conditions in the Southern Ocean are changing at a rate that exceeds the global average. But it is difficult to assess possible future states, because current climate models do not provide good simulations of the events in the southern regions (Constable et al. 2016).

### The pelagic environment

Marine microorganisms form the basis of Antarctic food webs. They include vast numbers of bacteria, phytoplankton (single-celled plants) and zooplankton (single-celled animals), and comprise around 90 per cent of the living matter produced in Antarctic waters. Bacterial communities occur throughout the water column of the Southern Ocean, as well as in the sea ice. These tiny organisms provide food for zooplankton, krill, and fish and other vertebrates. The biomass of phytoplankton is estimated to be 5 billion tonnes; there are also about 1.2 billion tonnes of bacteria and some 0.6 billion tonnes of protozoans (Marchant 2002). The number of species for many groups of organisms is still unknown. The Census of Antarctic Marine Life found many new species that are still being identified; this is particularly true for bacteria (Gutt et al. 2010). The phytoplankton (diatoms, dinoflagellates, cilliates and other protists) in the Southern Ocean comprise 560 known species (Scott & Marchant 2005), but only a few are widely dominant, and their community structure is not constant throughout the Southern Ocean (Ishikawa et al. 2002). One group, the diatoms, are responsible for most of the primary production. Their level of productivity varies greatly with season; it is highest in spring and early summer (Westwood et al. 2010). Most of their production is consumed or recycled by bacteria and protozoa (Becquevort et al. 2000).

Intense phytoplankton blooms occur in Antarctic waters during spring and summer, when increasing sunlight melts the sea ice and warms the ocean. The high light conditions and high nutrient content in the surface waters are ideal conditions for the growth of phytoplankton. During photosynthesis, phytoplankton take up $CO_2$ that dissolves in the ocean from the atmosphere. They also produce dimethyl sulfide, a natural aerosol, which is released into the atmosphere. Here, it helps cloud formation, because it acts as a cloud condensation nucleus (Woodhouse et al. 2010), and increases the reflectance of solar radiation from Earth. Thus, these single-celled organisms not only support the food web but also influence the biochemistry of the ocean, and play a vital role in affecting global climate by reducing $CO_2$ in the atmosphere and altering global heat balance. In turn, they are affected by anthropogenic changes to the atmosphere. Ozone depletion has increased the damage phytoplankton experience from increased ultraviolet B radiation. Anthropogenic environmental changes are likely to have far-reaching impacts on the Antarctic marine ecosystem.

A keystone species in the Southern Ocean ecosystems is krill—small shrimp-like crustaceans that rank highly on the menu of many top predators, such as fish, whales, seals, penguins and flying seabirds. Krill feed on phytoplankton and sometimes small zooplankton. Copepods (minute crustaceans) also graze on phytoplankton, making up most of the biomass in many pelagic zooplankton communities, and may be an alternative food source for higher predators. As a cold-water species, krill is particularly vulnerable to the warming of the Southern Ocean, particularly in conjunction with ocean acidification. Krill hatching success decreases with increasing $CO_2$ levels in the water (Kawaguchi et al. 2013).

Zooplankton comprise species that build shells made of aragonite or calcite. An increase in the acidity of the Southern Ocean is likely to first affect these planktonic species. $CO_2$-driven acidification reduces the availability of the carbonate ion that calcium carbonate ($CaCO_3$) shell–making organisms require to build their shells. Consequently, many organisms now have thinner shells and reduced growth rates (Doney et al. 2009b). The rapid change in the acidity of the ocean is already affecting calcifying organisms—for example, the shells of planktonic organisms in the Foraminifera are now about one-third lighter than in pre-industrial times (Moy et al. 2009). However, the AAD-led Southern Ocean Continuous Plankton Recorder Survey has observed very large blooms of planktonic Foraminifera, especially in the southern summer of 2004–05, when they dominated the surface plankton (up to 80 per cent of abundance) through much of the Southern Ocean south of Africa to Australia (Takahashi K et al. 2010).

It is important to note that different species respond differently to environmental changes. Although some are likely to be affected adversely, others might benefit from the changes (Iglesias-Rodriguez 2008). For example, diatoms, a major group of algae, may benefit from some of the environmental changes, such as increased stratification of the water column (Constable et al. 2016). However, changes at the base of the food web, such as to other phytoplankton and zooplankton, can potentially radically change the dynamics of the Southern Ocean ecosystem, and it is still unclear whether (or how) higher-order organisms will be affected.

### The benthic environment

The bottom of the Southern Ocean offers rich habitats on hard and soft substrata to many species, which grow much more slowly than their temperate counterparts. Both fixed and mobile species, including sponges, molluscs, starfish and worms, are highly diverse and abundant. Bryozoans (moss animals) are particularly diverse and are highly endemic (Brandt et al. 2007). Based on the outcomes of the Census of Antarctic Marine Life, CCAMLR proclaimed 2 vulnerable marine ecosystems to protect species assemblages and aid the conservation of biodiversity (SCAR 2010).

At depth, environmental conditions are stable, and species communities and assemblages do not appear to change much. A threat to the biodiversity of the benthos is iceberg grounding. Icebergs break off glacier snouts and ice shelves, and often get caught in currents that transport them away from their calving sites. In shallow water, icebergs can become grounded, which stirs up the sediment and crushes benthic fauna that is in the way. The damage caused by grounding icebergs tends to be local. So far, these grounding events appear to have contributed to species diversity in benthic communities by creating a patchwork of areas that are in different stages of recovery. However, an increased rate of iceberg calving may cause more frequent disturbances to benthic areas and not leave sufficient time for populations to recover. Fast-growing organisms are likely to have a better chance of resettling than slow-growing ones. In the long term, although the benthos may not remain scarred and unpopulated, its communities may change in their species composition, and some organisms are likely to be lost, at least locally.

### The nearshore benthic environment

Adjacent to coastal ice-free areas are the shallow nearshore benthic environments, which are teeming with life (Clarke 2008). This environment is thought to be under threat from increasing human activities and changing environmental conditions in some areas (Clark et al. 2015b).

## Terrestrial environments

Antarctica is almost entirely covered in permanent ice and snow, and permanent or seasonal ice-free areas of exposed rock are rare (21,700 $km^2$ out of 14 million $km^2$) (Bockheim 2015, Burton-Johnson et al. 2016). Ice-free areas are either isolated mountain tops, mountain ranges, dry valleys, exposed coastal fringes or offshore subantarctic islands.

Air temperatures vary with latitude and altitude. At coastal locations on subantarctic islands, average air temperatures are generally around 2–6 °C, with a range of less than 10 °C (Bergstrom et al. 2006a). Coastal average air temperatures around Australia's Antarctic stations are milder than the interior and can rise to more than 0 °C in summer, but drop to less than –30 °C in winter. The region between 60°S and 70°S is the cloudiest on our planet, with 85–90 per cent cloud cover throughout the year (Bargagli 2005). Winds that are generated in the interior of the continent drive cold, dense air towards the coast. Smooth ice surfaces on the ice plateau and steep slopes at the coast reduce friction and intensify katabatic winds, which are strongest at the edge of the continent (often 180 kilometres per hour or more).

The main requisite for life in Antarctica is the availability of liquid water (Bergstrom et al. 2006b), which is mediated by solar radiation, temperature, and ice or snow cover (Convey et al. 2014). Most life occurs in ice-free areas. More than 99 per cent of Antarctica's biodiversity is concentrated in areas that are permanently ice-free. In both the onshore and island realms, terrestrial habitat can be considered as islands or archipelagos surrounded by ice and/or sea, with most terrestrial biodiversity located near the coast (Frenot et al. 2005).

Within ice-free areas in Antarctica, terrestrial habitats include soft sediments (clays, sands, gravels), and habitats within, under and on top of exposed rock. In some areas, vegetation occurs where ancient penguin colonies used to be, or on extensive humic material derived from plants and built up over thousands of years. Visible life is mainly, although not completely, confined to lower altitude areas in coastal regions (Convey et al. 2014). In the subantarctic, many terrestrial ecosystems are built on extensive and often ancient peats, as well as on soil, gravel and rocks. Lakes and drainage systems are an important element of most ice-free areas of Antarctica and the subantarctic islands. A network of subglacial lakes also occurs across the Antarctic continent, and the lakes are likely to have biota in them (Kennicutt & Siegert 2011).

Most ice-free areas in Antarctica are young (less than 10,000 years old), but some ice-free refuges have been present for millions of years, allowing life to persist for multiple glacial cycles. Recent research has highlighted the role of volcanic areas in sustaining continuous conditions for life during past ice ages (Fraser et al. 2014). By using continent-wide biodiversity databases and ecological informatic approaches, recent biodiversity analyses have shown substantial spatial diversity across the continent, with 15 distinct ecoregions now recognised on the continent itself, and another 8 across the Southern Ocean islands (Terauds et al. 2012). Diversity within species, at local spatial scales of hundreds of metres to hundreds of kilometres, is also being discovered through phylogeographic approaches, reflecting the effects of both older glacial history and more recent events.

Higher vertebrates that use ice-free areas in Antarctica for nesting include Adélie penguins, and flying seabirds such as Antarctic petrels (*Thalassoica antarctica*) and snow petrels. Some seals use coastal Antarctic beaches as haul-out areas and fast ice (sea ice adjacent to land) for breeding. The subantarctic islands are major breeding and resting grounds for many species of penguin, flying seabirds (such as albatrosses and petrels), and fur and elephant seals. Most vertebrates, such as seabirds, penguins and seals, rely on the ocean for food.

Although the species richness of higher plants and insects is low in Antarctica, plants such as mosses and lichens are relatively well represented (Peat et al. 2007), as are invertebrates such as springtails, nematodes, tardigrades and mites (Velasco-Castrillon et al. 2014). Recent studies have also highlighted the diversity of microbial life in terrestrial Antarctica, with high-throughput DNA sequencing and metagenomic techniques (both used to analyse genomes) clearly showing that microbial diversity is much higher than previously thought (Fierer et al. 2012). The microbiotic communities (cyanobacteria, bacteria, fungi, viruses) are species-rich compared with communities elsewhere, and exist in streams, lakes, moss cushions and soil. Many microorganisms, such as some species of diatoms and cyanobacteria, are endemic to Antarctica (Vyverman et al. 2010). The environmental conditions that these species face across much of the continent are often described as some of the harshest on the planet. To survive these conditions, many of these species have developed unique physiological adaptations, including the ability to survive desiccation or freezing.

The subantarctic islands represent some of the rarest ecosystems on Earth. Subantarctic islands have a range of origins and ages, from remnant Gondwanan continental elements (South Georgia) to sea-floor material (Macquarie Island) that uplifted 600,000 years ago. There are at least 16 active volcanoes in the subantarctic and Antarctica, including (Bergstrom et al. 2006b):

- Big Ben on Heard Island in the southern Indian Ocean
- Mount Erebus and Mount Melbourne in the Transantarctic Mountains adjacent to the Ross Sea in Antarctica.

Terrestrial ecosystems are isolated from each other, and their floral and faunal communities are less complex than those at lower latitudes (Bergstrom & Chown 1999) or the Arctic region. For example, there are 900 species of vascular plants in the Arctic (Bliss 1971), compared with 2 species in the Antarctic (Komárková 1985).

Flora and invertebrate fauna are well developed on the subantarctic islands (see Box ANT6), with vegetation types ranging from tundra-like, sparse fellfields on the uplands to lush grasslands and herbfields on the coast. On the New Zealand subantarctic islands, lower-lying areas also have shrub, heath and coastal woodlands. Species diversity increases with decreasing latitude, but it is still lower in the subantarctic zone than in temperate regions, although species are often highly abundant. Compared with the terrestrial flora of Antarctica, subantarctic vascular plants are diverse and include tens of flowering plant species, including megaherbs and grasses. Mosses and liverworts are also a significant component of the landscape (Bergstrom & Chown 1999). Microbes, algae, fungi and lichens are also critical elements of subantarctic ecosystems. Trees and shrubs are absent from the Australian subantarctic islands, but do occur on other subantarctic islands. The faunal diversity is dominated by invertebrates and includes microarthropods, such as springtails and mites, and insects, including beetles and flies.

In Australia, Macquarie Island was the only breeding site for albatrosses or giant petrels where introduced species—rabbits, rats and mice—were present. An eradication program was successfully completed in 2012, and no rabbits or rodents have been sighted since. The populations of nontarget species most affected by the baiting under the eradication program appeared to recover well, except for skuas. They relied on rabbits as a major source of prey, which probably kept the skua population at a level well above its natural state. The vegetation is recovering quickly, and many seabird species are returning to the island to breed (see Box ANT1).

Long-term programs continue to monitor vegetation changes, and the abundance and distribution of nesting seabirds. To maintain the current status of Macquarie Island as free from introduced mammals, it is vital to implement rigorous biosecurity procedures. In 2013, new measures were introduced to facilities (such as the cargo facility at Hobart wharf) and to procedures. Both state and Australian government agencies are working together to achieve the highest level of biosecurity for transport of goods and people to Macquarie Island.

## Box ANT6 Rapid collapse of an alpine ecosystem through dieback

Old-growth cushion plants and mosses on subantarctic Macquarie Island are being decimated by recent climate change, with rapid, progressive and widespread death across the island. Endemic Macquarie cushions (*Azorella macquariensis*), estimated to be hundreds of years old in some areas, are dying because of windier and drier conditions (Bergstrom et al. 2015). For the past 4 decades, the environment has been altered dramatically—from continually wet and misty to periods of drying. From 2008 to 2013, researchers found that, in 88 per cent of the study areas, almost all plants had died, often leaving a desert-like landscape. The extent of the mortality of this keystone species is so severe that it has been declared critically endangered.

The primary cause of the species' collapse is suspected to be the failure of cushion plants and mosses to withstand changes in water availability in summer. For 17 consecutive years (1992–2008), there was a reduction in water available to the plants. During this period, there were accompanying increases in sunshine hours, wind speed, and water loss from the leaves of the plants and soil, despite overall increases in precipitation from storm events. An additional factor in the dieback appears to be the emergence of soilborne plant pathogens.

The cushion plants and mosses are an important habitat for many other species on Macquarie Island. The cushions act as a refuge for a range of spiders, mites and springtails. They also support other plants in what can be a very inhospitable environment. The species' collapse is taking away that critical habitat, and it will be difficult for the species to recover because plant growth rarely exceeds 5 millimetres per year.

An 'insurance' population of 54 irrigated plants has been set up on the island as a growth trial, and these plants are growing successfully. This is considered the best way to conserve the species until large quantities of seed can be harvested.

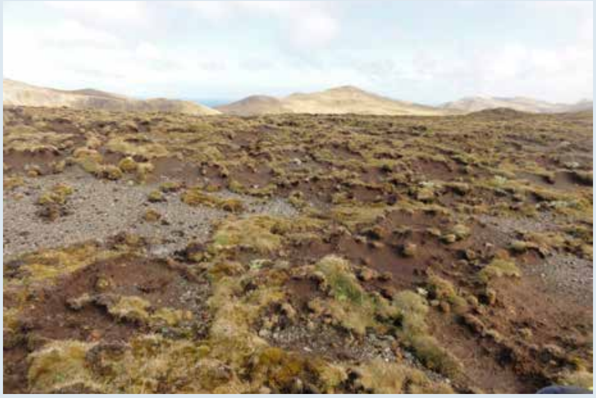
This rapid ecosystem collapse on Macquarie Island highlights the potential impact of climate-induced environmental change on vulnerable ecosystems elsewhere.

A remaining patch of healthy fellfield

Photo by Dana Bergstrom, Australian Antarctic Division, all rights reserved

A cushion plant, half of which is affected by dieback

Photo by Dana Bergstrom, Australian Antarctic Division, all rights reserved



Fellfield in which cushions have died and blown away, exposing red-brown peat

Photo by Dana Bergstrom, Australian Antarctic Division, all rights reserved

## Assessment summary 8

### State and trends of the terrestrial environment of Macquarie Island

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Coastal and mid-land vegetation | Recovering after non-native herbivores removed | Good, Improving | Adequate | Adequate | Comparable |
| Upland vegetation | Degraded through rapid dieback; highly probable linkage with change in climate | Poor, Deteriorating | Adequate | Adequate | Comparable |
| Coastal and mid-land terrestrial invertebrate populations | Probable recovery associated with vegetation recovery | Poor, Improving | Limited | Limited | Comparable |
| Upland terrestrial invertebrate populations | Reduced through loss of habitat (cushion plants and peat) | Poor, Deteriorating | Limited | Limited | Somewhat comparable |
| Stream invertebrate populations | Probable recovery associated with vegetation recovery | Poor, Improving | Limited | Limited | Comparable |

For additional information and an accessible version of the assessment summary, see SoE Digital.

**Recent trends**

- Improving
- Deteriorating
- Stable
- Unclear

**Grades**

- **Very good:** Communities are not affected by changes and operate at maximal reproductive capacity
- **Good:** Few communities are affected and operate below maximal reproductive capacity; structure and function of systems/communities are not impaired
- **Poor:** Some communities are affected and operate well below maximal reproductive capacity; structure and function of systems/communities are impaired
- **Very poor:** Affected systems/communities are barely functional

**Confidence**

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

## Vertebrate populations

Antarctic vertebrates encompass a variety of flying seabirds and penguins, several seals and whales, and numerous fish. The species diversity, especially on the Antarctic continent, is much lower than in temperate and tropical regions, and even the Arctic. However, the abundance of many species is very high. All highly depend on the Southern Ocean for food, and their breeding areas include terrestrial, fast ice and marine regions. Many of the large air-breathing vertebrates are also highly migratory and explore areas far outside the Antarctic and the Southern Ocean.

Status and trend data are available for only a few species—notably, 2 penguin species on the continent, some albatross populations, the giant petrel populations, and fur and elephant seals at Macquarie Island. Long-term population data do not exist for the ice-breeding seals and whales, most of the flying birds, and some of the penguins at Macquarie Island. Hence, trends and status are difficult to establish. Heard Island and McDonald Islands are visited infrequently, and data are largely lacking.

### Fish

The fish fauna of Antarctica is unique. Their species composition and, to a large extent, their distribution in the Southern Ocean have been well documented. Some 322 species are recognised in the Antarctic waters, but only about half (161 species) live in the high Antarctic—that is, south of the Antarctic Polar Frontal Zone (Eastman 2005). Of these, the vast majority (77 per cent) are notothenioids (a group of about 120 species that are found almost exclusively in the Southern Ocean). This is the most diverse group, with 129 species belonging to 5 families (Near & Cheng 2008). Their biomass makes up 91 per cent of the Antarctic fish fauna (Eastman 2005). Notothenioids have lived in the Antarctic environment for millions of years and are well adapted to life in a polar ocean. These fish evolved to produce glycoproteins that act as antifreeze agents in their blood, which is key to their survival in the freezing temperatures (Devries 1971).

There is little information on the status and trends of Antarctic fish populations. This is partly because of the vast area covered by the Southern Ocean, which renders population surveys near impossible, especially those frequent enough to estimate abundance and trends. Hence, formal stock assessments are only available for some of the exploited fish populations.

Historically, vessels from the Soviet Union and other Eastern Bloc countries conducted large-scale fishing operations in the Southern Ocean off the AAT in the mid-1960s. Marbled rock cod (*Notothenia rossii*) was caught in such quantities that the stock had declined by the 1970s and was depleted by the end of the 1980s. Off South Georgia, stocks had all but disappeared after only 2 years of fishing (Kock 1992). Currently, only 2 species of finfish are harvested in Australia's exclusive economic zone at Heard Island and McDonald Islands, and Macquarie Island: Patagonian toothfish and mackerel icefish. The latter is being targeted only at Heard Island and McDonald Islands.

CCAMLR regulates all legal commercial catches, but illegal, unreported and unregulated fishing still occurs in the high seas of the CCAMLR area, albeit at probably lower levels than in the 1980s, 1990s and early 2000s. It is worth noting that, since 2004, no illegal fishing was reported in the exclusive economic zone around Heard Island and McDonald Islands.

### Whales

Of the 14 recognised species of baleen whales, 8 frequent the Southern Ocean. Some 28 species of toothed whales also use the southern polar regions, and at least 22 appear to remain in the Southern Ocean year round (Van Waerebeek et al. 2010). Toothed whales are less well known in the Antarctic region than baleen whales (Leaper et al. 2008a). Some species, such as the baleen humpback whale (*Megaptera novaeangliae*), spend summer in Antarctic waters, but in autumn migrate north to warmer waters where they give birth to their young.

By the mid-1900s, several great whale species—for example, blue (*Balaenoptera musculus*), humpback and sei (*B. borealis*) whales—living in the Southern Ocean had become nearly extinct after decades of intensive hunting (Hutchinson 2006). Currently, despite efforts to protect them by banning commercial whaling and declaring the Southern Ocean an international whale sanctuary, rates of recovery vary among species and by region, and some populations still show no sign of recovery (Leaper et al. 2008b). The reasons for this are largely unknown. Blue, fin (*B. physalus*) and sei whales are listed by the IUCN as endangered, and sperm whales (*Physeter macrocephalus*) are classified as vulnerable to extinction. Officially, blue whales have not been hunted for 65 years, but there are only very limited indications of a possible population recovery (Ballance et al. 2006). The reason for this is probably illegal and unreported hunting. For example, in the 1960s, the Soviet Union reported catching 156 blue whales; however, the actual number appeared to be 1433 (Yablokov 1994). A more recent study of blue whales provided evidence of a slow increase in their global population, but their numbers still remain well below pre-exploitation levels (Branch 2007). In comparison, humpback and southern right whales (*Eubalaena australis*) are comparatively abundant again and are listed as being of least concern. However, the vast abundance of whales from pre-industrial times will likely remain a thing of the past (DEWHA 2009).

Knowledge about the size and structure of whale populations is very limited. Estimating the abundance of whale populations is a complex and complicated process. Issues can arise with species identifications, the timing of surveys, the areas covered and even the response of species to the presence of vessels (Leaper et al. 2008b). Many species have a circumpolar distribution, but their species-specific behaviours differ significantly. For example, although sperm whales use the Southern Ocean during the austral summer, it is generally only the large males that visit the regions south of the Antarctic Polar Frontal Zone (Leaper et al. 2008a). Sperm whales rank among the least well known whale species. Their population was severely reduced through commercial activities, particularly from 1945 to 1975. The most recent assessment concluded that, globally, sperm whales are currently at 32 per cent of their pre-whaling population levels (Whitehead 2002). A survey off Western Australia also documented that this species shows no sign of recovery (Carroll et al. 2014).

From 1978–79 to 2003–04, 3 circumpolar ship-based surveys of Antarctic minke (*B. acutorostrata*), sperm, fin, blue, humpback and killer (*Orcinus orca*) whales were done in the ice-free areas of the Southern Ocean (south of 60°S) to estimate their abundance (Branch 2006). Despite some methodological differences, the estimates for the populations of sperm, fin and killer whales increased from the second to the third survey. Minke whale numbers, however, were lowest during the third survey compared with previous estimates. Possible explanations include that more minke whales had travelled into the pack ice and that a larger number of whales were missed on the survey track (Branch 2006).

The most comprehensively studied whale is the humpback whale; its distribution and stock abundance are probably the best known of any whale species. The International Whaling Commission distinguishes 7 separate breeding stocks of humpback whales in the Southern Hemisphere, and an eighth that occupies the northern Indian Ocean but does not migrate to Antarctic waters (Branch 2011). The 3 circumpolar surveys comprehensively assessed the whales' summer abundance. The various breeding stocks of humpback whales vary in size (Branch 2006). The largest stock is probably breeding stock D, which migrates annually from summer feeding grounds in Antarctica to north-western Australia for winter (Kent 2012). This stock has a long history of exploitation (Chittleborough 1965). However, recent surveys indicate that the stock is increasing to a point that its delisting as a threatened species under Australian legislation has recently been proposed (Bejder et al. 2016).

### Seals

Four species of seals—crabeater (*Lobodon carcinophagus*), leopard (*Hydrurga leptonyx*), Ross (*Ommatophoca rossii*) and Weddell (*Leptonychotes weddellii*)—inhabit the sea ice zone that surrounds Antarctica. They rely on the sea ice at critical stages of their lives, particularly in their reproductive and moulting periods. Their populations are difficult to study because these seals are highly mobile, are dispersed across large and inaccessible regions, spend long periods of time foraging in the ocean where they are difficult to survey, and do not appear to occupy set territories. Sightings are usually of individuals or very small groups. Surveys to estimate their population sizes are infrequent, because the studies are expensive and labour-intensive. Consequently, population trends are largely unavailable.

In the past, estimates of the global population of crabeater seals ranged from 2 to 5 million individuals in the mid-1950s (Scheffer 1958), to about 75 million in the early 1970s (Erickson et al. 1971) and 11–12 million in 1990 (Erickson & Hanson 1990). Based on surveys conducted in 1972–73, Laws (1984) estimated that there were 772,000 crabeater seals in the Wilkes

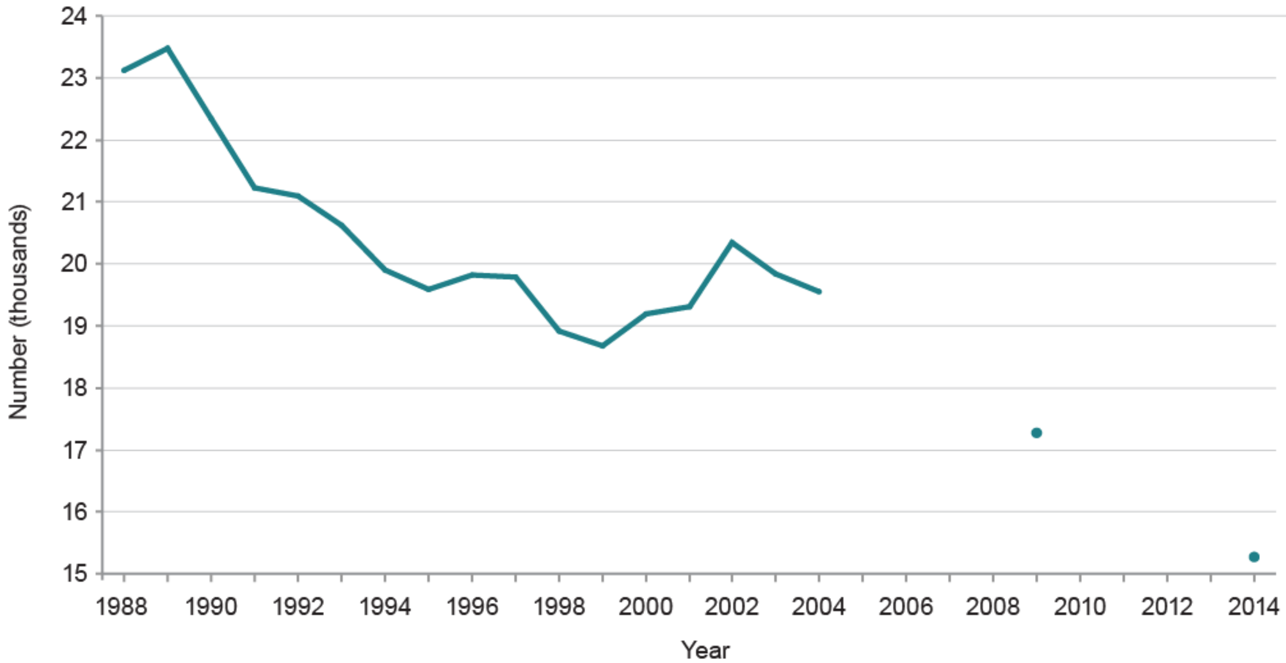
Land region of East Antarctica, and postulated that these seals should increase in number because of all the 'excess' krill available after many krill-eating whales had been removed from the Southern Ocean. A detailed aerial survey of 1.5 million km$^2$ from 64°E to 150°E, roughly coinciding with the area where Laws operated, was conducted in 1999–2000. If Laws's krill surplus hypothesis had been correct, several million crabeater seals could have been expected. However, the survey estimate for crabeater seals yielded fewer than 1 million individuals in the survey area, with a range of 0.7–1.4 million. Thus, it appears that crabeater seals are abundant, but that earlier estimates were too high. Leopard and Ross seals are probably also abundant, but less so than crabeater seals, with numbers in the tens of thousands (Southwell et al. 2008a,b).

Crabeater, leopard and Ross seals inhabit the northern region of the sea ice that consists of ice floes of varying sizes and density, known as pack ice. Weddell seals, on the other hand, are found on the fast ice—the sea ice that is attached to the continent. How the pack ice seals respond to environmental stressors may vary among species (Ainley et al. 2015). However, changes in the structure and size of ice floes could lead to the loss of pupping platforms. A reduction in sea ice persistence may decrease the availability of Antarctic krill, an important food source for all pack ice seals. However, if coastal ice-free areas increase in size, crystal krill (*Euphasia crystallorophias*) may become more abundant and may partially offset the loss of Antarctic krill (Pakhomov & Perissinotto 1996). Leopard seals have the most diverse diet among the ice seals and are the least likely to be immediately affected by changes in food availability. However, depending on the rate, kind and magnitude of change, they are likely to be affected eventually.

Fur seals (*Arctocephalus* spp.) and southern elephant seals (*Mirounga leonina*) inhabit the subantarctic islands, but can be encountered as far south as the Antarctic continent. Southern elephant seals, particularly young males, have numerous haul-out sites on the Antarctic continent, where they spend most of the austral summer moulting. Fur seals are infrequent visitors. Although several fur seal populations still appear to be increasing, albeit at varying rates depending on the location, the numbers of southern elephant seals at Macquarie Island appear to be generally declining (Figure ANT12). The reasons for this are unknown and difficult to investigate, because this species migrates across long distances for 8–10 months per year (Learmonth et al. 2006). However, elephant seals are probably subjected to different pressures throughout the year, as well as at various stages of their lifecycle. For example, sea ice extent in the summer foraging areas of females may be linked to survival of their offspring. Extensive sea ice may exclude the seals from high-quality foraging areas, which in turn negatively affects the survival of their pups (van den Hoff et al. 2014).

Crabeater seals on an ice floe

Photo by Paula Olson, Australian Antarctic Division collection, all rights reserved




Note: Animals are counted during a specific period in October, and the counts have been adjusted to estimate total numbers on 15 October. The estimated uncertainty is ±5%. Limited resources after 2004 have reduced the frequency of the count to once every 5 years.
Source: Gales (2001), updated 2014

**Figure ANT12 Total number of southern elephant seal adult cows at Macquarie Island, 1988–2014**

### Flying seabirds

Globally, 28 per cent of seabirds are threatened, and 5 per cent are critically endangered, making them the most threatened group of birds. Among them, petrels and albatrosses (Procellariiformes), and penguins (Sphenisciformes) make up 43 per cent of threatened taxa (Croxall et al. 2012). Populations comprising less than 100 breeding pairs are inherently vulnerable. About one-third of global albatross populations are in this category, including most breeding populations at Australia's subantarctic islands.

Seabirds typically live for several decades; they mature late and lay only 1 or 2 eggs per year, which usually do not get replaced when lost. Also, some albatross species breed only every second or sometimes third year. Although adult survival is usually very high (around 95 per cent of adults return the following year to their colonies), their low annual reproductive output does not enable seabirds to withstand even small increases in their natural mortality rates.

One of the most serious threats to seabirds, particularly those breeding at lower latitudes on the subantarctic islands, is commercial fishing operations. Within the Australian jurisdiction, incidental seabird mortality is strictly controlled and regulated. However, seabirds fly enormous distances and often forage in the high seas in international waters, where they interact with the pelagic longline fisheries. Seabirds get hooked when they scavenge for food behind the vessels; as the line sinks, they drown. Progress is being made, particularly through the efforts of the Agreement on the Conservation of Albatrosses and Petrels, in developing and improving best practices and procedures for minimising seabird deaths in fisheries. Efforts include improvements in line weighting in longline fisheries, development of underwater bait-setting devices (which deliver baited hooks out of reach of most diving seabirds) and implementation of new technologies to avoid bycatch in trawl fisheries.

On land, flying seabirds may experience disturbance by humans, loss of breeding habitat, increased competition for nest sites, and increased exposure to parasites and pathogens. On subantarctic islands, their breeding success can be reduced directly by non-native predators, such as cats, rats and mice. This is what happened, for example, on Macquarie Island (see Box ANT1). Introduced predators are a key threat, because they could increase the natural mortality among adult birds and reduce breeding success when chicks are preyed upon. Heard Island and McDonald Islands have so far remained free from introduced vertebrates. Introduced species, such as rabbits, can also have an indirect effect when overgrazing leads to destabilisation of the substratum, which in turn can lead to an increase in landslides across breeding areas (Scott & Kirkpatrick 2007).

Most seabird populations in the Antarctic are only infrequently surveyed, because it is difficult to access their colonies or because of their cryptic behaviour (the ability of an animal to avoid observation or detection) during breeding, or both. Hence, for many species, it is difficult to assess their population status reliably. In June 2015, the members of the Antarctic Treaty officially recognised the recently published report on Important Bird Areas in Antarctica, which identified some 204 areas as important for the conservation of flying seabirds and penguins (Harris et al. 2015).

### Penguins

Penguins make up about 90 per cent of the biomass of seabirds in Antarctica (Bargagli 2005). Like all seabirds, they are long-lived and produce only 1 or 2 eggs per year. They often live in large colonies in the coastal areas of subantarctic and Antarctic islands. During the breeding season, the foraging areas of the breeding population are limited, because they need to return regularly to their colonies to feed their offspring. Of the 18 species in the penguin family, 7 live and breed in the AAT and Macquarie Island, but only emperor (*Aptenodytes forsteri*) and Adélie (*Pygoscelis adeliae*) penguins inhabit colonies in the eastern high Antarctic. Adélie penguins spend the winter months at sea and return to their breeding colonies during the southern summer, whereas emperor penguins breed during the winter months and fledge their young in summer. Consequently, these 2 species are subject to marine and terrestrial processes at different times of the year.

From 2005 to 2011, a large-scale aerial survey was conducted along 3800 kilometres of coastline in East Antarctica, extending from 59.4°E to 136.0°E. Some 13 previously unreported breeding sites were discovered, and no breeding sites appeared to have been abandoned, indicating that the breeding distribution may have expanded (Southwell & Emmerson 2013a). The populations at these new breeding locations ranged from 425 to 6130 individuals (Southwell & Emmerson 2013b).

In 2009, satellite imagery obtained a first count of the global population of emperor penguins and estimated that some 238,000 penguins occupied 46 colonies around the Antarctic coastline (Fretwell et al. 2012). In 2015, the IUCN revised the listing of emperor penguins to near threatened because of the predicted decrease of their population as a result of changes in the sea ice environment (BirdLife International 2015). In East Antarctica, the size of 3 colonies has decreased significantly since the mid-1970s; the reasons for this are largely unknown. A link between breeding success and sea ice extent was suggested for 2 colonies, but could not be confirmed for the third (Barbraud et al. 2011, Robertson et al. 2014).

The greatest threats for penguins in East Antarctica are likely to be loss of breeding habitat (in the case of emperor penguins), a reduction in food availability because of climate change and ocean acidification. Changes in sea ice conditions have varied consequences. For example, a reduction in the sea ice extent potentially shortens foraging distances, but also means reduced krill production (Bretagnolle & Gillis 2010). It is difficult to predict to what extent penguins may be able to adapt to environmental change, particularly as the rate of change is likely to increase once the ozone loss is reversed, making adaptation difficult for these long-lived species.


Making good use of the Antarctic runway

Photo by Nicholas Brown, © Geoscience Australia, all rights reserved

# Assessment summary 9

## State and trends of Antarctic and subantarctic vertebrates

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Fish | The geographic distribution and species composition of Antarctic fish are reasonably well understood; however, estimates of abundance or population size are available only in some areas for a few commercially harvested species through CCAMLR stock assessments | Not assessed | ○ | ○ | ◆ |
| Toothed whales—sperm (Note: In 2011, 'toothed whales—sperm', 'toothed whales—killer' and 'toothed whales—other' were combined in 'toothed whales') | Some life history information is available. Modelling of population estimates is still hampered by questions about the effect of the removal of large males in commercial whaling operations. Southern Ocean sperm whales were last examined by the Scientific Committee of the International Whaling Commission in the early 1980s | Not assessed | ○ | ○ | ◆ |
| Toothed whales—killer (Note: In 2011, 'toothed whales—sperm', 'toothed whales—killer' and 'toothed whales—other' were combined in 'toothed whales') | Some life history information is available. There are 3 different ecotypes of killer whales, each of which has a different specialised diet. Data on population sizes and dynamics are lacking | Not assessed | ○ | ○ | ◆ |
| Toothed whales—other (Note: In 2011, 'toothed whales—sperm', 'toothed whales—killer' and 'toothed whales—other' were combined in 'toothed whales') | Other toothed whales in Antarctic waters include orcas; many species are data deficient, and their populations and trends cannot be estimated | Not assessed | ○ | ○ | ◆ |

## Assessment summary 9 (continued)

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Baleen whales—humpback (Note: In 2011, 'baleen whales—humpback', 'baleen whales—minke' and 'baleen whales—other' were combined in 'baleen whales') | The humpback is the most studied baleen whale in the Southern Ocean. Seven breeding stocks are recognised. Highly migratory, their distribution is reasonably well understood, but population size and trends are insufficiently known | | | | |
| Baleen whales—minke (Note: In 2011, 'baleen whales—humpback', 'baleen whales—minke' and 'baleen whales—other' were combined in 'baleen whales') | This group comprises Antarctic minke (*Balaenoptera bonaerensis*) and dwarf minke (*B. acutorostrata*). Dwarf minke was recognised as a separate species only recently. Some evidence of population structure is known based on DNA work. Population sizes and trends are unknown<br>There is some evidence that tourism could negatively impact on feeding behaviour and breeding success | | | | |
| Baleen whales—other (Note: In 2011, 'baleen whales—humpback', 'baleen whales—minke' and 'baleen whales—other' were combined in 'baleen whales') | Other baleen whales include the Antarctic blue, sei, fin and humpback whales; all species are listed by the IUCN on the Red List of Threatened Species. Some populations appear to be increasing, but the most recent estimates were made in the early 2000s | | | | |
| Ice-breeding seals | Populations are apparently abundant and unaffected by human activities; however, much is still unknown, and population trend data are not available. A survey of the crabeater seal population revised the size downwards, but that was because of improved methodologies | Not assessed | | | |

## Assessment summary 9 (continued)

| Component | Summary | Assessment grade: Very poor | Assessment grade: Poor | Assessment grade: Good | Assessment grade: Very good | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|---|---|---|
| Fur seals | Populations are still recovering from sealing exploitation, but are increasing | | | ↗ | | ● | ● | ◆ |
| Elephant seals | The number of cows at Macquarie Island is still decreasing; reasons are unknown | | ↙ | | | ● | ● | ◆ |
| Wandering albatross | Listed as vulnerable; only about 10 breeding pairs at Macquarie Island. Commercial fishing operations are a threat | ↙ | | | | ● | ● | ◆ |
| Small albatrosses | All species are listed by the IUCN because of conservation concerns. Many are caught as bycatch in commercial fisheries | | — | | | ◒ | ◒ | ◆ |
| Petrels in Antarctica | Long-term population data for these birds are not available; however, they still appear to be abundant | | | ? | | ◒ | ○ | ◆ |
| Subantarctic petrels | Long-term population data are available for most species at Macquarie Island; some populations are known to have decreased (e.g. at Macquarie Island). The numbers appear to be increasing after the eradication of cats, rabbits, mice and rats | | ? | | | ◒ | ○ | ◆ |
| Antarctic penguins—Adélie | Some evidence exists to show that the breeding distribution has expanded during the past decade, but population counts and trend data are limited to a few sites | | | ↗ | | ◒ | ◒ | ⬙ |
| Antarctic penguins—emperor | The species was uplisted to near threatened. In East Antarctica, 3 colonies decreased significantly in the 1970s–80s. The trend is ongoing. There are no long-term population data for the remaining colonies | | ? | | | ◒ | ◒ | ⬙ |

## Assessment summary 9 (continued)

| Component | Summary | Assessment grade | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Subantarctic penguins | Many species appear to suffer population declines, but long-term population data are available for only a few colonies<br>King penguins appear to be the only species with a growing population | Poor, Deteriorating | Limited | Limited | Comparable |

CCAMLR = Commission for the Conservation of Antarctic Marine Living Resources; IUCN = International Union for Conservation of Nature
For additional information and an accessible version of the assessment summary, see SoE Digital.

**Recent trends**

- Improving
- Deteriorating
- Stable
- Unclear

**Grades**

- **Very good:** Only a few, if any, species or species groups have declined as a result of human activities or declining environmental condition
- **Good:** Populations of a number of species or species groups have declined significantly as a result of human activities or declining environmental condition
- **Poor:** Populations of many species or species groups have declined significantly as a result of human activities or declining environmental condition
- **Very poor:** Populations of large numbers of species or species groups have declined significantly as a result of human activities or declining environmental condition

**Confidence**

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- **X Not previously assessed**

## Australian Antarctic Program's station environment

Although human activity across Antarctica has increased during recent decades, it remains much lower than for all other continents. Human activity in Antarctica is highly seasonal, with the peak presence and activity occurring during the summer months. Although Australia and other nations maintain a year-round presence in Antarctica, there are no truly permanent human populations.

Human activity in Antarctica is concentrated in ice-free areas, which account for approximately 0.18 per cent of the continent. Most Antarctic stations are adjacent to the coast to facilitate access by ship for resupply of stations with essential provisions, such as food and fuel. The environmental impacts of human activities in these areas must be carefully managed, because these ice-free areas also support the greatest biodiversity of terrestrial plants and animals. Human impacts include disturbance and modification of the landscape, and contamination of the air, land and coastal marine environments with a variety of pollutants.

The Protocol on Environmental Protection to the Antarctic Treaty was adopted in 1991 and signed into force in 1998. Its aim is to provide comprehensive and legally binding protection of the Antarctic environment. All human activities are to be assessed for their potential impact on the environment and associated ecosystems. Although the protocol prohibits the introduction of any species not native to Antarctica, there are limited exceptions, including the controlled use of hydroponic systems for growing fresh produce that otherwise would be unavailable for lengthy periods because of transportation constraints.

### Operation indicators

Under Article 17 of the Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol), all parties are required to report annually on steps taken to implement the protocol. These include the adoption of laws and regulations, administrative actions and enforcement measures to ensure compliance with the protocol. The Madrid Protocol also requires that contingency plans are established to respond to incidents with potential adverse effects on the Antarctic environment, or on dependent and associated ecosystems.

Each year, various ships and aircraft transport people and goods to and from Australia's 4 permanently occupied research stations of Casey, Davis, Mawson and Macquarie Island. During recent years, the winter populations at the Australian stations have remained relatively stable; they have typically been 16–22 people on the continent and 13–15 on Macquarie Island. An exception occurred on Macquarie Island in 2011 and 2012, when the winter population peaked at 38 during the Macquarie Island Pest Eradication Program, in which rodent and rabbits were eradicated from the island (see Box ANT1). For many years, Davis Station had the largest summer population, with up to 100 personnel. However, Casey Station now has a much larger number of expeditioners coming and going throughout the summer season because of the improved access to Antarctica by air transport. Prevailing weather conditions do not allow use of the runway during winter.

The effective number of people participating annually in the Australian Antarctic Program is shown in Figure ANT13. Participation since the mid-2000s has been lower than in the preceding decades, largely because of reduced construction activity at the 3 continental stations.

The AAD operates the icebreaking research and resupply vessel *Aurora Australis* from mid-October until April the following year. Winter travel to Antarctica is not possible because of the extensive sea ice that prevents access to the coastal areas where the stations are located.

The AAD undertakes voyages for a range of purposes, primarily the resupply of the stations, and deployment and retrieval of personnel, as well as marine science research. The *Aurora Australis* caters for all these purposes. Occasionally, other vessels may be chartered for a particular task, such as waste removal, Southern Ocean and marine science research activities, or transport of personnel to and from Macquarie Island. In October 2015, the Australian Government unveiled its plans for a new icebreaker that will offer scientists unprecedented and extended access to the Southern Ocean and Antarctica. The vessel is expected to be commissioned in late 2020.

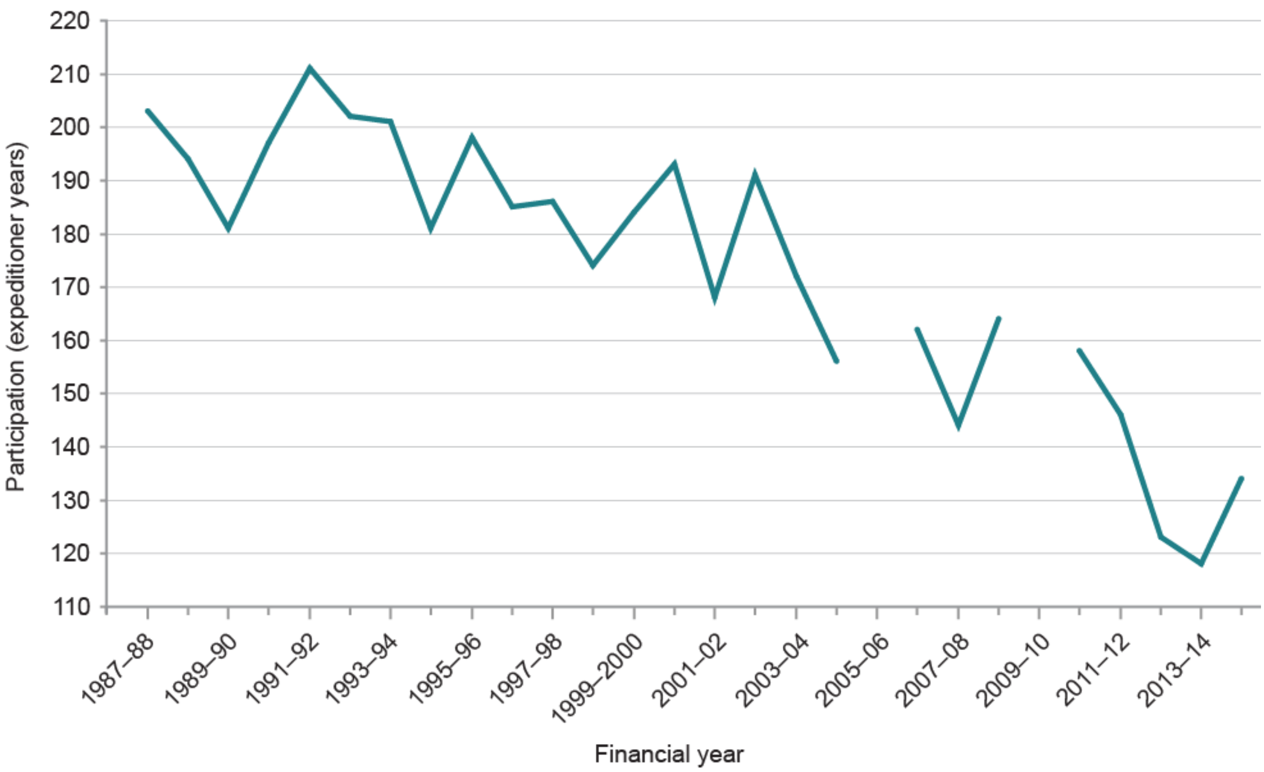
The AAD also uses a range of aircraft to transport passengers and cargo (see Shipping and aircraft operations). During the 2015–16 summer, the AAD and the Royal Australian Air Force successfully flew several joint operational missions to East Antarctica with a C-17 Globemaster III, which delivered heavy-lift cargo to Wilkins Aerodrome in support of the Australian Antarctic Program. The use of this type of heavy-lift aircraft has the potential to significantly improve the AAD's logistical and scientific capabilities.

The AAD uses a well-established set of operational indicators to monitor and assess human impact on the environment associated with the Australian Antarctic Program. Several of these are discussed below.

### Waste treatment and disposal

Annex III of the Madrid Protocol outlines the obligations of national programs for waste disposal and management. Antarctic research stations generate a variety of wastes, including liquid waste (human waste, water from kitchens and bathrooms, and from operational activities in workshops) and solid waste (e.g. materials for landfill and recycling). Burning of fossil fuels for power generation, powering of vehicles and waste incineration at the stations contributes to emissions into the environment.

Wastewater effluent is discharged directly to the sea adjacent to the stations. At Davis and Macquarie Island, sewage is macerated and released. Maceration is the minimum level of sewage treatment required under the Madrid Protocol. At Macquarie Island, sewage is




Note: Participation is measured in 'expeditioner years', which is the effective number of expeditioners per year spending the full year in Antarctica. This is evaluated across all stations, temporary field camps, and ship and aircraft journeys.
Source: Australian Antarctic Division

**Figure ANT13 Participation in the Australian Antarctic Program, 1987–88 to 2014–15**

discharged into a high-energy environment where the macerated particles are quickly diluted and dispersed. The AAD has recently installed a new wastewater treatment facility at Davis. The plant was commissioned during the 2015–16 summer (Box ANT7). This new facility will greatly improve the environmental outcome for the area. During the project's second stage, an advanced wastewater treatment plant will be installed, which will have the capacity to produce potable water.

At Casey and Mawson stations, treatment plants process the sewage before it is released into the ocean. Biological oxygen demand (BOD) measurements assess how effective waste treatment plants are in removing organic matter from the sewage and how much organic matter is being released into the ocean. Figure ANT14 provides an annual summary of BOD measurements for each of these stations since 2001, from measurements made at approximately monthly intervals. The values for 2011–15 are 24 milligrams per litre (mg/L) for Casey (from 49 measurements) and 11 mg/L for Mawson (from 53 measurements). By comparison, the marine emissions limit for accepted modern technology in Australia is 10 mg/L (DPIWE 2001). A value of 60 mg/L for an individual measurement indicates poor efficiency in the treatment plant, and this threshold is occasionally reached when occupation of the stations is highest. For 2011–15, the threshold was exceeded on 8 occasions at Casey and 4 occasions at Mawson.

The quantities of suspended solids are also measured at the 2 stations. Suspended solids indicate how efficiently the waste treatment plants break down organic matter, and the amount of organic matter that is released into the ocean because of human occupation. Figure ANT15 provides an annual summary of suspended solids measurements for the 2 stations since 2001, from measurements made at approximately monthly intervals. The values for 2011–15 are 3 mg/L for Casey (from 50 measurements) and 20 mg/L for Mawson (from 56 measurements). Similar to BOD measurements, a value of 60 mg/L for an individual measurement indicates poor efficiency in the treatment plant, and this threshold is occasionally reached when occupation of the stations is highest. For 2011–15, the threshold was exceeded on 3 occasions at Casey and 9 occasions at Mawson.

Waste is minimised wherever possible—for example, reducing packaging waste by delivering goods to Antarctica in minimal packing. Substances such as washing powders and dishwashing liquids are biodegradable.

As with any community in Australia, the Australian Antarctic and subantarctic research stations generate a volume of waste in proportion to the station population and level of activity. This waste has been generated since the stations were established. However, how the waste has been managed over time has changed as the organisation has moved into a more enlightened era in terms of environmental management and Antarctic stewardship.

When stations were first established, the practice of 'return to Australia' was not considered necessary, and waste was disposed of at localised tip sites near the stations. This was in keeping with the way waste was handled in Australia and elsewhere in Antarctica at that time. These practices ceased when the Madrid Protocol came into effect. However, the tip sites and related waste disposal practices, although abandoned, have left an ongoing environmental legacy (see Contaminated sites and pollution). Through the *Australian Antarctic strategy and 20-year action plan* (2016), the Australian Government has committed to developing a plan to remove legacy waste and continue the remediation of contaminated sites (Australian Government 2016).

Clean-up operations have already started. In 2011, the remaining legacy waste at the Thala Valley waste site at Casey was returned to Australia. The site is being monitored, and results will be validated in terms of environmental impacts. Tip sites at the Mawson, Davis and old Wilkes stations remain unresolved, and continue to present an environmental legacy and ongoing impact.

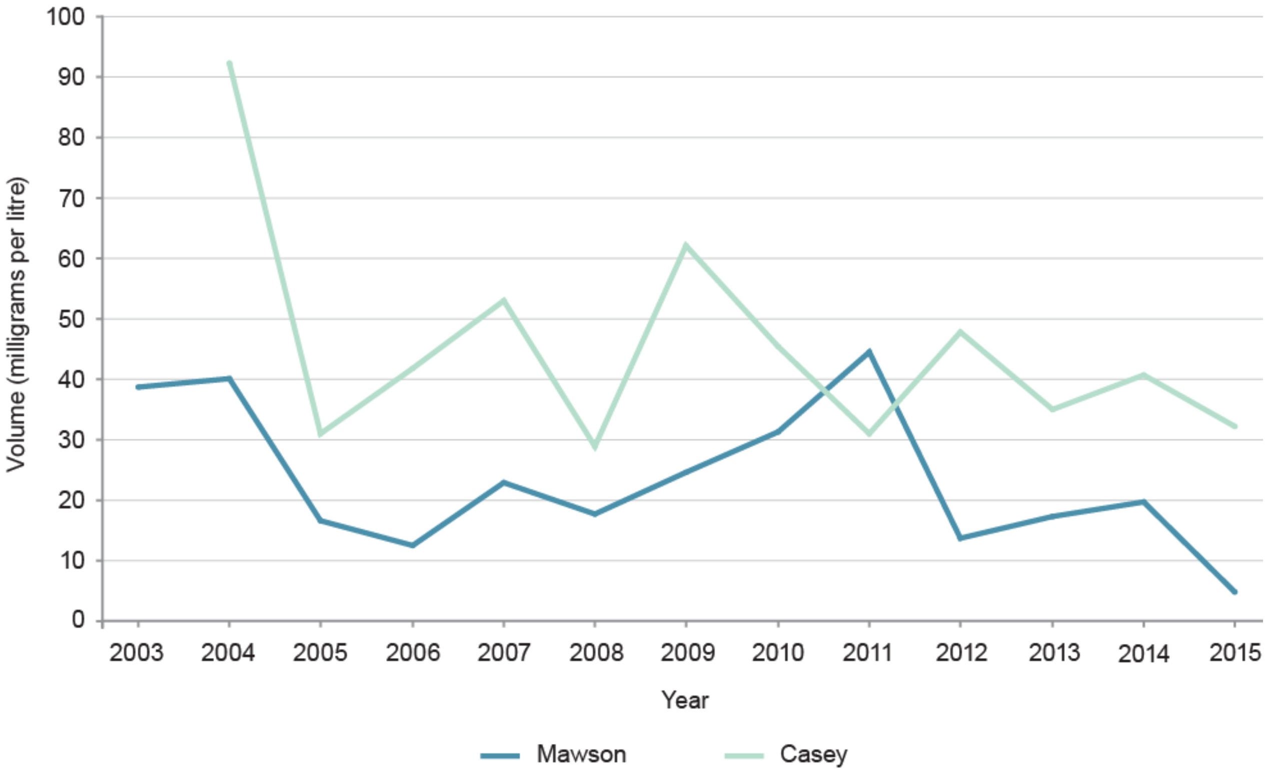
Waste generated annually and materials no longer required on station are returned to Australia for recycling, re-use or disposal. Waste typically includes general landfill and commingled recycling, such as paper, glass, aluminium and plastic (polyethylene terephthalate [PET] and high-density polyethylene [HDPE]), sewage sludge, paint, oil, steel, copper, brass, building materials and laboratory chemicals.


Hägglunds at Casey Station

Photo by Ian Phillips, Australian Antarctic Division, all rights reserved

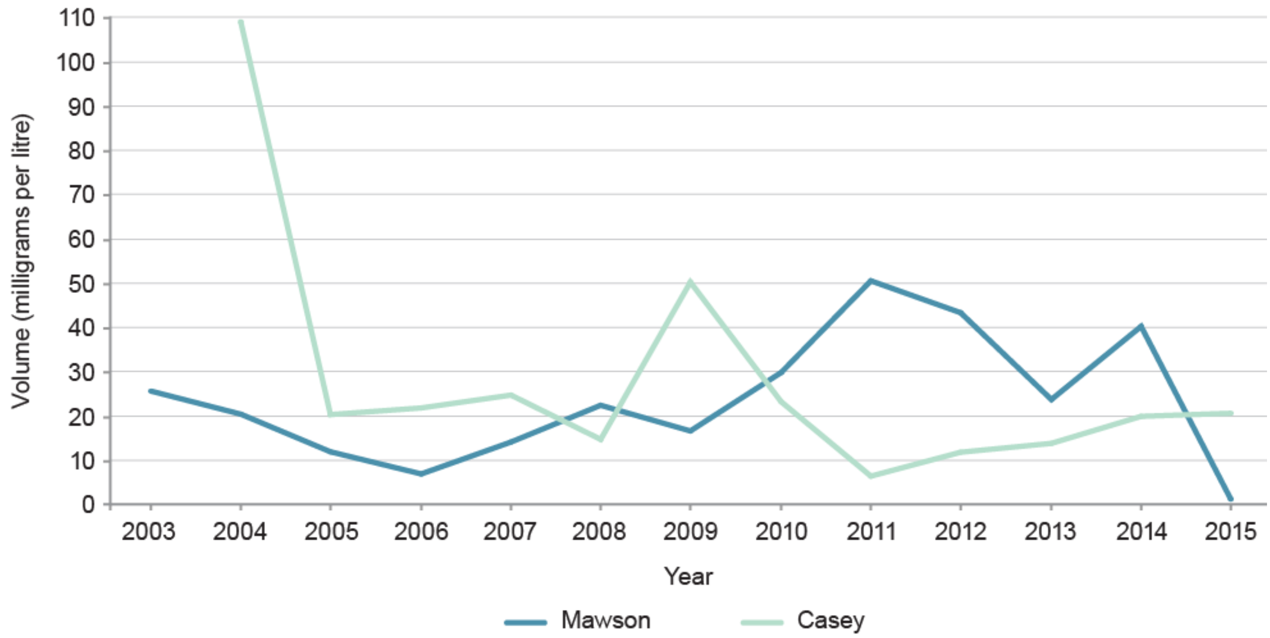
Some waste cannot be returned to Australia for quarantine reasons and is incinerated at the station. This includes kitchen scraps, medical waste and human waste returned to the station from field activities. Incineration results in a range of emissions to the environment, and Australia aims to minimise the amount of materials incinerated on the stations by diverting materials from incineration to re-use or recycling. The ash from incinerators is stored on station and returned to Australia for disposal. Data are collected on the amount of material incinerated, as well as all waste returned to Australia. New wastewater treatment facilities under construction have been designed to process food waste, and have the potential to greatly reduce the amount of material incinerated on station. The AAD regularly reviews the environmental impacts of waste activities, the extent of station community compliance with waste-management guidelines and the economics of recycling.

Waste is returned to Australia by ship, usually during the resupply of the stations. The amount of waste returned to Australia each year is highly variable and dependent on the availability of cargo space on the ship, shipping schedules, and sea ice and weather conditions during station resupply. Figure ANT16 shows the total mass of waste returned to Australia and incinerated at the stations from 1999–2000 to 2014–15.



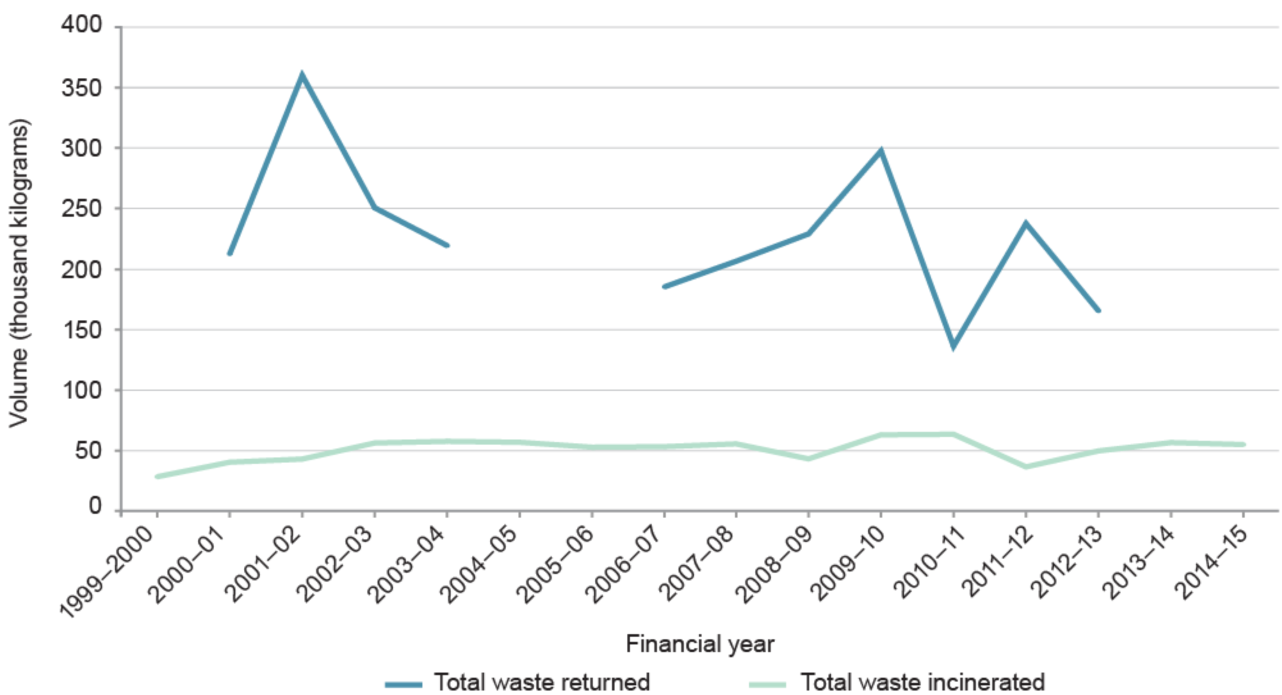

Note: Annual values are shown where 6 or more measurements are available.
Source: Australian Antarctic Division

**Figure ANT14 Average annual biological oxygen demand for Mawson and Casey stations, 2003–15**




Note: Annual values are shown where 6 or more measurements are available.
Source: Australian Antarctic Division

**Figure ANT15** Average annual suspended solids in the effluent of Mawson and Casey stations, 2003–15




Source: Australian Antarctic Division

**Figure ANT16** Mass of waste disposed of by the Australian Antarctic Program, 1999–2000 to 2014–15

## Box ANT7 Development of a new wastewater treatment facility at Australia's Davis Station

The Australian Antarctic Division (AAD) has developed a new wastewater treatment facility for Davis research station, to mitigate environmental impacts and risks to the coastal marine environment. In 2012, a comprehensive study looked at wastewater disposal into the coastal marine environment near Davis and identified several significant environmental effects, including the presence of some contaminants in the marine environment and food chain.

Thus, the AAD installed a new secondary-level wastewater treatment plant that uses best-practice technologies. The secondary treatment plant will reduce the risks of introducing non-native microorganisms and genetic material into the coastal marine environment. It is worth noting that this level of treatment exceeds any requirements addressed in the provisions of Annex III to the Madrid Protocol. The treatment plant was constructed and tested in Germany, and shipped to Antarctica during the 2014–15 season for commissioning during the 2015–16 season. A similar secondary treatment plant will be installed at Casey Station during the 2016–17 season, and at Mawson Station the following year.

In addition to the secondary treatment plant, an advanced-level wastewater treatment plant has been designed and constructed to recycle the effluent from the secondary-level plant to a standard that meets the Australian Drinking Water Guidelines for potable water. The advanced treatment plant will use novel combinations of existing technologies that have been successfully tested by academic and industry partners, and will build on research into the purification of recycled water. Once completed, the 2 treatment plants will work in conjunction and be housed in a purpose-designed building at Davis. The combined wastewater treatment process will produce discharge that will have no adverse environmental impacts and will also produce potable water for potential re-use on station.

To achieve the high environmental standards required, several proven technologies have been employed. The secondary-level plant is based on current membrane bioreactor technology. The advanced-level plant uses several advanced oxidation technologies, including ozone, ultraviolet light and chlorine, as well as ceramic microfiltration, activated carbon filtration and reverse osmosis.

The project had to address several challenges associated with installing and operating an advanced-level wastewater treatment plant in Antarctica. Because of the remote and isolated location, the plant has been designed to be highly resilient, and to be monitored and operated remotely from Australia, if necessary. The plant has also been designed to minimise the number of chemicals and consumables that are required to operate and maintain it.

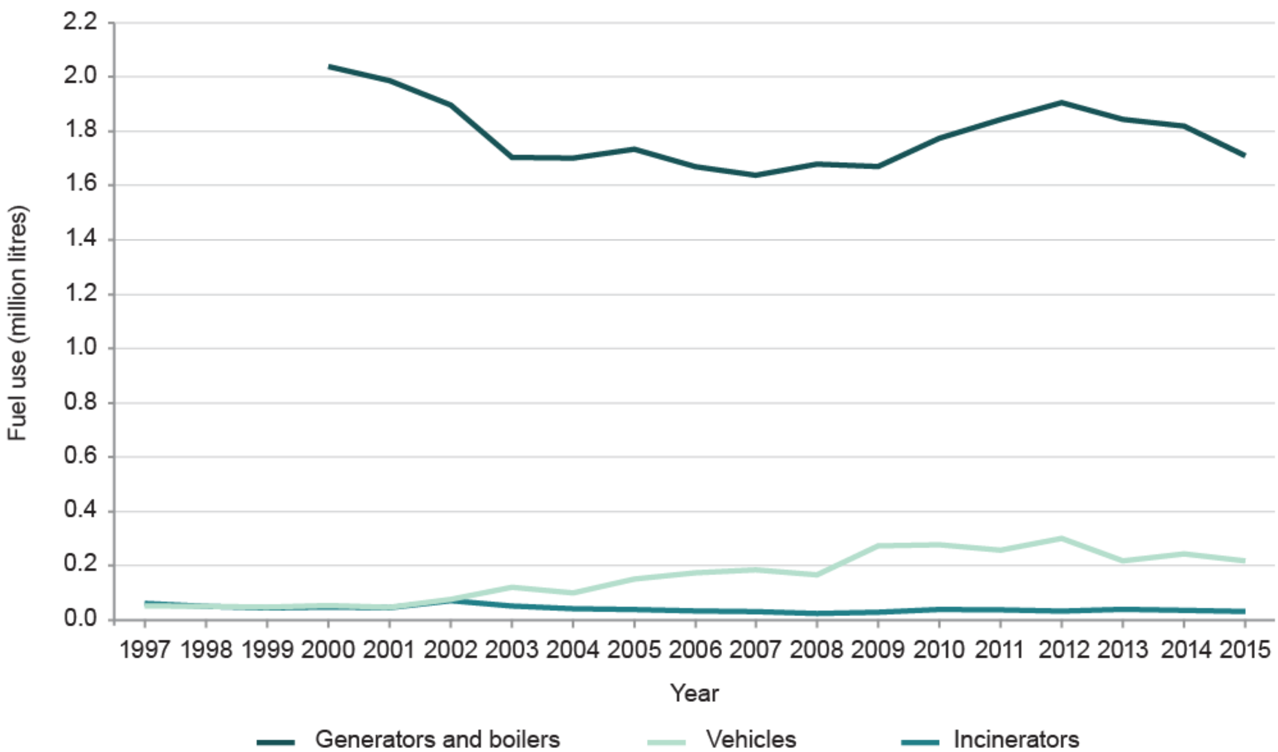
The secondary-level water treatment plant at Davis Station

### Fuel use

The quantity of fuel used by generator sets, boilers, vehicles and incinerators at all stations is recorded and reported annually (Figure ANT17), as is the use of fuel for shipping and aviation (see Shipping and aircraft operations). The environmental impact of transport and use of fuel in Antarctica is associated with emissions released from power generation and heating. A special cold-climate light-diesel fuel, special Antarctic blend (SAB), is used at the stations to power generator sets, to provide heat through boilers, and to run plants and equipment, including the station incinerators and vehicles. Operations at the Wilkins Aerodrome near Casey, which is used for the airlink to Australia, are largely responsible for the increase in vehicle fuel use since the mid-2000s.

In addition to reflecting population numbers and climatic conditions, fuel consumption reflects the energy efficiency of electrical and heating systems. The AAD is continually exploring energy-efficient equipment and energy-saving strategies. Although the occupancy of the stations is less during winter than summer, the need for electricity increases because the design of most buildings means that they cannot be closed down during winter and require additional heating. A few small buildings have their own electrical heating systems. Fuel-efficient ‘cold pump’ technology is used for the long-term storage of perishable food.

Vehicle use differs between summer and winter. During winter, vehicle use tends to be less than in summer—populations at the stations decrease to about 15–20 people, and vehicles are generally not used in bad weather. Station populations peak in summer, and the demand for resources tends to increase; this includes the use of water and fuel.




Source: Australian Antarctic Division

**Figure ANT17** Annual fuel used (total diesel and petrol) by generators, boilers, vehicles and incinerators on the 4 Australian stations, 1997–2015

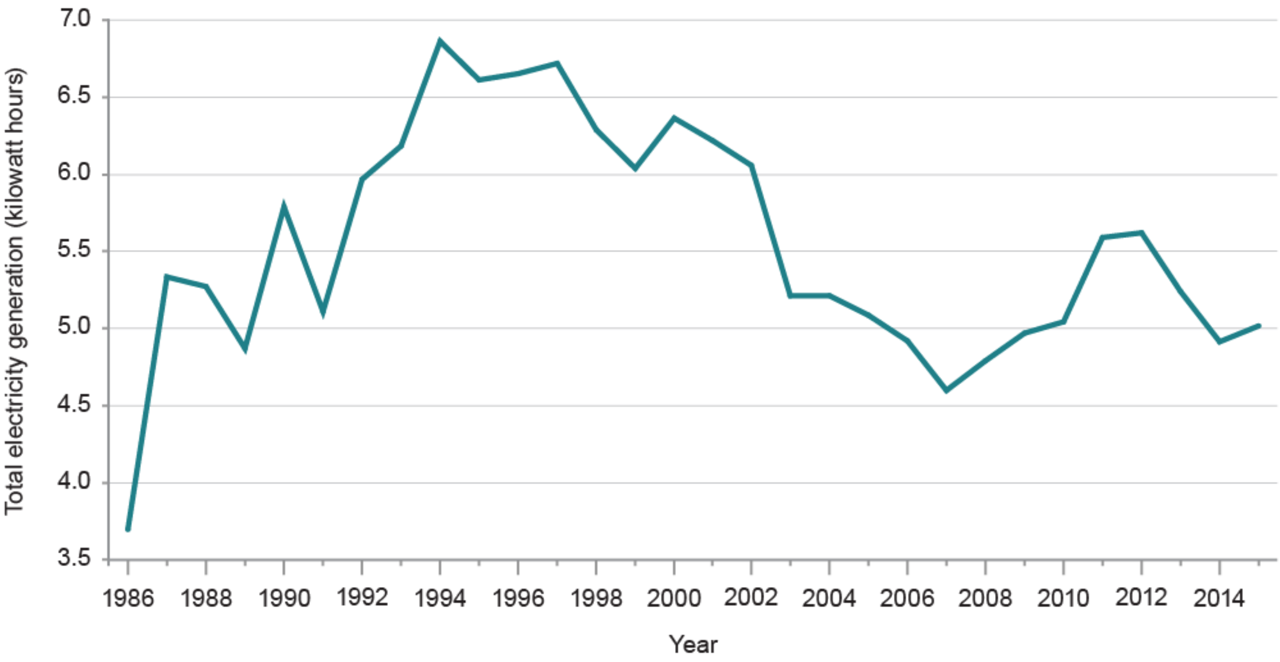
Casey Station has the highest level of fuel consumption, mostly because of the operation of Wilkins Aerodrome. Transport of passengers and cargo between Wilkins and Casey Station involves a 140-kilometre round trip. Also, the preparation and maintenance of the ice runway during summer requires the use of heavy plant at the aerodrome and approximately 10,000 litres of SAB per week. The maintenance of buildings and facilities at the aerodrome used by personnel throughout summer has an ongoing demand for energy. During winter, fuel use at Casey is similar to that at the other continental stations. At Macquarie Island, vehicle use is much lower than at the Antarctic stations and is largely limited to the immediate station surrounds.

Electricity use is affected by the season and weather, and can fluctuate from year to year depending on temperatures and the number of people on station at any one time (Figure ANT18). At Mawson Station, wind turbines continue to make a significant renewable contribution to the station's electrical and heating energy requirements. For the past decade, wind energy has provided around 40–45 per cent of the energy needs at Mawson. Furthermore, waste heat from the station's diesel-powered electrical generators is captured and used to warm the station buildings, in combination with boilers powered by the wind turbines and boosted by diesel-fired boilers.

### Shipping and aircraft operations

The quantity of fuel used by ships travelling to Australian Antarctic research stations and on marine science voyages differs because of variations in shipping demands among years. Marine gas oil is a marine version of normal diesel, and is used on the vessels to power the main engines and generator sets, to provide propulsion and general services—such as power and heating—to the vessels. IFO 40 (RMC 10) is a light-grade fuel oil used by some of the vessels engaged by the AAD. This fuel is used for the main engines and, in some cases, the generators.

The AAD's Australian–Antarctic Airlink operates a seasonal intercontinental air service from Hobart to the Wilkins Aerodrome, which is 70 kilometres inland from Casey Station. The air transport link can move up to 400 passengers each summer season and a limited amount of high-priority, lightweight cargo (current maximum of 1500 kilograms per flight). The Airbus A319-115LR was selected for this flight, partly because




Source: Australian Antarctic Division

Figure ANT18 Annual electricity production across the 4 Australian stations, 1986–2015 it has sufficient range for a return trip from Hobart to Antarctica without refuelling in Antarctica. This avoids a range of potential environmental risks associated with the transport, handling and storage of large volumes of jet fuel.

The AAD has been using BT-67 Basler (DC-3) and DHC-6 Twin Otter aircraft for intracontinental operations since 2010. These ski-equipped aircraft transport people and cargo from Wilkins to ski-landing areas at Casey, Davis and Mawson stations, and other field locations.

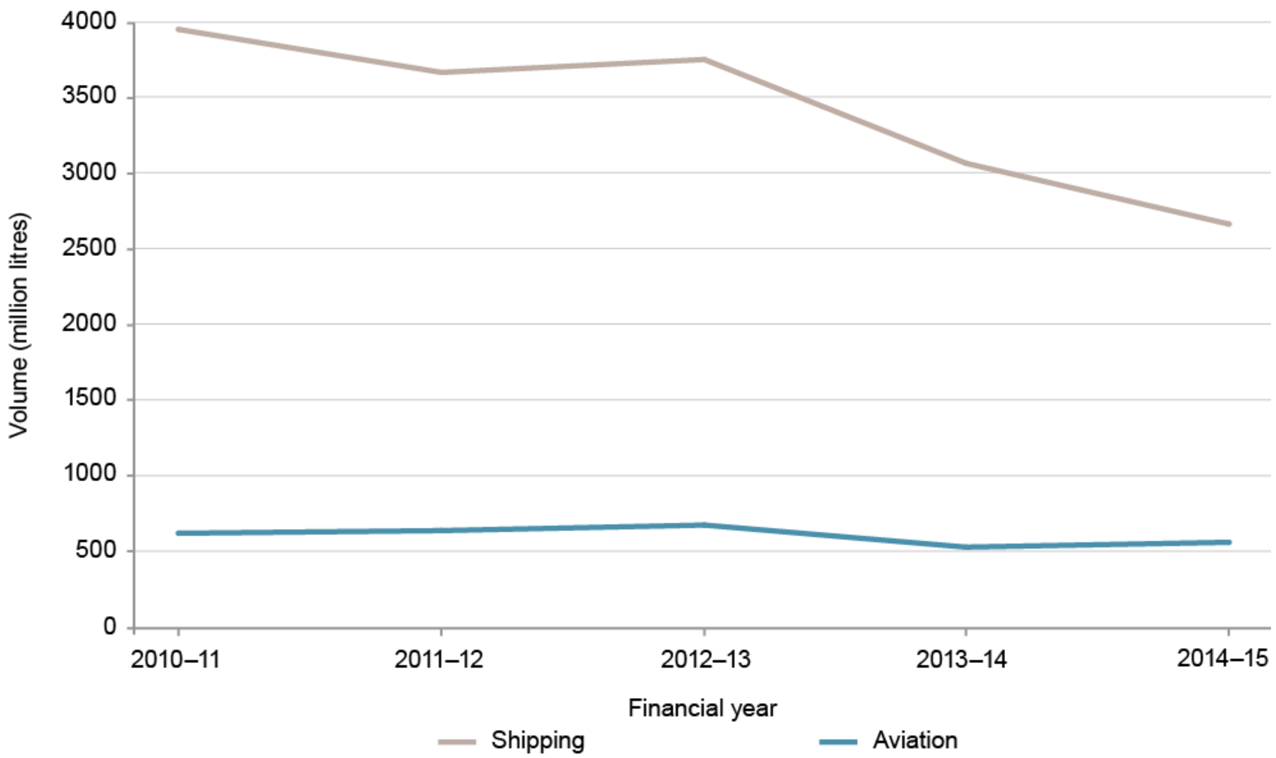
The fixed-wing aircraft work closely with up to 4 AS-350 B3 'Squirrel' helicopters to provide support to a range of projects and to provide helicopter services from the icebreaker *Aurora Australis*. When the sea ice runway no longer exists, helicopters are used to transport passengers between Davis Station and the ski-landing area on the plateau, 20 nautical miles away—a journey of about 20 minutes from the station.

In 2015, the AAD undertook an initial environmental evaluation of its aviation operations. This was the first wholesale environmental assessment of the range of aviation activities, and their actual, potential and cumulative impacts on the Antarctic environment. The result was the issuance of an environmental authorisation for 2015–20 under s. 12F of the *Antarctic Treaty (Environment Protection) Act 1980* with several conditions attached, including the need to develop appropriate options to monitor the impacts of aviation activities.

Annual shipping and aviation fuel use data for the Australian Antarctic Program are shown in Figure ANT19.

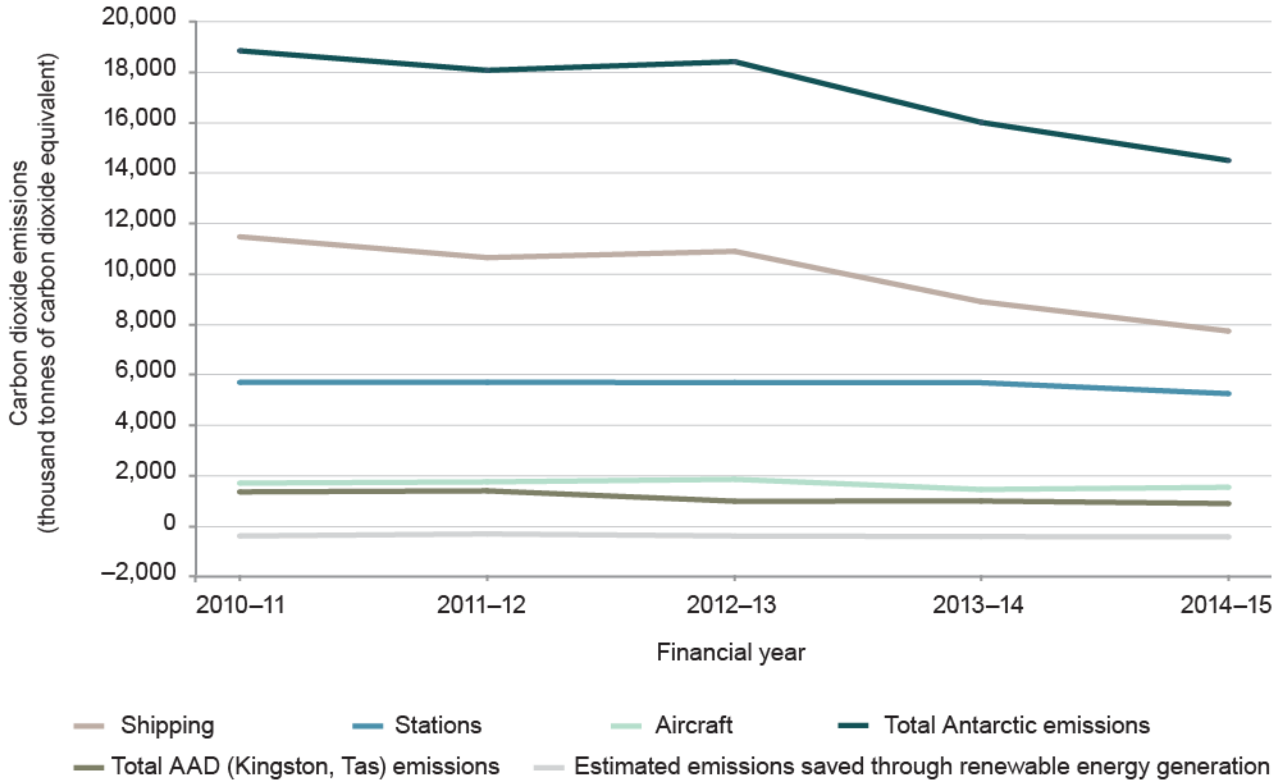
### Carbon dioxide emissions

Annual estimated $CO_2$ emissions for components of the Australian Antarctic Program are shown in Figure ANT20. Since 2010, there has been a general decline in emissions, largely because of a decrease in use of shipping fuel.




Source: Australian Antarctic Division

**Figure ANT19 Annual shipping and aviation fuel use, 2010–16**




AAD = Australian Antarctic Division
Note: Estimated emissions are shown for stations, shipping and aircraft; total Antarctic (stations, shipping, aircraft); Kingston support (excluding commercial flights and nonfleet vehicle use); and the generation of renewable energy (Mawson, shown as a negative contribution).
Source: Australian Antarctic Division

**Figure ANT20** Annual estimated emissions of carbon dioxide for the Australian Antarctic Program, 2010–11 to 2014–15

Aurora over Mawson Station

Photo by Ian Phillips, Australian Antarctic Division,

## Assessment summary 10
### State and trends of the Australian Antarctic Program's station environment

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Biological oxygen demand | Biological oxygen demand of effluent discharged into the ocean from the waste treatment plants at each continental station. Threshold ratings are occasionally reached when occupation of the stations is highest. There is a new sewage treatment facility at Davis Station, and one is under construction at Casey Station | | | | |
| Suspended solids | Amount of organic matter in effluent discharged into the ocean from the waste treatment plants at each continental station. Moderately high levels of suspended solids are discharged into the ocean. There is a new wastewater treatment plant at Davis Station, and one is under construction at Casey Station | | | | |
| Waste returned to Australia | Composition and weight of waste returned to Australia from Macquarie Island and the continental stations. The amount of waste returned to Australia is dependent on the cargo limit of the ship and varies between years | | | | |
| Incinerated waste | Total weight of material incinerated, and the weights of the major components at all stations, is decreasing. This is because of improved practices—for example, the amount of imported packing materials is being reduced | | | | |
| Fuel use by generators and boilers | Quantity of fuel used by generator sets and boilers at all stations. Fuel use is high but steady | | | | |

## Assessment summary 10 (continued)

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Fuel use by vehicles | Quantity of fuel used for vehicles at all station is highly variable and depends on the use of vehicles. Increased fuel use at Casey Station is related to Wilkins Aerodrome | Poor; Stable | Adequate | Adequate | Somewhat comparable |
| Electricity | Quantity of electricity used; also indicates fuel use. 'Smart' energy is being increasingly used at Mawson Station, where 40–45% of the electricity used is from renewable energy sources | Good; Improving | Adequate | Adequate | Comparable |
| Fuel use by ships | Fuel use of all vessels engaged in transport of goods and people, as well as marine science voyages, varies between years, because of differing demands and sea ice conditions. For example, more fuel is required in years of heavy sea ice | Poor; Stable | Adequate | Adequate | Somewhat comparable |
| Fuel use by aircraft | Although fuel use by fixed-wing aircraft has been highly variable in the past, it has been relatively stable for the past 5 years<br>Fuel use by helicopters is reasonably stable<br>Fuel use does not include aviation ground-support elements | Poor; Stable | Adequate | Adequate | Comparable |

For additional information and an accessible version of the assessment summary, see SoE Digital.

**Recent trends**

- Improving
- Deteriorating
- Stable
- Unclear

**Grades**

- **Very good:** No risk of pollution or contamination of environment
- **Good:** Low risk of pollution or contamination of environment
- **Poor:** Medium risk of pollution or contamination of environment
- **Very poor:** High risk of pollution or contamination of environment

**Confidence**

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

## Contaminated sites and pollution

Contaminated waste disposal is a product of past practices of Antarctic expeditions, and is referred to as legacy contamination. Before the Madrid Protocol was signed in 1991, rubbish was dumped at various locations near the stations, or was disposed of by leaving it on the sea ice until it broke out.

Because of past practices, waste material is present in the terrestrial and nearshore marine environments. Some contaminants are known to be present in quantities that are potentially hazardous to the environment. Although frozen for much of the year, these contaminants can be mobilised during the summer months when there is increased water flow through areas from the snowmelt.

The largest ongoing risk and source of new pollution in Antarctica is associated with bulk fuel storage. Large quantities of SAB fuel (more than 1 million litres per year) is transferred from the ship and stored at the stations. The climate in Antarctica presents significant challenges for infrastructure and operations, and there is always the risk of spills when transporting or storing fuel. Land-based fuel spills, some as large as 11,500 litres, have occurred in the past 5 years, because of mechanical failures or human error during transfer from ship to shore. A review of spill incidents from the 1980s to 2013 identified:

- 1 spill of more than 100,000 litres (234,000 litres from MV *Nella Dan* sinking off Macquarie Island in 1987)
- 6 spills of 10,000–90,000 litres
- 10 spills of 1000–9000 litres
- 6 spills of 200–900 litres
- 32 spills of less than 200 litres.

Approximately 65 per cent of spills are the result of equipment or mechanical failure, and the remaining 35 per cent are because of human error. In some instances, fuel storage tanks leaked during winter, and the leaks went unnoticed until the summer melt revealed that they had drained their contents. Today, all tanks are bunded (surrounded by a secondary containment that minimises or eliminates any fuel leakage). Hence, the environmental damage is reduced or avoided altogether.

Recently, several tip sites and old fuel spill sites have been assessed and remediated, including the Casey tip site. The most significant fuel spill remediation under way at the time of writing is at Casey Station; in late 2015, a connection in the fuel transport infrastructure leaked and contaminated the site. This incident is the subject of an investigation, and a comprehensive risk assessment has been conducted to identify the best course of action in containing and remediating the site.

The AAD has successfully remediated soils contaminated from several fuel spill events, and used remediated soils in building projects at Davis (Box ANT8) and Casey stations.

Some station buildings contain asbestos, and the AAD has started to identify how to address this. For example, asbestos removal from the former living quarters at Davis Station resulted in a significant amount of asbestos being returned to Australia in 2015. Other areas, such as Heard Island, present a greater challenge. The decay of buildings and structures, and the extent of asbestos debris on the island was assessed in 2012. However, there has not yet been an opportunity to undertake any clean-up activity at the site of the former Australian National Antarctic Research Expeditions station at Atlas Cove on Heard Island. The AAD provides warning and advice to government and nongovernment operators that intend to visit the site, as part of the assessment and authorisation process provided for in the Heard Island and McDonald Islands Marine Reserve Management Plan, and the *Environment Protection and Management Ordinance 1987* to the *Heard Island and McDonald Islands Act 1953*.

Despite the large distances that separate Antarctica from the rest of the world, pollution generated elsewhere on Earth can travel to Antarctica by air or water. Some persistent organic pollutants, such as the insecticide DDT and its derivatives, can be transported to the polar regions through a process known as ‘global distillation’. This process occurs when volatile chemicals evaporate in the warmer places in which they are used and condense in colder places.

Antarctica provides an important site for monitoring global background levels of known contaminants that are controlled by the Stockholm Convention on Persistent Organic Pollutants. Antarctica also serves as an early warning of the global environmental build-up of new and emerging contaminants.

## Box ANT8 Remediation and re-use of soil from a fuel spill near Lake Dingle, Vestfold Hills

On 15 January 2010, a helicopter was carrying a sling load of three 200-litre drums of special Antarctic blend (SAB) diesel fuel from Davis Station to a nearby aircraft ski-landing area. The load became unstable and, for the safety of the aircraft and personnel, it was released from a height of approximately 60 metres. The drums ruptured on impact, and the fuel seeped into sandy soil adjacent to Lake Dingle.

The initial response was conducted in accordance with the station fuel spill contingency plan, and a response team with spill equipment was at the site within an hour.

While the initial efforts were under way to contain and remove the contamination source, a multidisciplinary team assembled to assess the site and work out the best clean-up options.

Considering the environmental values of the site and the options available for clean-up, it was decided to remove all soil contaminated with more than 100 milligrams of fuel per kilogram of soil (mg-fuel/kg-soil) from the site and to remediate it in a contained treatment cell referred to as a 'biopile'.

In early 2010, approximately 130 tonnes of excavated soil from the spill site were flown by helicopter to Davis Station. In the following season (2010–11), an additional 38 tonnes of soil were removed from the impact point using a portable vacuum suction unit driven with compressed air.

A detailed soil and water sampling program was conducted to assess the spill site after excavation works. No samples with fuel concentrations above the 100 mg-fuel/kg-soil target were detected, and there was no evidence of fuel contamination in Lake Dingle or in waters migrating from the spill site towards the lake.

Fuel drums following impact at Lake Dingle

Photo by Tim Spedding, Australian Antarctic Division, all rights reserved

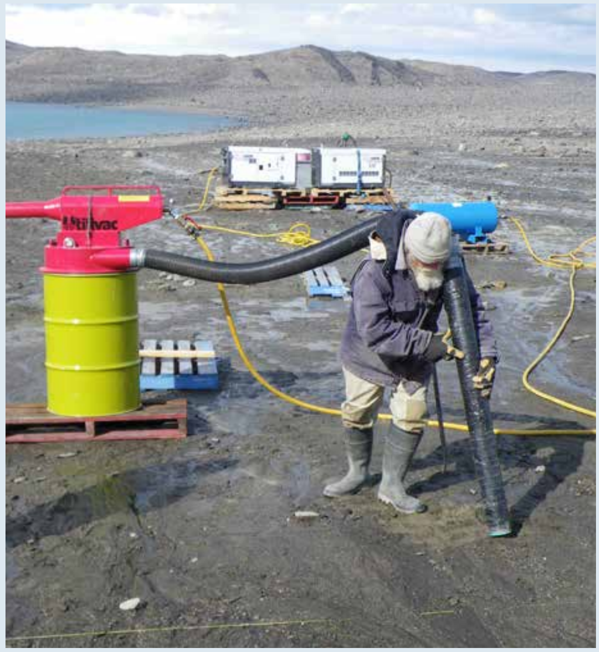
## Box ANT8 (continued)

The biopile was designed and built using materials typically used in engineered landfill designs. The barrier had 3 layers of material, providing a superior barrier and confidence that the hydrocarbon contaminants were being contained within the biopile. A geotextile cover was placed on top of the contaminated soil in 2013 to prevent dust migration and provide a barrier between the soil and animals (e.g. elephant seals). To improve the natural breakdown of hydrocarbon contaminants by native microorganisms, a mixture of nitrogen, phosphorous and potassium was added to the biopile.

Managing the biopile included removing excess water that accumulated from the snowmelt each season from inside the biopile, to prevent water from spilling over the containment barriers and potentially contaminating the surrounding environment. The operation also included aerating the soil each year by turning it with an excavator. The soil and leachate were sampled every year to measure nutrient (fertiliser) and fuel concentrations, the latter of which decreased each year.

Ongoing soil analysis confirmed that, by late 2014, contaminant concentrations in the biopile soil were at a level where the soil could be re-used for building footings. This is a site-specific and use-specific re-use option for the remediated soil. Remediated soil not used for building footings is kept on station, and any alternative re-use will require further risk assessment specific to the proposed re-use option.

The clean-up of the Lake Dingle fuel spill is the first example of the remediation and re-use of fuel-contaminated soil onsite in Antarctica. Soil is a valuable and scarce resource in Antarctica, and this approach was used to offset the environmental impact of soil excavation required for infrastructure works.



Vacuuming contaminated soil from the Lake Dingle spill

Photo by Tim Spedding, Australian Antarctic Division, all rights reserved

Remediated soil from Lake Dingle spill available for use in future building works

Photo by Tim Spedding, Australian Antarctic Division, all rights reserved

## Assessment summary 11

### State and trends of contaminated Antarctic sites

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Thala Valley | Terrestrial section of Thala Valley clean-up finalised; some material remains in the nearshore marine environment | Very good ↗ | ● | ● | ◆ |
| Old Casey station | Historical fuel spill (1980s) | Poor — | ● | ● | ◆ |
| Casey Station main powerhouse | Fuel spill at main powerhouse (1999); contaminants reached the melt lake from which fresh water is obtained for the station | Very good ↗ | ● | ● | ◆ |
| Wilkes station | Abandoned station (built in 1957); old tip site and fuel cache are still present and contain a large volume of contaminated material | Poor — | ● | ● | ◆ |
| Tip site at Davis research station | Old tip site near Davis research station | Poor — | ◒ | ◒ | ◆ |
| Lake Dingle fuel-spill remediation | Fuel spill (2010) | Good ↗ | ◒ | ◒ | X |
| Tip site at Mawson research station | Old tip site, large land-based debris removed. Some material remains in the nearshore marine environment | Poor — | ◒ | ◒ | ◆ |
| Macquarie Island fuel farm | Historical fuel spill (1980s) | Good ↗ | ● | ● | ◆ |
| Macquarie Island main powerhouse | Historical fuel spills (1980s–2000) | Good ↗ | ● | ● | ◆ |

## Assessment summary 11 (continued)

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Casey fuel line leak (October 2015) | Leakage of 3500 litres of special Antarctic blend fuel from above-ground fuel line. Containment barriers were constructed and an extensive area (less than 5000 m$^2$) of contaminated soil requiring treatment and remediation was identified | Poor, Stable | Adequate | Adequate | X (Not previously assessed) |

For additional information and an accessible version of the assessment summary, see SoE Digital.

**Recent trends**

- Improving
- Deteriorating
- Stable
- Unclear

**Grades**

- **Very good:** Remediation activities completed; remediation monitoring continues
- **Good:** Remediation in progress and/or containment of contaminates achieved
- **Poor:** Preliminary impact assessment under way, including identification of contaminants
- **Very poor:** No action yet

**Confidence**

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

## Heritage values

Antarctica's unique environment is internationally recognised, and a wide range of its heritage values are protected under the Madrid Protocol. In addition to the general, continent-wide protection provided by the protocol, extra levels of protection can be applied to areas of outstanding environmental, scientific, historic, aesthetic or wilderness values by a range of frameworks (Table ANT1). For example, they can be designated as Antarctic Specially Protected Areas (ASPAs). Sites of particular significance to Australia have also been added to our National Heritage List. Australia's subantarctic islands, which do not come under the Antarctic Treaty, are on the World Heritage List. The old part of Mawson Station—the oldest continuously occupied Antarctic station—and Mawson's Huts in Antarctica are listed on the Commonwealth Heritage List.

### Natural heritage

Australia's 2 subantarctic islands or island groups—Heard Island and McDonald Islands in the Southern Ocean, and Macquarie Island in the south-west Pacific—were listed on the World Heritage List and the National Heritage List in 1997 and 2007, respectively, because of their 'outstanding universal value'. The inclusion of these areas on the World Heritage List underlines not only the physical and natural values of these areas, but also their international importance. Moreover, these areas are significant for Australia's Antarctic history, because both contain sites of cultural heritage value (Australian Government 1990, PWS 2006). Heard Island and McDonald Islands is an Australian territory, managed by the AAD. In 2014, the total area of the Heard Island and McDonald Islands Marine Reserve was increased by about 6200 km$^2$ to incorporate additional marine areas with high conservation values. The AAD has since released the second Heard Island and McDonald Islands Marine Reserve Management Plan, which reflects these changes, and outlines key provisions for management activities within the marine reserve and for protecting conservation values.

Macquarie Island is part of Tasmania, and is in the care of the Tasmanian Parks and Wildlife Service. However, the AAD coordinates and manages the maintenance of the station and field huts, as well as logistic operations.

Australia also manages 12 ASPAs, including one at Commonwealth Bay, and helps to manage, with other nations, the Larsemann Hills Antarctic Specially Managed Area (ASMA). Since 2015, 41 Important Bird Areas (IBAs) in the AAT have been identified by BirdLife International as important breeding sites for flying seabirds and penguins. Four ASPAs (Taylor Rookery, Rookery Islands, Scullin and Murray Monoliths, and

**Table ANT1 Status of listings of Australia's natural and historic heritage in Antarctica**

| Site type | Site | National Heritage List | Commonwealth Heritage List | World Heritage List | ASPA/ASMA (designated by ATCM) | HSM (designated by ATCM) |
|---|---|---|---|---|---|---|
| Natural | Heard Island and McDonald Islands | Listed 2007 | N/A | Registered 1997 | N/A | N/A |
| | Macquarie Island | Listed 2007 | N/A | Registered 1997 | N/A | N/A |
| Historic | Mawson's Huts Historic Site | Listed 2005 | Listed 2004 | N/A | ASPA 162, designated 2004 | HSM 77: Cape Denison, designated 2004 |
| | Mawson Station | N/A | Listed 2004 | N/A | N/A | N/A |

ASMA = Antarctic Specially Managed Area; ASPA = Antarctic Specially Protected Area; ATCM = Antarctic Treaty Consultative Meeting; HSM = Historic Site or Monument; N/A = not applicable

Amanda Bay) are included in this list. To be nominated as an IBA, a site must fulfil certain criteria identified by Birdlife International (Harris et al. 2015). Antarctic IBAs were formally recognised during the annual Antarctic Treaty Consultative Meeting by Antarctic Treaty nations in Bulgaria in 2015. The Antarctic Treaty parties agreed to draw on the information about these IBAs in advancing Antarctic environmental protection objectives.

## Historic heritage

Significant sites associated with cultural heritage can be found in the AAT, at Heard Island and McDonald Islands, and at Macquarie Island in the Southern Ocean. There are 4 key types of cultural heritage sites in the region (Lazer 2006), associated with:

- early scientific endeavour and exploration (1911–14)
- the sealing industry on Heard Island and McDonald Islands, and Macquarie Island
- the British, Australian and New Zealand Antarctic Research Expedition (1929–31)
- Australian National Antarctic Research Expeditions and agencies of other nations that established research stations in the AAT after World War 2.

Any conservation work on the historic sites in Antarctica is assessed for its impact under the *Antarctic Treaty (Environment Protection) Act 1980*. The *Environment Protection and Biodiversity Conservation Act 1999* also applies in some cases. The preferred approach is to leave heritage items in situ. However, artefacts of particular significance may be recovered from Antarctica for conservation treatment or protection. These artefacts include books, clothing, scientific and mechanical devices, field equipment and many others that, if left in situ, would deteriorate and be lost. The items are catalogued in the Antarctic Heritage Register, housed in the AAD data centre.

One of Australia's most important historic sites of international significance is Mawson's Huts, which were erected in 1911 at Cape Denison, Commonwealth Bay, by the men of the Australasian Antarctic Expedition under the leadership of Douglas Mawson. The expedition was the first major and, as it turned out, most dramatic scientific program of the young nation. At the time, it was important for the application of new technologies, such as the use of wireless transmissions between Antarctica and the outside world via a relay post at Macquarie Island. The expedition collected a wealth of biological, magnetic, geological and meteorological data.

The base that Mawson and his team established at Cape Denison in 1911 was never intended to be a long-term establishment. Although the huts were solidly built and survived the Antarctic conditions for many decades, wind ablation and snow intrusion have taken their toll, and the structural elements of the site have been deteriorating since their construction. The main hut and the magnetograph house are in sound condition, and the integrity of their interiors is high. In 1998, the magnetograph house was altered by addition of timber cladding on the roof. The transit hut and absolute magnetic hut are in poor condition; both huts have been stabilised to preserve them as standing ruins. The Memorial Cross is in good condition (AAD 2007). Most of the portable artefacts outside the huts are still in the same locations as when Mawson left the site in 1914 (Mawson 1915, Lazer 2006).

In 2005, the Australian Government registered the remains of the 4 huts and associated artefacts on Australia's National Heritage List as the Mawson's Huts Historic Site, and launched a conservation management plan to protect the site. The site is also designated as an Antarctic Historic Site under the Madrid Protocol. It was afforded a higher level of protection when, in 2014, the Antarctic Treaty parties agreed to change the status of the Cape Denison area, within which the huts are located, from an ASMA to an ASPA under the Madrid Protocol. The site may only be visited under a permit. In 2013, the AAD launched a revised Mawson's Huts Historic Site Management Plan. All activities undertaken at the site, including conservation activities undertaken by the Australian Government or on behalf of the Australian Government by the Mawson's Huts Foundation, are governed by the provisions of the plan.

For several years, the Australian Government has facilitated the Mawson's Huts Foundation to undertake conservation work at the Mawson's Huts site. The Mawson's Huts Foundation has completed essential repairs to the huts and substantively weatherproofed the living quarters, even though access to the site has been hindered by unfavourable sea ice conditions in recent years. The most recent expedition to the site (2015–16) saw a substantial amount of snow and ice removed from the interior of the main hut, and ongoing works to improve the stability and conservation of the structures and artefacts at the site.

In addition to Mawson's Huts, several sites within the AAT are formally protected under the Antarctic Treaty System through their designation as a Historic Site or Monument (Table ANT1). These include rock cairns at Proclamation Island, Enderby Land and Cape Bruce erected by Sir Douglas Mawson, and a cairn erected by Sir Hubert Wilkins in 1939 in the Vestfold Hills, Ingrid Christensen Coast. Several other historic sites and monuments have been declared under the Antarctic Treaty provisions to protect sites of significance to other nations active in the AAT.

In 2014, the AAD released the Mawson Station Heritage Management Plan. Mawson is the oldest station in Antarctica that has been continually occupied. The management plan provides a framework to identify, protect, conserve and transmit the heritage values of Mawson Station, noting that the station's buildings reflect the evolution of Antarctic construction methods spanning several decades.

Most sealing industry sites are on subantarctic island coasts, and are at risk from the effects of the extreme weather, climate change and a dynamic coastline, as well as human interference and encroachment by vegetation. At Heard Island and McDonald Islands, a significant amount of cultural heritage material has been lost or has had to be relocated since recording of the cultural heritage began in the mid-1980s. Many of the portable artefacts are slowly deteriorating and only have a limited lifespan (Lazer & McGowan 1987). Several buildings at the site of the former Heard Island Station have deteriorated, and a significant amount of debris is now evident, including asbestos. Many sites on Macquarie Island are now partially buried. Shipwreck material, structural elements and portable artefacts are slowly deteriorating (Clark 2003, Carmichael 2004, Lazer 2006). Ruins of the masts and huts on Wireless Hill survive, but are deteriorating (Townrow 1988, Carmichael 2004, Lazer 2006). One of the remaining masts was removed in 2011.

Mawson's main hut

Photo by Nisha Harris, Australian Antarctic Division, all rights reserved

## Assessment summary 12

### State and trends of listed or specially protected sites in Antarctica and the subantarctic that are managed by Australia

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Heard Island and McDonald Islands | Retreating glaciers open potentially new habitat for flora and fauna; visits to the island are infrequent, which makes monitoring difficult | Good ? | ◒ | ◒ | ◆ |
| Macquarie Island | Rodent and rabbit eradication program has been completed, and the island's vegetation that had suffered from overgrazing is improving rapidly. However, some plant species, such as the Macquarie Island cushion plant (*Azorella macquariensis*), continue to show signs of significant stress due to drier conditions | Poor ↗ | ● | ● | ◆ |
| Taylor Rookery (ASPA 101) | This penguin colony is currently the only emperor penguin colony that is known to be situated entirely on land. The population of penguins has been monitored annually since 1988, and some historical information is also available. The number of breeding pairs continues to decrease | Poor ↙ | ● | ● | ◆ |
| Rookery Islands (ASPA 102) | Six different seabird species are breeding on the islands<br>A very small colony of southern giant petrels is 1 of only 4 known colonies in East Antarctica | Good — | ◒ | ◒ | ◆ |
| Ardery Island and Odbert Island (ASPA 103) | These islands provide breeding habitat for several species of petrels and are examples of their habitat. Visits to the islands are infrequent, and no regular census work is done | Good ? | ◒ | ◒ | ◆ |
| North-East Bailey Peninsula (ASPA 135) | Scientific reference site for vegetation typical of the area.<br>A number of flora studies were conducted in the 1980s. Changes in snow availability appear to put local vegetation under water stress | Good ↙ | ◒ | ◒ | ◆ |

## Assessment summary 12 (continued)

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Clark Peninsula (ASPA 136) | Designated to protect the largely undisturbed terrestrial ecosystem that includes associations of macrolichens and bryophytes. There is also a colony of Adélie penguins. Possibly similar issues with regard to water resources as ASPA 135, but so far there is insufficient evidence | Good: ? | | | |
| Marine Plain (ASPA 143) | The area is representative of an important ice-free terrestrial ecosystem<br>The area contains important sites for studying the palaeoecology and palaeoclimate | Good: ? | | | |
| Frazier Islands (ASPA 160) | A group of 3 small islands, all of which are occupied by a variety of seabirds, including small colonies of southern giant petrels (*Macronectes giganteus*)<br>Trends are difficult to estimate because of a lack of data; a significant change in the population size cannot be demonstrated | Good: — | | | |
| Scullin and Murray Monoliths (ASPA 164) | The greatest concentrations of breeding seabirds in East Antarctica are found here; bird numbers range from tens to hundreds of thousands<br>Remote location makes regular visits impossible | Good: ? | | | |
| Hawker Island (ASPA 167) | The declaration of this area as an ASPA means that all colonies of southern giant petrels in the Australian Antarctic Territory are now protected | Good: — | | | |
| Amanda Bay (ASPA 169) | The only large emperor penguin colony in Prydz Bay is located here<br>In the past, few visits were made to this area. Automated cameras installed in 2011 will enable better monitoring of this colony | Good: ? | | | |

## Assessment summary 12 (continued)

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Larsemann Hills (ASMA 06) | Two major peninsulas represent a significant part of the ice-free fraction of East Antarctica. Three permanently occupied non-Australian stations exist here | Good; ? (Unclear) | Limited | Limited | Comparable |
| Stornes (ASPA 174) (Note: Assessed as part of Larsemann Hills in 2011) | Located within the Larsemann Hills, Stornes is the first ASPA that has been designated primarily for its outstanding geological features, which are collectively known as hard rock occurrences | Good; — (Stable) | Adequate | Adequate | Somewhat comparable |

ASMA = Antarctic Specially Managed Area; ASPA = Antarctic Specially Protected Area
For additional information and an accessible version of the assessment summary, see SoE Digital.

**Recent trends**
- ↗ Improving
- ↙ Deteriorating
- — Stable
- ? Unclear

**Grades**
- **Very good:** Component in excellent state; management plan in place
- **Good:** Component is undergoing conservation work; management plan in place
- **Poor:** Component in poor condition but can be rescued; management plan in place
- **Very poor:** Heritage component is damaged beyond repair

**Confidence**
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## Assessment summary 13

### State and trends of historic heritage in Antarctica

| Component | Summary | Assessment grade (Very poor / Poor / Good / Very good) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|---|
| Mawson's Huts (ASPA 162), Commonwealth Bay (ASMA 03) | Site subject to ongoing conservation work in accordance with the management plan | Very good, Improving | Adequate | Adequate | Comparable |
| Old Mawson Station | Management plan in place | Good, Improving | Adequate | Adequate | Comparable |
| Old Davis Station | Ongoing routine maintenance | Good, Stable | Adequate | Adequate | Comparable |
| Heard Island and McDonald Islands | Oil barrels and sealers' graves deteriorating; buildings deteriorating with consequent debris including asbestos; visits are infrequent, making monitoring activities challenging<br>A management plan is in place with a management strategy, although no active conservation actions are carried out | Poor, Deteriorating | Limited | Limited | Comparable |
| Macquarie Island | A number of old structures removed, but the remains of oiling and sealing works are still on the island | Poor, Stable | Adequate | Adequate | Comparable |

ASMA = Antarctic Specially Managed Area; ASPA = Antarctic Specially Protected Area

For additional information and an accessible version of the assessment summary, see SoE Digital.

**Recent trends**

- Improving
- Deteriorating
- Stable
- Unclear

**Grades**

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# Effectiveness
## of Antarctic management

### At a glance

Antarctica is governed through the international agreements of the Antarctic Treaty System, including the Protocol on Environmental Protection to the Antarctic Treaty, and the Convention on the Conservation of Antarctic Marine Living Resources. These agreements establish Antarctica as a natural reserve devoted to peace and science; environmental protection and conservation of marine living resources are key objectives. Parties to these agreements implement environmental management arrangements for activities in Antarctica conducted by their nationals. Australia is active in international forums to advance our national interest in Antarctic environmental protection, including through efforts to advance the objectives of the Protocol on Environmental Protection and the Commission for the Conservation of Antarctic Marine Living Resources in relevant international forums. Australia administers associated domestic legislation, conducts and supports science to inform the wise management and protection of Antarctica, and manages Australia's Antarctic program in a way that promotes best practice in environmental stewardship.

In the Australian Antarctic Program, Australia implements and manages practical measures to minimise the effects of our Antarctic activities, and address past impacts through cleaning up former work sites and waste disposal sites. Australia also plays a significant role in combatting illegal, unreported and unregulated fishing in the Southern Ocean.

Research ensures that management of activities in Antarctica and the Southern Ocean is based on sound scientific principles and the best available scientific knowledge. Australia's research contributes to understanding how environmental systems function and how global climate change affects the Antarctic environment.

Although climate change cannot be mitigated through the management of activities in Antarctica, Australian research helps to inform strategies to maximise the resilience of the Antarctic environment and ecosystems.

Protecting Antarctica's environment is a key national interest for Australia. Australia has played, and continues to play, a key role in leading and fostering the development of international environmental management initiatives through the Antarctic Treaty System, such as developing the protected areas system (including marine protected areas under CCAMLR), and establishing practices and standards for the clean-up of contaminated sites.

There are 4 main types of human activities in the Antarctic region:

- fishing
- national Antarctic programs
- commercial tourism
- other nongovernmental activities, such as private expeditions.

The AAD administers Australia's national Antarctic program, which focuses mainly on the East Antarctic region of the continent, but also Australia's subantarctic islands and the Southern Ocean. Other countries—such as China, India, Japan, Norway and Russia—also operate in East Antarctica, including within the AAT. Tourism, including by Australian tour operators, occurs mostly in the Antarctic Peninsula region, away from the Australian Antarctic Program's main areas of interest.

## Governance

The Antarctic Treaty System is the primary international governance framework for the Antarctic region. Australia's engagement with the international forums of the Antarctic Treaty System supports Australia's objectives of protection and management of the Antarctic region, including the AAT. These objectives are embodied in Australian legislation and are given effect through the administration of this legislation by the AAD.

### International engagement

Internationally, Australia has taken a leading role in promoting environmental protection within the Antarctic Treaty System since its inception. Australia actively participates and leads discussions in key Antarctic international forums, including the Antarctic Treaty Consultative Meeting (ATCM), the Committee for Environmental Protection, CCAMLR, the Council of Managers of National Antarctic Programs, and the Agreement on the Conservation of Albatrosses and Petrels.

### Australian legislation

The obligations contained within Australia's international agreements are incorporated into Australian domestic law:

- The legal regime for the AAT is established in the *Australian Antarctic Territory Act 1954*.
- The *Antarctic Treaty Act 1960* gives effect to the Antarctic Treaty. Other Australian legislation implements parts of the Antarctic Treaty System into Australian law, including the *Antarctic Treaty (Environment Protection) Act 1980*, which gives effect to the Madrid Protocol and sets out environmental protection obligations for all activities in the Antarctic Treaty area.
- The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) applies to activities undertaken on Australian land (such as the AAT), including those that may have significant impact on matters of national environmental significance.
- The Convention on the Conservation of Antarctic Marine Living Resources is implemented in domestic law through the *Antarctic Marine Living Resources Conservation Act 1981*.

The legal regime for Heard Island and McDonald Islands is established in the *Heard Island and McDonald Islands Act 1953*. Under this Act, the *Environment Protection and Management Ordinance 1987* provides for the protection of the environment and controls access to the territory. The territory is also a World Heritage–listed site and a proclaimed Commonwealth Reserve under the EPBC Act. All activities in the territory must be in accordance with the Heard Island and McDonald Islands Marine Reserve Management Plan.

The Macquarie Island Commonwealth Marine Reserve is adjacent to the Macquarie Island Nature Reserve, which is managed by the Tasmanian Government. The marine reserve is subject to the EPBC Act, with activities in the reserve governed by the South-east Commonwealth Marine Reserves Network Management Plan 2013–23. Macquarie Island is also a World Heritage–listed site.

### Marine environment

This section relates to international agreements of relevance to the Antarctic marine environment other than the Convention on the Conservation of Antarctic Marine Living Resources and the Antarctic Treaty/Madrid Protocol, which are the primary instruments.

The International Whaling Commission was established in December 1946 when the International Convention for the Regulation of Whaling was signed by 15 nations, including Australia. The commission operates independently from the Antarctic Treaty System. Currently, it has 88 member states, and biannual meetings are held in the various member countries. A committee of approximately 200 whale biologists offers scientific advice to the commission.

Seals living in Antarctic waters are protected and managed under agreements separate from the Convention on the Conservation of Antarctic Marine Living Resources. The Convention for the Conservation of Antarctic Seals is part of the Antarctic Treaty System. It entered into force generally in 1978 and for Australia in 1987. This convention applies to all earless seals and southern fur seals. Currently, there is no commercial sealing in the Antarctic.

The International Maritime Organization (IMO) is a United Nations agency with responsibility for the safety and security of shipping, and the prevention of marine

Glacial lake, Vestfold Hills, Antarctica
Photo by Chris Wilson, Australian Antarctic Division, 

pollution by ships. IMO agreements apply to shipping in Antarctic waters, and are an important avenue for enhancing Antarctic environmental protection.

In recognition of the risk of pollution associated with heavy fuel oils, which break down more slowly than other fuels, the parties to the Antarctic Treaty initiated discussions with the IMO to limit the use and carriage of heavy and intermediate fuel oils in ships in Antarctic waters. An amendment to MARPOL (International Convention for the Prevention of Pollution from Ships) 73/78 Annex I, banning the use of heavy fuels in the Antarctic area, entered into force on 1 August 2011.

With the participation and support of the parties to the Antarctic Treaty, the IMO adopted the International Code for Ships Operating in Polar Waters (Polar Code). The aim of the Polar Code is to provide for safe ship operation and the protection of polar environments; the code will enter into force on 1 January 2017. The Polar Code includes provisions relating to equipment, design and construction, and operations of vessels in polar waters, including the waters of the Antarctic region. Australia was active in the negotiation of the Polar Code in the IMO.

# Management processes

Several processes contribute to the overall management of the Antarctic region, including the framework for protected areas, as well as activities on the stations and in the field.

## Protected areas

Under the Madrid Protocol, all of Antarctica has a high level of environmental protection. However, certain areas can be afforded additional protection if they have outstanding environmental, scientific, historic, aesthetic or wilderness values. The parties to the Antarctic Treaty have developed guidelines for assessing areas suitable as ASPAs and preparing the required management plans, which are submitted by the proposing party to the Committee for Environmental Protection and approved at an ATCM. The management plans identify:

- the reasons for designating an area as an ASPA
- restricted zones
- the conditions under which permits may be granted
- the conditions under which an area may be accessed and the kinds of activities that may be conducted.

Reviews every 5 years help to determine whether the management objectives are achieved and the values are preserved. Entry into an ASPA is prohibited unless a permit has been issued either by the AAD or the equivalent government department of another country.

Australia administers management plans for 12 ASPAs in Antarctica.

## Australian Antarctic Division environmental management system

In 2002, the AAD became the first national Antarctic program to implement an environmental management system certified to the international standard ISO 14001. The environmental management system continues to provide a framework for the systematic management of how the Australian Antarctic Program interacts with the environment.

Each station has a nominated environmental officer who is responsible for reporting environmental issues as they occur and suggesting improvements in the way activities are carried out. However, environmental protection is everybody's responsibility. A web-based reporting system allows any expedition member to submit information or suggestions on environmental issues.

## Training and awareness

The AAD, as lead agency for Australia's Antarctic program, ensures that everyone involved in the program is aware of their personal responsibility to care for the environment. When appointed, all expeditioners must agree to abide by a code of personal behaviour, which includes a practical commitment to Australia's environmental management responsibilities. Induction and training of new employees includes an introduction to the relevant Australian laws and the AAD's approach to environmental matters. At Australia's Antarctic and subantarctic stations, the station leader is responsible for environmental management, and is assisted by the station environment committee, a station environmental officer and a station waste-management officer.

## Management achievements

Australian officials actively participate in the international forums of the Antarctic Treaty System to promote improved environmental protection and conservation outcomes for the Antarctic region.

There are numerous examples of management achievements in recent years:

- Australia hosted the 35th ATCM and the 15th meeting of the Committee for Environmental Protection in June 2012. These meetings helped Australia demonstrate its commitment to protecting the Antarctic Treaty, the Madrid Protocol and the Antarctic environment.
- Since 2014, an Australian has held the influential and high-profile position of Chair of the Committee for Environmental Protection, which is established under the Madrid Protocol to advise the parties on how best to achieve their shared objective of comprehensively protecting the Antarctic environment.
- Australia, with France and Spain, led diplomatic efforts in 2012, 2013 and 2014 to encourage Antarctic Treaty parties that had not yet acceded to the Madrid Protocol to do so. Pakistan acceded to the protocol in 2012, and Venezuela and Portugal acceded in 2014.
- The Committee for Environmental Protection adopted the *Non-native species manual* in 2011, following work initiated by Australia, New Zealand and France. The manual seeks to safeguard Antarctic biodiversity by providing practical guidance to help parties prevent or minimise the introduction of non-native species to Antarctica, and the transfer of species between sites in Antarctica.
- In 2012, the Committee for Environmental Protection and the ATCM endorsed the results of research led by Australia and the Scientific Committee on Antarctic Research, which identified 15 biologically distinct ice-free Antarctic Conservation Biogeographic Regions. The Antarctic Treaty parties agreed that the biogeographic regions can be used as a framework to support conservation management, including further development of the Antarctic protected areas system, and minimise the unwanted transfer of species between Antarctic locations.
- In 2012, following a proposal from Australia, New Zealand and France, the Committee for Environmental Protection finalised a study of the environmental aspects and effects of Antarctic tourism. The study found no evidence of significant environmental effects, but highlighted the need for improved site monitoring and data to inform environmentally sound tourism management.
- An Antarctic clean-up manual, which provides practical guidance on cleaning up past Antarctic waste disposal sites and abandoned worksites, was adopted in 2013 by the Committee for Environmental Protection, following a proposal by Australia and co-sponsorship by the United Kingdom. The manual assists parties to use the most environmentally effective and cost-effective approaches to clean-up activities.
- Site-specific guidelines continue to be an effective tool to promote the safe and environmentally sensitive conduct of Antarctic tourism. In 2013, Australia participated in an international team that conducted an onsite review of areas used by tourists in the Antarctic Peninsula region. This work resulted in improvements to 11 site-specific guidelines, and new guidelines for 2 additional sites.
- In 2014, following a proposal led by Australia, the Antarctic Treaty parties established a new ASPA to protect the outstanding and unique geological values in the Larsemann Hills region, close to Australia's Davis Station.
- Australia participated in an international steering committee, led by New Zealand, to guide the development of an online Antarctic Environments Portal. The portal aims to support sound management of the Antarctic environment by providing an accessible source of 'policy ready' scientific summaries for key Antarctic environmental issues. The portal was endorsed by the Committee for Environmental Protection and the ATCM, and launched in 2015.
- In 2015, Australia supported development of a report by BirdLife International about IBAs in Antarctica. This report provides a foundation for long-term monitoring of seabird populations in the region, and their response to climate change and other environmental effects.

Minke whale (*Balaenoptera acutorostrata*)

- In CCAMLR, Australia has played a leading role in discussions about how to improve the conservation of Antarctic marine living resources. For example, in 2011, Australia was successful in obtaining CCAMLR agreement to a binding conservation measure on a 'General framework for the establishment of marine protected areas'. Since then, Australia, France and the European Union have been active in progressing a proposal for an East Antarctic Representative System of Marine Protected Areas. Although consensus has not been reached, significant progress has been made during the past 4 years.
- Australia's patrol presence in the Heard Island and McDonald Islands region has resulted in no reported illegal fishing activity in the Heard Island and McDonald Islands exclusive economic zone since 2004.
- In 2012, CCAMLR adopted a binding Compliance Evaluation Procedure, which started in 2013. For the first time, CCAMLR has been able to assess CCAMLR member compliance with a core set of conservation measures. The Compliance Evaluation Procedure has allowed an objective assessment by CCAMLR of member noncompliances and the assigning of a compliance status. This has led to responses that include changing procedures in member countries, imposing sanctions on vessels and improving conservation measures, where required.
- In 2012, the Heard Island and McDonald Islands toothfish fishery gained Marine Stewardship Council (MSC) certification. This process is independent of the Australian Government; however, the MSC certification is testament to the good management of the fishery. MSC certification has also been received for the other target species in the Heard Island and McDonald Islands Fishery—mackerel icefish—and for Australia's other subantarctic toothfish fishery around Macquarie Island.
- In 2011, CCAMLR adopted 2 resolutions on fishing vessel safety. The first requires CCAMLR members to provide information related to their flagged fishing vessels to the relevant Maritime Rescue Coordination Centre before the vessel enters the CCAMLR area. The second resolution, 'enhancing the safety of fishing vessels in the Convention Area', calls on CCAMLR members to consider and implement appropriate measures to increase the safety of their fishing vessels.

In recent years, there has been near zero seabird bycatch by legal fishers operating in CCAMLR-managed fisheries. However, bycatch of seabirds, including endangered albatrosses and petrels, remains unsustainable in the Southern Hemisphere. All 22 species of albatross protected under the Agreement on the Conservation of Albatrosses and Petrels are also listed by the IUCN as threatened. It is estimated that, worldwide, up to 300,000 seabirds are killed each year during interactions with coastal and high-seas fisheries (see Vertebrate populations). Coastal fisheries are subject to state legislation and fisheries regulations; in contrast, some high-seas fisheries are open-access operations. Although the high seas have been divided into management areas of various regional fisheries management organisations, the incentives to avoid overexploitation and to operate sustainably are in some cases weak (Crothers & Nelson 2007). Many of the high-seas tuna fisheries, including in the Pacific, Atlantic and Indian oceans, have only recently adopted conservation measures concerning seabird bycatch mitigation, and effective implementation of the known, effective bycatch mitigation measures is lacking. Bycatch from illegal, unreported and unregulated fishing is difficult to estimate, but known to occur at a higher rate than from legal fisheries because of the likely absence of bycatch mitigation measures. Australia, through its active engagement with the Agreement on the Conservation of Albatrosses and Petrels and other international forums (including CCAMLR and regional fisheries management organisations), is actively pursuing the adoption of sustainable fishing practices that minimise seabird bycatch.

From 2011 to 2015, Australian officials held lead positions on the executive committee and environment expert group of the Council of Managers of National Antarctic Programs. They have also chaired meetings of the key decision-makers for the national Antarctic programs that are operating stations in the Larsemann Hills—a site of high conservation value in East Antarctica. These forums were used to advance the protection of the AAT environment. Specifically, Australia:

- convened a workshop to engage Antarctic programs in a coordinated, multidisciplinary environmental data collection initiative, the Southern Ocean Observing System
- co-convened a workshop to provide Antarctic programs with advice on achieving best-practice wastewater management

- negotiated an agreement on mechanisms that will strengthen the protection of the Larsemann Hills, notwithstanding growing pressures on the region through station growth
- developed an incident reporting system, which facilitates information sharing on significant environmental issues and lessons management
- distributed maps of wildlife concentrations in the AAT to enable other countries' aviation contractors to adopt appropriate flight paths
- supported research to quantify the factors that impede waste management and station clean-up actions, consistent with obligations arising from the Madrid Protocol
- contributed to work with the Scientific Committee on Antarctic Research to develop techniques and checklists to raise supply chain managers' awareness of issues around non-native species introductions
- convened a web forum to facilitate environmental managers' information exchange
- contributed practice-based information to Antarctic Treaty meetings on, for example, the management of hydroponics in Antarctica, mechanisms for repairing or remediating environmental damage, oil spill management readiness, methods and technologies for improving energy management, development of environmental training packages, and the role and management of remotely piloted aircraft supporting national Antarctic program activities.

Macquarie Island huts

Photo by Nicholas Brown, © Geoscience Australia, all rights reserved

## Assessment summary 14
### Effectiveness of Antarctic environmental management

| Summary | Assessment grade (Ineffective / Partially effective / Effective / Very effective) | Confidence (In grade / In trend) | Comparability (To 2011 assessment) |
|---|---|---|---|

**World Heritage of subantarctic islands and protected areas under the Antarctic Treaty**

**Understanding**: Nomination of Antarctic Specially Protected Areas under the Antarctic Treaty, and World Heritage listing for the subantarctic Heard Islands and McDonald Islands, and Macquarie Island are based on their recognised natural and cultural values

**Planning**: Management plans are in place and are reviewed regularly

**Inputs:** Financial, human and information resources are available to implement the management plans

**Processes:** For Heard Island and McDonald Islands, there is stakeholder consultation, and all management plans are open to public consultation

**Outputs and outcomes:** Identified natural and cultural heritage values are being preserved

## Assessment summary 14 (continued)

| Summary | Assessment grade (Ineffective / Partially effective / Effective / Very effective) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|
| **Land use and management** | | | | |
| **Understanding:** A good understanding of the impacts of human activities in our operational environment exists | Effective — | ● | ● | ◆ |
| **Planning:** The AAD's environmental management policy provides an overarching policy framework for all activities in the Australian Antarctic Territory and the subantarctic islands. This policy is consistent with Australia's obligations under the Antarctic Treaty | Effective ↗ | ● | ● | ◆ |
| **Inputs:** The AAD administers an environmental management system supported by a program of scientific research | Effective ↗ | ● | ● | ◆ |
| **Processes:** The environmental management system is certified to the internationally recognised standard (AS/NZS ISO 14001:2004). The AAD's environmental policy was last reviewed in 2009 | Effective ↗ | ● | ● | ◆ |
| **Outputs and outcomes:** Relevant management information collected through the environmental management system is used to guide management decisions | Effective ↗ | ● | ● | ◆ |

## Assessment summary 14 (continued)

| Summary | Assessment grade (Ineffective / Partially effective / Effective / Very effective) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|
| **Adaptation to climate variability and climate change** | | | | |
| **Understanding**: There are still a number of significant uncertainties about the impacts of climate change; however, scientific programs are in place to further our understanding of processes and future implications | Partially effective ↗ | ◒ | ◒ | ◆ |
| **Planning:** The forecast infrastructure plan takes into account energy efficiencies and carbon emissions | Partially effective ↗ | ◒ | ◒ | ◆ |
| **Inputs:** Adaptive management is resourced within the current operational framework | Partially effective ↗ | ◒ | ◒ | ◆ |
| **Processes:** Scientific studies are examining potential effects of climate change | Effective ↗ | ◒ | ◒ | ◆ |
| **Outputs and outcomes:** As scientific results become available, policies are formulated | Effective ↗ | ◒ | ◒ | ◆ |

## Assessment summary 14 (continued)

| Summary | Assessment grade (Ineffective / Partially effective / Effective / Very effective) | Confidence: In grade | Confidence: In trend | Comparability: To 2011 assessment |
|---|---|---|---|---|
| **Introduced and invasive species** | | | | |
| **Understanding:** There is a good understanding of threats and impacts of non-native species, on both the Antarctic continent and subantarctic islands | Effective, Improving | Adequate | Adequate | Comparable |
| **Planning:** Policies are in place to minimise the risk and impact of non-native introductions | Very effective, Improving | Adequate | Adequate | Comparable |
| **Inputs:** Human resources are allocated to implement policies to minimise the risk of non-native introductions | Effective, Stable | Adequate | Adequate | Comparable |
| **Processes:** Environmental training and information are provided to all personnel and the public | Effective, Improving | Adequate | Adequate | Comparable |
| **Outputs and outcomes:** The legacy of non-native introductions into Antarctic and subantarctic environments (e.g. rabbits and rodents on Macquarie Island) has been mitigated through eradication efforts | Very effective, Improving | Adequate | Adequate | Comparable |

AAD = Australian Antarctic Division

For additional information and an accessible version of the assessment summary, see SoE Digital.

**Recent trends**

- Improving
- Deteriorating
- Stable
- Unclear

**Grades**

- **Very effective**
- **Effective**
- **Partially effective**
- **Ineffective**

**Confidence**

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

## Assessment summary 14 (continued)

| Management context (understanding of environmental issues; adequacy of regulatory control mechanisms and policy coverage) | |
|---|---|
| **Elements of management effectiveness and assessment criteria** | **Grades** |
| **Understanding of context**<br>Decision-makers and environmental managers have a good understanding of:<br>• environmental and socio-economic significance of environmental values, including ecosystem functions and cultural importance<br>• current and emerging threats to values.<br>Environmental considerations and information have a significant impact on national policy decisions across the broad range of government responsibilities | **Very effective:** Understanding of environmental and cultural systems, and factors affecting them is good for most management issues<br>**Effective:** Understanding of environmental and cultural systems, and factors affecting them is generally good, but there is some variability across management issues<br>**Partially effective:** Understanding of environmental and cultural systems, and factors affecting them is only fair for most management issues<br>**Ineffective:** Understanding of environmental and cultural systems, and factors affecting them is poor for most management issues |
| **Planning**<br>Policies and plans are in place that provide clarity on:<br>• objectives for management actions that address major pressures and risks to environmental values<br>• roles and responsibilities for managing environmental issues<br>• operational procedures, and a framework for integration and consistency of planning and management across sectors and jurisdictions | **Very effective:** Effective legislation, policies and plans are in place for addressing all or most significant issues. Policies and plans clearly establish management objectives and operations targeted at major risks. Responsibility for managing issues is clearly and appropriately allocated<br>**Effective:** Effective legislation, policies and plans are in place, and management responsibilities are allocated appropriately, for addressing many significant issues. Policies and plans clearly establish management objectives and priorities for addressing major risks, but may not specify implementation procedures<br>**Partially effective:** Legislation, policies and planning systems are deficient, and/or there is lack of clarity about who has management responsibility, for several significant issues<br>**Ineffective:** Legislation, policies and planning systems have not been developed to address significant issues |
| **Management capacity (adequacy of resources, appropriateness of governance arrangements and efficiency of management processes)** | |
| **Inputs**<br>Resources are available to implement plans and policies, including:<br>• financial resources<br>• human resources<br>• information | **Very effective:** Financial and staffing resources are largely adequate to address management issues. Biophysical and socio-economic information is available to inform management decisions<br>**Effective:** Financial and staffing resources are mostly adequate to address management issues, but may not be secure. Biophysical and socio-economic information is available to inform decisions, although there may be deficiencies in some areas<br>**Partially effective:** Financial and staffing resources are unable to address management issues in some important areas. Biophysical and socio-economic information is available to inform management decisions, although there are significant deficiencies in some areas<br>**Ineffective:** Financial and staffing resources are unable to address management issues in many areas. Biophysical and socio-economic information to support decisions is deficient in many areas |

## Assessment summary 14 (continued)

| | |
|---|---|
| **Processes**<br>A governance system is in place that provides for:<br>• appropriate stakeholder engagement in decisions and implementation of management activities<br>• adaptive management for longer-term initiatives<br>• transparency and accountability | **Very effective:** Well-designed management systems are being implemented for effective delivery of planned management actions, including clear governance arrangements, appropriate stakeholder engagement, active adaptive management and adequate reporting against goals<br><br>**Effective:** Well-designed management systems are in place, but are not yet being fully implemented<br><br>**Partially effective:** Management systems provide some guidance, but are not consistently delivering on implementation of management actions, stakeholder engagement, adaptive management or reporting<br><br>**Ineffective:** Adequate management systems are not in place. Lack of consistency and integration of management activities across jurisdictions is a problem for many issues |
| **Achievements (delivery of expected products, services and impacts)** | |
| **Elements of management effectiveness and assessment criteria** | **Grades** |
| **Outputs**<br>Management objectives are being met with regard to:<br>• timely delivery of products and services<br>• reduction of current pressures and emerging risks to environmental values | **Very effective:** Management responses are mostly progressing in accordance with planned programs and are achieving their desired objectives. Targeted threats are being demonstrably reduced<br><br>**Effective:** Management responses are mostly progressing in accordance with planned programs and are achieving their desired objectives. Targeted threats are understood, and measures are in place to manage them<br><br>**Partially effective:** Management responses are progressing and showing signs of achieving some objectives. Targeted threats are understood, and measures are being developed to manage them<br><br>**Ineffective:** Management responses are either not progressing in accordance with planned programs (significant delays or incomplete actions) or the actions undertaken are not achieving their objectives. Threats are not actively being addressed |
| **Outcomes**<br>Management objectives are being met with regard to improvements to resilience of environmental values | **Very effective:** Resilience of environmental values is being maintained or improving. Values are considered secured against known threats<br><br>**Effective:** Resilience of environmental values is improving, but threats remain as significant factors affecting environmental systems<br><br>**Partially effective:** The expected impacts of management measures on improving resilience of environmental values are yet to be seen. Managed threats remain as significant factors influencing environmental systems<br><br>**Ineffective:** Resilience of environmental values is still low or continuing to decline. Unmitigated threats remain as significant factors influencing environmental systems |

Snow blowing off the plateau

Photo by Barbara Wienecke, © Australian Antarctic Division, all rights reserved

# Resilience
## of the Antarctic environment

### At a glance

Although organisms living in Antarctica have evolved to cope with severe events, it is challenging to measure their level of resilience and to predict how future climate change will affect Antarctic ecosystems. This is largely because our understanding of key parameters is still limited, and with it our ability to assess adaptability and, hence, resilience of organisms and ecosystems.

The key process threatening the resilience of both the physical and living environments of Antarctica is climate change.

The Antarctic and Southern Ocean physical environments are key components of the overall global climate system. The Southern Ocean plays a major role in buffering heat and $CO_2$ uptake, thereby slowing the rate of climate change and impacts, and providing some resilience on a planetary scale. However, this comes with the problem of ocean acidification, which is nonresilient in that $CO_2$ levels remain elevated long after the cessation of emissions (Archer & Brovkin 2008).

Changes in the physical environment may be gradual or abrupt, and are complicated by feedbacks. The primary issue is the potential for state changes as climate change thresholds are crossed. As discussed in earlier sections of this report, large changes are already seen (e.g. ice loss from parts of West Antarctica, changes in the deep ocean), and conditions are thought to exist that could see more extensive or rapid changes in future.

Large uncertainties exist around the response and resilience of the physical system. Reducing these uncertainties requires several lines of research:

- studying past behaviour using palaeoclimate data
- observing present behaviour with long-term monitoring
- modelling to explore current change and predict the future.

For the living environment, the question of the level of resilience inherent in Antarctic ecosystems has not received much attention because it is complex and many parameters that are required to assess resilience are still unknown. The Scientific Committee on Antarctic Research produced a comprehensive review of the impact of climate change on the Antarctic environment in 2009, which highlighted areas where knowledge is still lacking. Although marine and terrestrial ecosystems are now better understood than in the past, baseline data on biogeography and biodiversity are still scarce, as are fundamentally important long-term monitoring data (SCAR 2009). Researchers have only just started to investigate how organisms adapt to current climate change, and how resistant and resilient organisms and systems are.

For many, if not most, vertebrate species, important aspects of the dynamics of populations are either largely unknown or have been studied only at a few sites. Without comprehensive insights into variables—such as age of first reproduction, survival of different age classes, fecundity, and the extent of emigration out of and immigration into populations—and the drivers that influence these variables, we are unable to make long-term predictions about the viability of species in a changing environment. A thorough understanding of the ecological framework in which organisms live is also important when considering their resilience. For example, several Antarctic organisms live at South Georgia, where the summers are up to 3 °C warmer than on the Antarctic Peninsula. Thus, the vulnerability of species needs to be determined based on their ecological circumstances (SCAR 2009).

Natural disturbances are part of life in Antarctic and subantarctic ecosystems, and the populations of endemic species are generally capable of surviving shock events because they have evolved strategies that allow them to rebuild after mass mortalities. Among these strategies are longevity among seabirds, and the ability of moss spores to survive for a long time.

Shock events that test the level of resilience of a system occur in Antarctica just as they do in other parts of the world, ranging from intense storms affecting large areas to more localised incidents, such as scouring of the benthic environment by drifting icebergs. As long as these shock events are rare, populations and communities can recover. However, increases in the magnitude and frequency of such events, as well as the duration of serious disturbances, are likely to become major challenges to the resilience of benthic communities. The slowest-growing species may never recover if the interval between disturbance events is too short for them to develop and grow into mature organisms. However, populations of fast-growing species may benefit if the competition for space, for example, is reduced.

Historically, we know that populations of some species of whales, seals and penguins suffered human-induced mortality rates that pushed these species to the brink of extinction. Once hunting ceased, several species recovered—some, like king penguins, in a spectacular manner (Gales & Pemberton 1988, van den Hoff 2009).

However, these recoveries took place in a world where environmental conditions were not exposed to the rapid change that is currently under way. Today, several environmental components are changing (e.g. increasing sea temperatures, ocean acidification, higher intensities of ultraviolet radiation). The changes are complex and not always unidirectional, and there is currently little evidence on how the various factors will interact. There is no doubt that some organisms will benefit from these changes in the short term, but it is difficult to predict the effect of rapid climate variations on ecosystems. Many species may be vulnerable because their capacity to adapt operates at a much slower rate than the changes currently observed.

RSV *Aurora Australis* in pack ice

Photo by Australian UAV, all rights reserved

# Risks
## to the Antarctic environment

### At a glance

As for other regions, distant human activities can contribute to the key risks to the Antarctic environment, including global population, economic pressures and the effects of climate change. Management can mitigate many of the population and economic impacts, and climate change will be the main and uncontrollable pressure bringing about change.

Earth's polar regions are likely to be affected by changing climate conditions. These changes represent the highest risk to the region, since they are unlikely to be mitigated by any locally implemented management measures. The impacts of climate change on the Antarctic environment are detailed in the Introduction section of this report.

Population and economic growth are leading to other risks. Many fish stocks around the world are depleted or fully exploited and few are given the chance to recover. A growing human population has led to demands for new sources of protein, and thus the pressure on the industry to catch krill is likely to increase. In the past, the fishing nations that are active in the Southern Ocean had never reached the catch limits for krill set by CCAMLR. However, in the 2009–10 season, the fishery reached the trigger level in one of the subareas in the South Atlantic, and, for the first time, the fishery was closed before the end of the fishing season. Since then, consecutively in the 2012–13, 2013–14 and 2014–15 seasons, the trigger limit was reached in the same subarea, and earlier each year (June, May and May, respectively). Newly developed technology has allowed vessels to catch a maximum of about 800 tonnes per day, compared with about 400 tonnes landed by conventional vessels (Nicol et al. 2011). This advanced fishing technology has contributed to a rise in the krill catch to almost 300,000 tonnes in 2014, and high catch rates may force the krill fleet to expand into new areas to avoid exceeding the existing catch limits.

The consequences of krill fishing continuously operating at the catch levels set by CCAMLR are unknown, but have been evaluated to be sustainable and consistent with the maintenance of krill-dependent predators. The impact on the krill population of environmental changes, such as ocean acidification (Kawaguchi et al. 2009), will also have to be considered when recalculating precautionary catch limits for Southern Ocean fisheries.

Recently, the IUCN Red List categorised Antarctic krill as 'least concern'. The assessment is based on krill biology—including its generation time, mortality and population size—and current management action. The 'least concern' categorisation was given primarily because there are no trends detected in the most recent 3-generation time period (15 years) and because of the very large population size. The cumulative impacts of climate change, including ocean acidification, were identified as the major threat. Regarding conservation actions recommended by the IUCN, conservation needs to include continued precautionary management of the fishery and more research on the impact of climate change on this species.

Acidification of the world's oceans is occurring because of several concurrent processes, but there is still much uncertainty about how, for example, climate change affects these processes. It is well established that levels of anthropogenic $CO_2$ are increasing in the atmosphere, transferring 1 million tonnes of $CO_2$ to the world's ocean per hour (Hester et al. 2008). For the Southern Ocean, the process of overturning circulation (where deep water upwells and releases $CO_2$ to the atmosphere) is particularly important. As the atmosphere warms, surface waters warm, which increases stratification and limits gas exchange of this upwelled water with the atmosphere. This, in turn, causes greater retention of $CO_2$, allowing more time for respiration of organic matter by marine bacteria. All these processes increase acidification (Hester et al. 2008). Several studies are highlighting diverse and sometimes unexpected consequences on marine ecosystems:

- The effects of ocean acidification on the availability of nutrients compromise the ability of organisms to deposit and maintain exoskeletons of calcium carbonate. With less calcium in their shells, they are lighter and less likely to sink into deeper waters. This reduces the flux of organic material to the deep ocean (a process known as the 'biological pump', which sequesters carbon from the atmosphere to the deep sea) and increases the amount of $CO_2$ in the upper water column (Hofman & Schellnhuber 2009). The overall effect of climate change on the biological pump is influenced by many competing pathways (e.g. photosynthesis, grazing, sinking, respiration). The outcome is currently uncertain, but is likely to have severe biological impacts within decades, and could dramatically affect the structure and function of marine ecosystems (Feely et al. 2004; Orr et al. 2005, 2009; Doney et al. 2009b; Hutchins et al. 2009; Shi et al. 2010). Such changes would have profound effects on ecosystem services, including the productivity of fisheries and the efficiency of the Southern Ocean sink for atmospheric $CO_2$. These changes are most pronounced in the polar regions, where the acidity of the waters is changing twice as fast as in the warmer tropical and subtropical regions.
- Growth and survival of fish populations could be impaired in an acidifying ocean. Tropical fish larvae that were exposed to increased levels of $CO_2$ changed their behaviour in a way that made them 5 to 9 times more prone to predation. Such an increase in mortality can reduce the long-term survival of fish populations (Munday et al. 2010).
- A decrease in the ocean's pH may affect the absorption of sound in the ocean, making the oceans noisier (Hester et al. 2008, Ilyina et al. 2009). Whether this will affect marine mammals —for example, in their ability to communicate—is currently unclear.

Human activities are increasing on the Antarctic continent. The human footprint on Antarctica is small compared with the total size of the continent; however, the impacts are not evenly spread. Human activity and associated impacts are concentrated around stations, which tend to be built on ice-free land close to the sea. This land is also important habitat for the plants and animals of Antarctica. In East Antarctica, many ice-free areas have stations, and new stations are now being commissioned. Currently, more than 50 research stations across Antarctica accommodate up to 4000 people during summer and 1000 during winter (Tin et al. 2009).

Mining and mineral exploration activities are banned indefinitely in the Antarctic Treaty area through the Madrid Protocol. The Madrid Protocol and CCAMLR have so far been successful in managing human activities in the Antarctic region, and achieving their environmental protection and conservation objectives.


Landing expeditioners for a field trip

## Assessment summary 15

### Current and emerging risks to the Antarctic environment

| | Catastrophic | Major | Moderate | Minor | Insignificant |
|---|---|---|---|---|---|
| Almost certain | Sea level rise through melt and ocean warming<br>Increased warming of the atmosphere, leading to loss of ice cover and changes in sea ice seasonality | Reduction in the severity of the ozone hole, reducing (improving) surface ultraviolet B radiation but allowing greater surface warming in summer<br>Stronger winds and shift in oceanic fronts bringing warm water towards the coast, leading to increased destabilisation of ice shelves and margins of the ice sheet | Localised persistent contamination of soil or water due to human activities | Localised transient minor contamination of soil, water or air due to human activities | |
| Likely | Changes in ecosystem structure<br>Increased illegal fishing, leading to impacts on both targeted and dependent species, as well as bycatch<br>Breakdown in food web productivity | Increased pollution (water and air)<br>Increase in commercial fishing activities, leading to impacts on targeted and dependent species<br>Lack of knowledge of interactions of processes, leading to poor management decisions<br>Increases in numbers of non-native species, with subsequent effects on native species and communities<br>Improved survival of pathogens, with subsequent effects on native species and communities | More continental stations, intensifying pressures on local environments | | |
| Possible | Loss of biodiversity<br>Loss of keystone species as their physiological limits are exceeded | More extreme weather events due to climate change | Growth of tourism and consequent increase in environmental impact | | |
| Unlikely | | | | | |
| Rare | | | | | |

Not considered

# Outlook

## for the Antarctic environment

### At a glance

Currently, the Antarctic environment is still in a comparatively good condition. However, the pressures on the continent and the surrounding ocean will increase. For example, the extraction of marine resources is not only going to continue but will intensify in the future. Most importantly, numerous climate change processes are now under way that are likely to alter the physical Antarctic environment over the next decades to centuries. In turn, ecosystems and species populations will be affected. Organisms either must adapt or will disappear. The most likely candidates to vanish are those that have adapted to narrow environmental limits, such as emperor penguins, and invertebrates that grow and develop slowly. New fisheries will open as species more adapted to warmer conditions than currently found in the Southern Ocean move south.

Climate change and the future of Antarctica remain topics of intense scientific research and debate, as analyses of data are still hampered by uncertainties and, in some areas, data deficiencies. Climate change is unlikely to be linear, and various regions will be affected on different scales, as the dissimilar developments in East and West Antarctica already demonstrate. Despite all uncertainties, the risks associated with climate change are significant and deserve our full attention.

To assess the future of Antarctica and the Southern Ocean, a global perspective is required. Despite Antarctica's remoteness from centres of human population, the pressures generated in the rest of the world affect Antarctic and Southern Ocean ecosystems through the linkages provided by atmospheric and oceanic circulations. Although the rate has slightly decelerated, the global human population is still increasing and is expected to reach 9.3 billion in 2050 (UN 2015). Increasing demands for protein sources can only increase the possibility that, at some stage, people will look to Antarctica and the Southern Ocean to source them, especially when existing sources reach their limits in other parts of the world.

Recent assessments of the impacts of climate change on Antarctica and the Southern Ocean highlight that changes have been observed in the Antarctic environment, and continued changes are expected in the climate and weather patterns of Antarctica, as well as in the physical and chemical properties of the Southern Ocean (SCAR 2009, Turner et al. 2014). Although many of the underlying processes driving the changes are still not well understood, the processes that are changing the Antarctic environment appear to be well under way and likely to continue for at least the next several decades.

Although several indicators vary markedly in their regional expression and intensity (particularly between West and East Antarctica), overall trends in the Antarctic system are similar throughout the region. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change predicts that future Antarctic changes will include (Stocker et al. 2013):

- warming of the Southern Ocean and freshening of at least its upper water masses
- warming of the Antarctic surface
- strengthening of the Southern Annular Mode (SAM).

The strengthening of the SAM is currently countering part of the warming of the surface that is accompanying increasing greenhouse gas levels, particularly during summer. During the next half-century, it is likely that the rate of warming of the Antarctic surface will increase as the forcing of the SAM by ozone depletion diminishes (WMO 2014).

During the next decades, particularly if the production of anthropogenic $CO_2$ continues at its present rate, ocean acidification will become more pronounced in the cold Southern Ocean than in warmer regions. The amount of $CO_2$ that can be absorbed by the Southern Ocean is limited, and, if $CO_2$ production is not reduced, the Southern Ocean may no longer act as a $CO_2$ sink. A similar effect will be achieved as the ocean warms, because warmer waters have less capacity to act as a $CO_2$ sink than cold waters. For the past 2 centuries, the hydrogen ion concentration of surface water has increased by approximately 25 per cent in the world's oceans, lowering the pH by 0.1 unit and making the water less alkaline. The current rate of change is about 100 times higher than that shown by the palaeorecord (Royal Society 2005). Given the amount of $CO_2$ already in the atmosphere, a reversal of ocean acidification is unlikely in our lifetime (Royal Society 2005).

In all likelihood, the distribution of species will change as those adapted to warmer climes expand their ranges south. Those organisms already existing in the high Antarctic either must adapt or will disappear. The most likely candidates to vanish in the long term are those that have adapted to live within very narrow environmental limits. This limitation, plus their generally long lives, mean that, with the increasing rate of change in their environment, fewer and fewer generations will be able to acclimatise and adapt to the new conditions. Range expansions have already been reported from the Antarctic Peninsula region. Some animal, plant and microorganism populations are expected to expand in areas where more liquid water will become available and temperatures will increase.

We cannot yet predict the extent to which biodiversity will be affected by the expected future changes. However, ocean acidification, in particular, is likely to have a profound effect on the Antarctic ecosystem because it affects organisms at the base of the food web. Whatever changes may occur in the biodiversity of Antarctica, the effects are expected to cascade through the entire ecosystem.

Orange lichen on an icy rock

Photo by Peter Hargreaves, Australian Antarctic Division, all rights reserved

# Acronyms and abbreviations

| Acronym or abbreviation | Definition |
| --- | --- |
| AAD | Australian Antarctic Division |
| AAT | Australian Antarctic Territory |
| AR5 | Fifth Assessment Report |
| ASMA | Antarctic Specially Managed Area |
| ASPA | Antarctic Specially Protected Area |
| ATCM | Antarctic Treaty Consultative Meeting |
| CCAMLR | Commission for the Conservation of Antarctic Marine Living Resources |
| $CO_2$ | carbon dioxide |
| DNA | deoxyribonucleic acid |
| DTT | dichlorodiphenyltrichloroethane |
| GPS | global positioning system |
| Gt | gigatonne |
| IPCC | Intergovernmental Panel on Climate Change |
| IUCN | International Union for Conservation of Nature |
| $km^2$ | square kilometres |
| Madrid Protocol | Protocol on Environmental Protection to the Antarctic Treaty |
| POP | persistent organic pollutant |
| SAB | special Antarctic blend |

# Glossary

| Term | Definition |
|---|---|
| Antarctic bottom water | A type of water mass that forms around Antarctica. It is very cold and salty, and therefore dense. |
| Antarctic Treaty area | The area south of 60°S. |
| benthic | Associated with the sea floor. |
| baleen whales | Whales that use baleen plates to sieve plankton and other small organisms from the water as their food. |
| ecological informatic approach | A study approach that integrates environmental and information sciences to define entities and natural processes. |
| endemic | Unique to a spatially defined area; in this report, used mainly to refer to large bioregions of the continent and marine environment. |
| exclusive economic zone | The marine seabed, subsoil and waters between the 3 nautical mile boundary and the 200 nautical mile boundary off the coast of Australia. |
| gigalitre | One thousand million litres. |
| katabatic winds | Winds that are caused by local downwards motion of cool air. |
| keystone species | A species that has a profound effect on a particular environment. |
| Montreal Protocol | The Montreal Protocol on Substances that Deplete the Ozone Layer aims to reduce or eliminate human use of substances that deplete the atmospheric ozone layer. |
| notothenioid | Notothenioidei is a suborder of fish, most of which are endemic to Antarctic waters. |
| overturning circulation | The movement of water masses of different densities caused by variations in ocean salinity and temperature. |
| ozone hole | The reduction in the amount of ozone in the lower stratosphere above Antarctica that has occurred each spring since around 1980. |
| pH | A measure of acidity or alkalinity on a log scale from 0 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline, or basic). |
| phylogeographic approach | A study approach that looks at the historical processes that may be responsible for the geographic distribution of species. |
| sea ice seasonality | The timing of annual ice advance and retreat, and duration of the resultant coverage. |

| Term | Definition |
|---|---|
| stratification | The formation of layers, classes or categories. |
| trigger limits | Criteria levels within guidelines that trigger action; specifically, those that indicate a risk to the environment and a need to investigate or fix the cause. |
| trophic | Related to an organism's place in a food chain. Low trophic levels are at the base of the chain (e.g. microorganisms, plankton); high trophic levels are at the top of the chain (e.g. sharks). |

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# Index

Note: An ‘f’ following a page number indicates a figure.

**S**



**T**



**U**



**V**

**W**

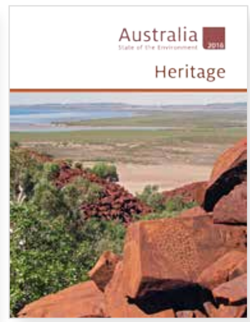


**Z**

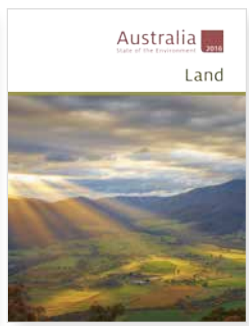
# Australia
## State of the Environment 2016

*Australia state of the environment 2016* (SoE 2016) is an independent national assessment of the state of the Australian environment. It includes 9 thematic reports on atmosphere, built environment, heritage, biodiversity, land, inland water, coasts, marine environment and Antarctic environment. It also includes a synopsis of the detailed theme assessments (*Overview*), highlighting what they mean for the outlook for the Australian environment; a report on the drivers of change in the Australian environment (*Drivers*); and a report detailing the approach to SoE 2016 (*Approach*).

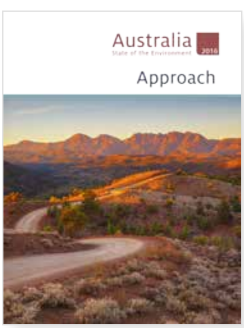


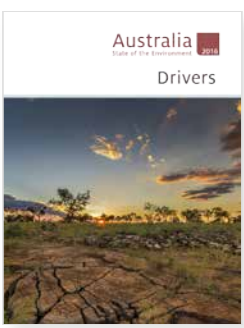



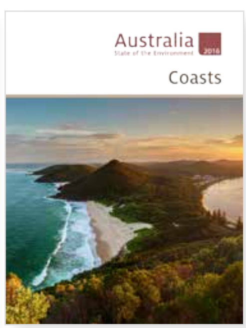








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