# Australian Antarctic Territory, Territory of Heard Island and McDonald Islands, and observations on Macquarie Island Tasmania

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**Links to data:**

In the following text, there are hyperlinks to indicator documents which informed the particular statement or comment to which they are linked. It should be noted that, at different points in the commentary, different words might trigger links to the same indicator document. The links are context-dependent. In some cases, hyperlinks are made to indicator documents which are now populated but for which data were unavailable to the commentary authors at the time of writing the commentaries.

## Introduction

The Australian Antarctic Territory is defined as 'that part of the territory in the Antarctic seas which comprises all the islands and territories, other than Adélie Land[1], situated south of the 60th degree south latitude and lying between the 160th degree east longitude and the 45th degree east longitude'. This is equivalent to 42 per cent of the Antarctic continent.

For this report, Australia's sub-Antarctic Territory of Heard Island and McDonald Islands, and Macquarie Island (Tasmania) are also included as the Department of the Environment and Heritage, through the Australian Government Antarctic Division, has management

1 Terre Adélie, claimed by France: 136 °E to 142 °E.

responsibility for Heard and McDonald Islands and for the station precinct on Macquarie Island. The report also coves the Southern Ocean between Australia and Australia's Antarctic Territory.

Antarctica plays a key role in regulating the world's weather, climate and oceanic processes. Antarctica has an enormous influence on the natural and 'human' environment within Antarctica, as well as globally.

Antarctica and the high-latitude Southern Ocean are especially important to Australia because of their proximity, their influence on regional climate processes, and the significance of the Southern Ocean to our fisheries.

In turn, the region is influenced by activities undertaken by humans within Antarctica and outside, as well as by what is occurring naturally in the global and local environment.

Antarctica provides a platform for better understanding the functioning and health of the planet, and provides an early warning system for the rest of the world. For example, the discovery of stratospheric ozone thinning over Antarctica by United Kingdom scientists spurred global action to reduce atmospheric pollution levels.

The Australian Antarctic Territory theme commentary addresses three main issues:

- climate, atmosphere and the ice
- marine ecosystems
- human pressures.

Antarctica and the surrounding Southern Ocean are vast, remote and inhospitable. Human activities in the Antarctic have always been hazardous and expensive, and are likely to remain so. Research in many disciplines has been undertaken over only the last 50 years, collecting data from geographically sparse, remote and infrequently visited sites. The opportunities offered by satellite and airborne remote sensing equipment have really only been available since the 1970s, and are not directly applicable to all disciplines.

Therefore, although the Antarctic is the focus of issues of global concern such as climate change, sea-level rise and the effects of the 'ozone hole', this report is necessarily cautious about speculation on some issues.

This report notes the inevitability of changes in the Antarctic environment due to global factors such as climate change, and atmospheric and oceanic pollutants. The Antarctic itself plays a key role in the global climate system, and much important research focuses on the cause-and-effect relationships and feedback loops between this region and the rest of the world. Symptoms and effects of global change in the Antarctic may become initially apparent at the most subtle of levels—in slight changes to sea-ice formation and ocean chemistry, and in the biological health of the microscopic marine organisms at the bottom of the food chain.

A general conclusion is that observed changes in many parameters are what might be expected in response to changes in the global climate and atmospheric chemistry. While there appears to be a decrease in the ice mass of West Antarctica, there appears to be an increase in that of East Antarctica, which includes all of the Australian Antarctic Territory. Of particular note, the report concludes that the rate of thinning of stratospheric ozone appears to be declining, and may be stabilising, in part possibly as a result of the global effort to control ozone depleting substances since 1990s.

With respect to marine organisms, the report notes the recovery of seal populations since the cessation of wide-scale commercial hunting in the early 20th century, but also the continued illegal, unregulated and unreported fishing in the Southern Ocean which confounds attempts by Australia and other concerned nations to establish a sustainable fishery, and to reduce its effects on the wider environment. Of particular concern is the decline in numbers of Wandering Albatross and Southern Giant Petrels as a result of the illegal, unregulated and unreported fishery, which has little incentive to avoid seabird bycatch. Southern Ocean whales are believed to be slowly recovering from the exploitation of the 19th and 20th centuries, but population data remains particularly difficult to obtain on such widely ranging animals over such a vast area.

The environmental impacts of human activities in Australia’s Antarctic Territory are believed to be fairly stable, and highly localised to the immediate environs of the permanent stations. Abandoned waste dumps are a legacy of the mid-20th century activities of national operators and, together with remediation of localised hydrocarbon-contaminated sites and sewage discharge, remain a priority for the Australian program. The Australian Government Antarctic Division has removed around half of the contaminated waste from the old Casey tip, leads research to manage contaminants in frozen ground amongst Antarctic operators, and is investigating replacements to the sewage treatment plants at the Australian stations. Tourism remains concentrated around the Antarctic Peninsula, with insufficient regular activity in Australia’s Antarctic Territory to determine a trend.

The threat of introduced plants, animals, invertebrates and disease to the Antarctic environment is largely ill-defined among Antarctic operators; however, Australia has developed standards and guidelines to prevent such introductions and is working with other Antarctic Treaty parties to refine and implement them widely.

# Climate, atmosphere and the ice

External pressures of global warming and other environmental changes can be expected to have a major direct effect on the physical systems of the Antarctic region. Antarctica and the surrounding Southern Ocean are dominated and shaped by snow and ice which, while controlled by the climatic regime and very sensitive to climate change, also influence and provide major feedbacks to the global oceanic and climate system.

Many globally significant processes are driven by the unique climate and geography of the Antarctic. These include the uptake of carbon dioxide by the Southern Ocean; the overturning circulation of the deep ocean; the balance between storage and discharge of water in the continental ice sheet; modification of surface energy, mass and momentum exchange by ice masses; and energy transfer between all levels of the atmosphere to space.

Variations in the winter extent of sea-ice play a key role in global oceanic circulation and are thought to have profound effects on algal growth under the ice and the reproduction of Antarctic krill, a small, highly abundant crustacean which is a major component of the Antarctic food chain.

For Antarctic and high southerly latitudes, a number of indicators show changes in atmospheric and ice-related parameters. Many of the changes are broadly consistent with overall expectations for a warming climate. Temperatures at Australian Antarctic stations reflect the broader Antarctic picture, which shows little warming across most of the continent except for the Antarctic Peninsula that does not form part of Australia's Antarctic Territory. Some stations report weak cooling, and none of the trends, either positive or negative, are statistically significant. These and other Antarctic temperature trends have been associated with atmospheric circulation changes and may be linked with stratospheric ozone depletion in recent decades.

Ultraviolet radiation values at Australian stations are elevated, relative to expectations for sites at comparable northerly latitudes, and this is directly attributed to stratospheric ozone depletion (the 'ozone hole').

Satellite data have shown significant ecosystem-level effects of exposure to ultraviolet B (UVB) radiation. This occurred below a threshold stratospheric ozone concentration of 300 Dobson Units (DU), reducing the seasonal increase of chlorophyll by around 60 per cent at less than 300 DU. Inhibition occurs over time scales greater than one day, suggesting this is due to indirect effects of exposure to enhanced UVB radiation. Results indicate that ozone depletion can substantially reduce phytoplankton biomass, with consequences for productivity, trophodynamics and biogeochemistry in Antarctic waters. Exposure to increased levels of UVB, through ozone depletion appears to be detrimental to endemic species of moss in the Australian Antarctic Territory (Robinson et al 2005).

Glacier and ice sheet changes are occurring and consistent with expectations for a warming climate. The sub-Antarctic glaciers of Heard Island are retreating rapidly and creating new areas for vegetation colonisation and expansion. On the Antarctic Peninsula and over large parts of West Antarctica, total ice volume is decreasing. Ice volume in East Antarctica is increasing, apparently from increased snow accumulation. The ice volume of Antarctica as a whole is increasing, with a small offset (that is, decreasing influence) on sea-level rise. Historical and proxy data suggest a decrease in total sea-ice cover through the latter part of the 20th century.

# Climate

## Air temperature

There have been no significant continent-wide trends in air temperature change over the Antarctic, excluding the region of the Antarctic Peninsula, over the past 50 years. No clear conclusion can be drawn about any trends in inland Australia Antarctic Territory air temperatures, in contrast with data from the Antarctic Peninsula where the average warming over the last 40 years is greater than 0.4 °C per decade.

Nine of twelve Antarctic coastal stations (including the Australian stations of Casey and Davis) show a slight warming within this period, and three (including Australia's Mawson) show a slight cooling. On average there is a warming trend around the coast of less than 0.1°C per decade (Jacka et al 2004).

The situation over the inland ice sheet is less clear because of the dearth of long-term observations. Weak cooling over much of the interior is widely reported in longer term instrumental records. Jacka and colleagues (2004) reported an average warming of 0.1 C per decade for the interior, but with very high variability between sites; this includes data from less reliable and more recent automatic weather stations. No clear conclusion can be drawn about any trends in inland Antarctic air temperatures.

The overall pattern of Antarctic temperature changes is consistent with global atmospheric circulation changes in the latter part of the twentieth century. Specifically, the atmospheric pattern known as the Southern Annular Mode (SAM) has strengthened in recent decades. This has been associated with the strong warming in the Peninsula and the tendency to cooling elsewhere across the continent. Thompson and Solomon (2002) linked this strengthened SAM with stratospheric ozone loss.

# Atmosphere

## Ultraviolet radiation and stratospheric ozone reduction

Changes in stratospheric ozone over the Antarctic have a direct impact on the solar ultraviolet radiation (UVR) levels at the earth's surface, with an increase in the biologically active UVB radiation expected due to ozone reduction.

Australia's Antarctic stations have annual UVR totals significantly above those expected for their latitude and higher than those recorded at Macquarie Island and at many locations in Europe and the United Kingdom (Gies et al 2004a). This is believed to be due to the reduction of ozone, allowing increased transmission of UVB radiation.

The differences in yearly UV Index totals at Australia's Antarctic stations are attributed to weather, cloud cover and ozone variations. Variability from year to year for Casey and Davis, which have long data records, is approximately seven per cent and nine per cent respectively, contrasting with two per cent to four per cent for Australian mainland sites. Maximum daily UV Index values for Australia's Antarctic stations in spring are comparable to those measured in the southern capital cities of Australia (Gies et al 2004b).

There is, on average, a 60 per cent loss of total column ozone above Antarctica in spring. This is the major cause of summertime ozone losses at mid-latitudes in the southern hemisphere, including southern Australia (Ajtic et al 2004). Ozone loss over Antarctica appears to have stabilised during the 1990s, although there is no direct evidence of long-term ozone recovery.

### Atmospheric concentrations of greenhouse gases

Changes in greenhouse gas concentration at Mawson and other Antarctic stations are similar to those recorded at mid–high-latitude southern hemisphere regions such as Cape Grim, Tasmania. Data from Antarctic stations show an increase in the levels of carbon dioxide, nitrous oxide and methane through the industrial period; variations in the growth rates, particularly interannual changes in the direct record; and decadal changes in the lower resolution ice record.

There has been long-term growth in atmospheric carbon dioxide levels; the highs and lows in atmospheric carbon dioxide levels are correlated with El Niño events. There has been long-term growth in atmospheric methane levels, although the rate of increase has declined over the past 20 years. Atmospheric nitrous oxide levels have increased.

Aside from the implication for climate change, increased atmospheric concentrations of greenhouse gases are believed to be related to observed changes in marine organisms and seawater acidity. Laboratory experiments have indicated that elevated carbon dioxide levels produces changes in the thickness and morphology of calcium carbonate tests of a key planktonic organism (*Emiliania huxleyi*) as a result of increasing the acidity of seawater (Cubillos 2005). Ocean acidification is also expected to have a major impact on populations of pteropods (small planktonic snails), an important prey in the Southern Ocean, and also plays an important role in the uptake of carbon dioxide (Royal Society 2005).

If increasing acidity decreases the thickness and integrity of the skeletal structures of plankton organisms that are key to the marine food web and are also responsible for the removal of carbon dioxide from the marine environment of the Southern Ocean, then the loss of these species will not only have a significant impact on the food chain but will also reduce the ocean's ability to absorb carbon dioxide from the atmosphere (Royal Society 2005).

## The ice

No significant changes are reported in overall Antarctic sea-ice extent through the period of satellite data (that is, since the 1970s), although significant regional changes are evident, particularly around the western Antarctic Peninsula. It appears from historical and palaeo-climate data that decreases have occurred before the satellite period (de la Mare 1997).

Total water storage in the Antarctic ice sheet appears to have increased over the period 1992–2003, reducing potential sea-level rise over the same period by around 0.1 mm per year (out of the overall increase in sea level of 1.8 mm per year). West Antarctica is showing overall mass loss and east Antarctica mass gain. These changes are consistent with modelled expectations in a warming climate.

There have been significant changes in dates of maximum fast-ice thickness and fast-ice breakout at Davis and Mawson stations.

Heard Island's glaciers, in particular Brown Glacier, are all in retreat, consistent with warming in the southern Indian Ocean.

## Extent of Antarctic sea-ice

Antarctic sea-ice is a potentially sensitive indicator of climate change. Observations of the overall extent of Antarctic sea-ice show large interannual variability but show no statistically significant trend through the period of satellite observations since the 1970s (Parkinson 2004). Considerable regional variability is apparent, however, with a statistically significant decrease in the west Antarctic Peninsula region but an increase in the Ross Sea sector (Zwally et al 2002). Work is currently underway to relate interannual through decadal variability in sea-ice extent to large-scale modes of atmospheric circulation.

Despite the lack of a clear trend in the extent of Antarctic sea-ice in the record from 30 years of satellite observations, there are suggestions of a decline in its extent over the longer term. Australian research has found a link between sea-ice extent and biochemical markers in ice cores from the continent. This provides a longer record that suggests a reduction of about 20 per cent in sea-ice in the 80°E–140°E longitude sector over the latter half of the 20th century (Curran et al 2003). A similar decline has been inferred from historical whaling records (de la Mare 1997).

## Antarctic ice sheet mass balance

Antarctic ice sheet mass balance is the net increase or decrease in total stored water in the polar ice cap: a globally important parameter, but difficult to quantify on a continental scale. The ice sheet contains an estimated 75 per cent of the world’s fresh water—equivalent to a sea-level rise of 61 metres. While there is no suggestion that the entire ice sheet will melt, even a small imbalance between the rate at which water is deposited on the ice sheet as snow and the rate of loss through melting and ice discharge has significant consequences for sea-level change.

Recent Australian research has focused on the Lambert Glacier Basin, one of the major east Antarctic drainage basins, and the Amery Ice Shelf, into which it discharges. This work has provided estimates of the total ice discharge and the net basal melt beneath the ice shelf (Fricker et al 2000).

Different parts of the continent appear to respond differently to the warming of global climate. Snow accumulation is measured by analysis of ice cores and by atmospheric modelling, but there is no single agreed measurement technique or definitive time series for overall mass balance changes.

Consistent with expectations for a warming climate, observations in East Antarctica suggest an increase in ice mass due to increased snow accumulation, while the Antarctic Peninsula and West Antarctica show acceleration in the ice flow from several major outlet glaciers, leading to a thinning and overall loss of ice mass in that region.

However, significant uncertainty surrounds ice losses due to basal melting at the glacier–ocean interface, particularly in response to warming. Increases of two metres per year of basal melting under some regions of floating ice shelves have been suggested as realistic responses to ocean warming in recent decades (Rignot and Jacobs 2002). The loss of ice shelves in some regions has resulted in the accelerated ice discharge from inland glaciers (Rignot et al 2004).

The present estimates for total Antarctic mass balance are:

- • mass increasing at 33±8 Gt/a over the period 1992–2003 (Alley et al 2005, Davis et al 2005)
- • equivalent sea-level change—increase in ice-sheet volume corresponds to a decrease in sea-level of approximately 0.1 mm per year (1992–2003), which is an offset of about 5 per cent against the rate of global sea-level rise over the same period (1.8 mm per year).

## Antarctic fast-ice changes

Sea-ice forms on coastal waters near the Australian Antarctic stations in March- and April, and at Mawson and Davis, after perhaps an early break-out when the ice is still thin, it grows *in situ* and remains land-fast until the next summer. The maximum thickness and extent of the fast-ice is usually reached in about October at Mawson, and in November at Davis. At Mawson, where the near-coastal water depth can be well over 200 metres (for example about 1400 metres in the Neilsen Basin), the ice growth is slowed by heat supplied from the ocean, and interannual variability in ice thickness is partly due to changes in this heat supply (Heil et al 1996). At Davis, the ocean is much shallower, and changes in fast-ice reflect changes in atmospheric forcing. Growth rate, persistence, extent and maximum thickness of fast-ice are related to the atmospheric and oceanic climate at the particular region or site.

At Mawson and Davis fast-ice observations have been made since the 1950s, sometimes intermittently. Annual maximum ice thickness does not show any long-term trend at either location; however, the interannual variability in thickness increased significantly at Mawson in the 1980s and at Davis in the 1990s. At Mawson there is a trend in the date of annual maximum ice thickness of +4.8 days per decade, with maxima occurring later in the 1990s than in the 1950s (Heil and Allison 2002).

At Davis the dates of annual maximum ice thickness and final fast-ice breakout are both delayed (each by +4.3 days per decade), and the delayed ice breakout contributes to a prolonged persistence of the Davis fast ice (+6.7 days per decade). Surface air temperature measurements at Davis from 1969–2003 show a cooling trend for summer and autumn, but a warming in winter and in spring. The tendency towards later dates of annual maximum ice thickness is correlated with winter and spring warming (Heil in press).

## Brown Glacier changes, Heard Island

All glaciers on Heard Island have retreated in extent since 1947. The total land area covered by glaciers has decreased from 288 $km^2$ in 1947 to 253 $km^2$ in 2000, that is, by 12 per cent (Ruddell 2006). The retreating ice has exposed 35 $km^2$ of new terrain, including several large lagoons, representing nearly 10 per cent of the total area of the island.

Brown Glacier showed surface elevation decreases of 5.9 to 11.7 metres between 2000 and 2003 (Thost and Truffer submitted). The glacier has decreased in area by about 35 per cent and thinned by 30.3 m, or around 0.5 m per year, in the period 1947–2004 (Thost and Truffer submitted). Ice loss in this period was more than twice the 1947–2004 average.

Changes in Heard Island glaciers correlate with underlying climate change in the southern Indian Ocean—temperature observations in the area show a warming of 0.9 °C over the same period (Thost and Allison 2005).

# Marine ecosystems

The elevated biological productivity of parts of the Southern Ocean region, such as the sea-ice zone, supports a high biomass and considerable biological diversity.

The ecosystems of the Southern Ocean have been subjected to considerable human-induced pressure for over 200 years. Sealing, whaling and fishing have had significant effects on the stocks of marine species and, more recently, human-induced climate change may be changing the physical environment of the oceans.

Some seal populations have yet to show signs of recovery from the exploitation of the 19th century. Whales were severely over-harvested in the early and mid-20th century, and although some species (for example humpbacks) are making a slow recovery, the status of others (for example blue whales) is uncertain. Minke whales have been harvested less than other species but there is still debate over their numbers, highlighting a need to improve the methods of estimating the abundance of large marine mammals.

Fish have been harvested on a commercial scale in the Southern Ocean since the 1960s and many stocks have never recovered from the initial phase of over-exploitation. Current finfish fisheries are low in tonnage but high in value so have suffered greatly from illegal, unregulated and unreported fishing. The krill fishery remains one of the world's last under-exploited marine stocks with a catch limit some 40 times the current catch. Concerns in Southern Ocean fisheries management include: the problem of bycatch (seabirds, fish and invertebrates); the definition of ecological units for management for all harvested stocks; illegal, unregulated and unreported fishing; stock assessment; and the effects of a changing environment on management approaches.

Climate change is the main environmental concern for marine ecosystems. The current warming trend is expected to affect the rate of nutrient upwelling, and the melting rate of the pack ice in spring. Increased levels of carbon dioxide will affect the acidity of the upper layers of the ocean which will have effects on the health and normal function of marine organisms.

## Plankton and microbes

Plankton are sensitive to environmental change and are proven indicators of ocean health, with higher fidelity than direct physical measurement due to their amplified responses to changes in their environment (Hunt and Hosie 2003, 2005).

Planktonic and microbial communities in the Southern Ocean are very complex and diverse, with over 500 species recently documented (Scott and Marchant 2005), covering a size range from 0.7 µm to 4 mm. They constitute by far the major component of the region's biomass, and have comparatively rapid generation times, with a succession of species dominating during the season. Since 1991 zooplankton has been routinely and repeatedly surveyed (Hosie et al 2003). Major changes in the North Atlantic and in the North Pacific are well-documented and it is believed that similar changes are occurring in the southern hemisphere.

Time series analysis of plankton of the permanent open ocean zone has shown relatively stable associations between each summer for the typical dominant zooplankton. These permanent open ocean zone zooplankton maintained a consistent association with each other from spring to autumn. However, the sea-ice zone showed a marked change in species composition around 2000. In the 1990s, krill were dominant, and overall zooplankton abundance was very low. In 2000, 2002, 2003 and 2004, overall abundances were higher and the smaller copepod crustaceans dominated—a group more typical of the permanent open ocean zone. It is too early yet to determine if this is a permanent regime shift or part of a cyclic pattern.

The permanent open ocean zone north of the sea-ice zone has a higher abundance and diversity of plankton than previously thought (Hosie et al 2003). The open ocean is typically dominated by small zooplankton such as smaller copepod crustaceans, krill species and appendicularians (a free-swimming relative of the sessile sea-squirt), all typical and prominent grazers of phytoplankton. Large single-celled animals, protists, are also common and abundant. The sea-ice zone, by contrast, is characterised by larger copepod crustaceans, and larger species of krill such as the Antarctic krill (*Euphausia superba*), the coastal crystal krill (*Euphausia cystallorophias*) and the smaller big-eye krill (*Thysanoessa macrura*) (Hosie et al 2003).

## Fisheries

Fishing is the only large-scale commercial resource harvest currently undertaken in Australia's Antarctic Territory. However, from 2005 about 1000 minke whales will be taken yearly from the Southern Ocean by Japan under its scientific whaling programme. Fish of the Antarctic region have long been exploited, often with lasting effects on species and whole ecosystems. A number of species have become threatened by over-harvesting or illegal fishing. While fisheries in the Antarctic region today are focused on Patagonian toothfish, icefish and, to a lesser extent, krill, there is some potential for new fisheries to emerge. Australia has commercial fisheries in the vicinity of Heard and the McDonald Islands and around Macquarie Island, and in the waters off Australia's Antarctic Territory.

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) was signed in 1981 to address concerns that an increase in krill catches in the Southern Ocean could have a serious effect on populations of krill and other marine life, particularly on birds, seals and fish, which mainly depend on krill for food. CCAMLR aims to conserve the marine life of the Southern Ocean, while not excluding harvesting carried out in a rational manner. The CCAMLR Commission meets annually at its headquarters in Hobart.

Patagonian toothfish have been harvested recently at a number of locations in the sub-Antarctic, and a closely related species is harvested in Antarctic waters. The fishery has attracted unauthorised operators from several countries that are working outside the regulatory framework. Such illegal, unregulated and unreported fishing is of concern because it undermines attempts to manage stocks sustainably. The high value of Patagonian toothfish means that this species has been targeted by both legal and illegal fishing operations, and in some areas the stocks have been negatively affected. Most operations for Patagonian toothfish have utilised long-line fishing techniques, which take much bycatch, particularly seabirds. Seabird mitigation measures in the legal toothfish fishery have been extremely successful but there still remains a substantial problem with the illegal fishery.

There is continuing interest in fishing for toothfish and other fish species off Australia's Antarctic Territory. This may result in a slight rise in catches for this region but substantial rises in catches are unlikely. Squid fisheries remain a possibility but fishable stocks of commercial species have not been found. Krill remains the only large Southern Ocean stock which has a current harvest level far below that which is believed to be sustainable. It is likely that the next decade will see an expansion in the krill fishery, driven largely by demands for aquaculture feed.

There has been a decline in estimated illegal, unregulated and unreported catches over the last three years, although estimates for 2005 are at similar levels to 2004. Pressure from surveillance operations in traditional fishing areas within the Convention Area appears to have forced illegal, unregulated and unreported fishing on to high seas areas within the Convention Area.

Further development of finfish fisheries is unlikely because most known fish stocks are either close to maximum levels of exploitation or are in a depleted state. There were 4–6 notifications (covering 6–11 vessels) for new and exploratory finfish fisheries in 2005–06 in Divisions 58.4.1, 58.4.2, 58.4.3a and 58.4.3b (IMAF 2005). Depending on the size of the precautionary catch limits, this implies that if all vessels operated simultaneously, the available catch per vessel could be lower than that required for economic viability, especially for those vessels operating in high latitudes where fishing faces considerable operational difficulties.

Between 1980 and 1996 (and in the years before CCAMLR) there were considerable catches of krill in Divisions 58.4.1 and 58.4.2, peaking at over 100 000 tonnes per year in 1981 and 1982. There is evidence of increasing interest in the krill fishery, which might result in a spreading out of fishing effort from the South Atlantic where it is currently concentrated, but there are currently no formal proposals for harvesting krill off East Antarctica. Because precautionary catch limits have been set for Divisions 58.4.1 and 58.4.2 and there are no regulations requiring notification of intent to commence krill fishing, a fishery in these divisions could occur at any time.

The total krill catch limit off east Antarctica is currently 890 000 tonnes per year, based on Australian surveys conducted in 1982 and 1996. The Australian Government Antarctic Division will update the earlier results following a survey of Division 58.4.2 in 2006.

## Cetaceans

Baleen and toothed cetaceans occur in the marine waters adjacent to the Australian Antarctic Territory and around Heard and the McDonald Islands and Macquarie Island. The baleen whales—blue, fin, sei, humpback, southern right and minke—are the species which were subject to commercial whaling. Toothed whale fauna is more diverse and includes the once commercially hunted sperm whales (primarily males, which feed in the higher latitudes) and bottlenose whales, along with killer whales, a number of dolphin species, the spectacled porpoise, pilot whales and the poorly understood beaked whale species.

Over the past few decades, populations of southern hemisphere humpback whales and southern right whales have been increasing annually. Some populations of humpback whales are estimated to return to pre-exploitation abundance estimates within the next ten years. Much less is known about the recovery of the baleen whales, which do not migrate near land masses.

No estimates exist for fin, sei or sperm whales. Blue whales are estimated to be increasing, but still to be at less than one per cent of their pre-exploitation abundance. Ship-based surveys to estimate the abundance of minke whales have been conducted for the past 30 years, but the methodology and analysis is complex and an understanding of potential bias is incomplete. Estimates of about 760 000 minke whales around Antarctica were agreed at the International Whaling Commission (IWC) in 1989 for the preceding decade, but there are no currently agreed estimates.

New acoustic techniques are being developed, with the potential to yield relative abundance estimates for vocal species. These techniques are best developed for blue and fin whales, but are likely to be applicable to other baleen whales and some toothed whales.

New techniques are being developed in Australia to track large whales with satellite tags, and to determine from small biopsy samples critical elements of their life history. This will improve greatly the understanding of population structure and survey design for cetaceans.

The only direct take of cetaceans in Australia’s Antarctic Territory is that of Japan’s scientific whaling. This greatly expanded program has the potential to expand further in the future and may be at levels that affect the targeted populations. Efforts by pro-whaling countries in the IWC may also see a resumption of commercial whaling in the Southern Ocean.

Southern Ocean cetaceans do not seem to be subject to other direct takes such as bycatch. However, indirect effects, such as the potential ecological consequences of global climate change, may have potent effects on the cetacean assemblages.

## Seals

Historically, the main threat to seal populations has been through direct exploitation. Land-breeding seals have been more susceptible and vulnerable to harvesting than ice-breeding seals because they form dense aggregations on land when breeding. The land-breeding seals were exploited heavily throughout the 19th century and populations at most breeding locations declined to very low levels, rendering continued exploitation increasingly uneconomic, although it continued at decreasing levels well into the 20th century.

An indirect threat to seal populations is the exploitation of their prey (krill and fish) through fishing. CCAMLR currently needs improved estimates of predator abundance, including seal abundance, to take into account the food requirements of predators when setting catch limits for krill and fish. Other impacts, such as global climate change, may affect seal populations through changes in primary and secondary production and water circulation.

Populations of land-breeding seals have increased from low levels after heavy exploitation at Heard and the McDonald Islands and Macquarie Island in the 19th century and into the early 20th century. A decline in pupping rates on Heard Island and in pup growth rates on Macquarie Island coincides with an increase in sea surface temperatures north of the islands over the last 15 years.

Fur seal populations continue to increase at both Heard Island and Macquarie Island. Southern elephant seal populations, after recovering very substantially since early exploitation, have declined by about half between the 1950s and the 1980s, but numbers are currently stable. The cause of their earlier decline is not certain but seems associated with wide-scale changes in the Southern Ocean beginning in the middle 1960s. A recovery plan that has been prepared for sub-Antarctic fur seals and southern elephant seals calls for continued population monitoring of those species. Other land-breeding seals have very substantially recovered from the low post-exploitation levels and are no longer considered to be endangered.

Data on the status and trends of ice-breeding seals are far less certain. Recent surveys in Australia’s Antarctic Territory in 1999–2000 have provided uncertain estimates of the current status for this group of species, and it is therefore difficult to assess trends.

The 1999–2000 Australian Antarctic Pack Ice Seals Survey estimated the crabeater seal population between 60 ºE and 150 ºE at around 950 000, although there is considerable uncertainty in the 95 per cent confidence limits despite the extensive survey using the most sophisticated methods available. Ross seals were estimated to be around 60 000. No estimates for leopard or Weddell seals are yet available. It will be difficult to make inferences about population trends from early and recent survey data because of differences in survey and analytical methods, and inherent uncertainty in population estimation.

## Flighted sea birds

Numerous species of flighted seabirds occur in great numbers in the Australian Antarctic Territory and on the Australian sub-Antarctic islands. While many of those are visitors only, some species do breed in Australia’s Antarctic Territory and associated areas, in colonies typically comprising thousands to tens of thousands of breeding pairs. Due to the overlap of commercial fishing areas with the foraging ranges of seabirds, the two interact directly. It is believed to be here that most of the mortality among seabirds occurs, particularly among various species of albatross and medium-sized petrels, as birds drown either by swallowing baited hooks or by being entangled in fishing gear.

The most immediate effects of climate change in the Southern Ocean include changes to sea-ice extent and acidification. Both of these factors are likely to influence the lower trophic levels of the food web—the prey of seabirds.

Seventy-two species of birds have been recorded at Macquarie Island, 34 species of seabird at Heard Island (of which 15 are recorded as breeding on the islands), and six flighted seabirds are known to breed in the ice-free areas of Australia’s Antarctic Territory. Two endemic terrestrial birds at Macquarie Island—the banded rail (*Rallus philippensis macquariensis*) and the red-fronted parakeet (*Cyanoramphus novaezelandia erythrotis*)—became extinct in the 19th century. The Heard Island cormorant (*Phalacrocorax nivalis*) breeds on Heard Island, and is the only endemic marine bird species in Heard and the McDonald Islands. The only non-marine endemic bird species on Heard Island is the black-faced sheathbill (*Chionis minor*).

Heard Island cormorants are listed as vulnerable, and breed in four small colonies. The population estimate has increased from about 200 pairs (Green 1997) to about 1100 pairs, with the recent discovery of a new colony (Woehler 2006).

Macquarie Island shags (*Phalacrocorax purpurascens*) are listed as vulnerable, and breed mainly on hard-to-access offshore stacks or islets (Brothers 1985); their current population status is not known but 11 colonies appeared to have 472 breeding pairs in October 2003 (M Schulz and J Lynn unpublished data).

Albatrosses and petrels are probably the most threatened birds worldwide, and both breed at Macquarie Island. While albatross populations are affected by commercial longline fishing activities globally, the breeding populations of Black-browed (*Thalassarche melanophyrys*) and Grey-headed (*Diomedea chrysostoma*) albatrosses at Macquarie Island appear to have remained relatively stable (Terauds et al 2005). However, both populations are small and any change in, for example, adult survival can significantly reduce the number of potential recruits to the colonies.

With fewer than 15 pairs breeding annually the Wandering albatross (*Diomedea exulans*) is the most critical of the seabird populations at Macquarie Island. However, access to major breeding areas on the island has been restricted, with the result that the population is now three times larger than in the 1980s (Gales et al 2004).

The number of Southern giant petrels (*Macronectes giganteus*) at Macquarie Island has doubled since the 1970s and appears to be stable. However, giant petrels are known followers of fishing vessels, and continuous monitoring of the population is required (Gales et al 2004).

In Australia's Antarctic Territory, giant petrel (*Macronectes* species) populations appear to have declined since their discovery some 40 years ago (Woehler et al 2003).

The Macquarie Island population of Subantarctic or Brown skuas (*Stercorarius antarcticus*) comprised some 550 breeding pairs in the mid-1980s. No recent island-wide counts have been made (Schulz and Gales 2004).

For the smaller petrels breeding on Macquarie Island, introduced species, such as house cats (*Felis catus*) and black rats (*Rattus rattus*), have been a threat as these predators attack the birds in their burrows and destroy eggs and chicks. The recent eradication of cats from the island has led to the return of some burrowing petrels that had not been seen on the island for many years. However, the populations of rats and house mice need urgent attention as they continue to threaten the small petrels directly, and indirectly through the destruction of habitat, such as for example the tussock grass (*Poa cookii*) beneath which the critically endangered blue petrel (*Halobaena caerulea*) breeds in burrows.

Many of the seabird colonies are in remote areas and their status is largely unknown. However, even in the vicinity of stations, regional data on seabird populations are rare and long-term trends cannot be determined (see, for example, Croxall et al 1995).

# Penguins

Seven species of penguin are known to breed regularly in, or occasionally visit, the ice-free areas of Australia's Antarctic Territory, Heard Island and Macquarie Island, and to feed in the oceans surrounding these areas.

A recent review, which assessed penguin population trends at sites where data were available for a minimum of five repeated annual counts over a ten-year period, could analyse data for only two species at three sites in Australia's Antarctic Territory, Heard Island and Macquarie Island.

Gentoo penguin breeding populations at Heard Island have been estimated at 10 000 pairs in the 1950s and 16 600 pairs in 1987. The breeding population at Macquarie Island was estimated at 3800 pairs in 2002.

Breeding populations of king penguins are difficult to estimate because not all the breeding population is present at breeding sites at any one time. At Heard Island, data collected between 1963 and 1993 suggest the population is doubling every five years (Woehler 2006). The most recent estimate of the breeding population is 15 000 pairs. At Macquarie Island the population of 150 000–170 000 pairs in 2000 is believed to be continuing to increase, following a rapid recovery from commercial harvesting early last century.

The macaroni penguin is the most abundant penguin species at Heard Island, with breeding populations estimated at 1 000 000 pairs at each of Heard and McDonald islands, although no seabird data are available for the McDonald Islands since 1980. There is no information on trends in macaroni penguins. Rockhopper penguins are very difficult to assess because of the broken and difficult terrain they inhabit, but breeding populations have been tentatively estimated at 10 000 pairs at Heard Island, 100 pairs at the McDonald Islands, and possibly up to 100 000 pairs at Macquarie Island. Declines in rockhopper populations of up to 80 per cent have been reported at several locations elsewhere in the sub-Antarctic, but it has not been possible to determine whether similar declines have occurred in Australia's region.

Royal penguins have been estimated at approximately 850 000 breeding pairs at Macquarie Island, but no information on trends is available. Chinstrap penguins have occasionally been observed visiting Heard Island but do not breed there. The status of penguin populations at the McDonald Islands is uncertain. The habitable area of the McDonald Islands has increased greatly since eruption began in 1992, and it is likely that populations of many species have grown significantly.

Adélie penguins breed at numerous ice-free sites across the entire Australian Antarctic Territory and non-breeding birds are occasionally seen at Heard Island. The estimated total breeding population of 662 000 Adelie pairs has been derived from data collected at all sites over the 32-year period 1956–88. Data from the CCAMLR Ecosystem Monitoring Program (CEMP) indicate no trend in the breeding population of Adelie penguins at Béchervaise Island (near Mawson) over the past 15 years, but counts prior to the CEMP suggest a sudden increase in the local breeding population just before the commencement of CEMP. Estimates of the Adelie breeding population have increased steadily at Whitney Point (near Casey) from 1960 to the present, with current estimates about 6 times greater than in 1960.

Emperor penguins breed at several sites across Australia's Antarctic Territory, and non-breeding birds are occasionally seen at Heard Island. An estimate of the Emperor penguin breeding population in Australia's Antarctic Territory of 59 000 pairs has been derived from data collected over the 27-year period 1958–85. Counts of breeding populations have been one-off or intermittent at all sites except one, Taylor Glacier, where regular counts have been undertaken since 1988. The Taylor Glacier counts indicate a slight but steady decrease in numbers from 1988 to the present, with an average population of about 2900 breeding pairs.

# Human pressures

There are nine permanent stations in Australia's Antarctic Territory, not including the United States' Amundsen-Scott base at the south geographic pole. Six are coastal, and include the three Australian stations: Mawson, Davis and Casey. When considered against the almost six million square kilometres of Australia's Antarctic Territory (42 per cent of Antarctica), this is an extremely low density, and far lower than either the Antarctic Peninsula or West Antarctica, which together share the other fifty-odd permanent stations.

Some environmental disturbance is an inevitable consequence of human activities in Antarctica. There are five main human activities with a potential for adverse impact on the Antarctic environment: the conduct of scientific research, logistic operations, tourism, construction of buildings and infrastructure, and commercial harvesting of living resources. The major concerns associated with these activities are the transport, transfer and storage of large quantities of diesel fuel, introduction of non-native species and disease, generation of waste and pollution, disturbance of the physical environment, and wildlife disturbance by visitors and vehicles.

Some proxy indicators of environmental pressure, such as fuel use, visitor numbers and wastewater production, indicate the potential environmental impacts of human activities and provide a benchmark against which to frame management measures. Data on these indicators are difficult to obtain for the non-Australian stations, and so the overall picture of station pressures on Australia's Antarctic Territory environment cannot be determined accurately.

Australian research is being directed towards reducing the impact of human pressures by improving renewable energy sources, understanding the environmental effects of terrestrial and marine contaminants, and establishing the minimum-approach distances to wildlife. The Australian Government Antarctic Division has implemented procedures and guidelines to prevent and detect the introduction of non-native species to Antarctica and the sub-Antarctic, and is working with its Antarctic Treaty partners to refine and implement them throughout all Antarctic operations.

Managing tourism and non-government visits is far from straightforward. The multi-national nature of Antarctic tourism, the complex political and juridical situation in Antarctica and the sparseness of Antarctic infrastructure create a layer of management challenges on top of the more obvious environmental protection and safety aspects.

## Visitors

Tourist visits to Australian sub-Antarctic islands and the Australian Antarctic Territory account for a small proportion (less than one per cent) of the world total of Antarctic-bound shipborne tourists. The data suggest no increase in tourist visits to Australian sites, in contrast with a clear trend of increasing numbers of visitors to Antarctica as a whole: the total number continues to grow at a rate of over 10 per cent per annum, to over 30 000 shipborne tourists in 2004–05, not counting guides and crew (IAATO 2005). Since 2002–03, 100 tourists on four vessels have visited Commonwealth Bay, the site of Mawson's huts.

Tourist visits are concentrated on the Antarctic Peninsula and the Ross Sea region (ASOC, and UNEP 2005), which is not part of Australia's Antarctic Territory. Most tourists visiting Antarctica do not stay ashore overnight, and most Antarctic Treaty parties allow no more than incidental use of their facilities by tourists.

Increased tourism in Antarctica gives rise to various concerns, including the potential for direct and cumulative environmental impacts resulting from wildlife disturbance, pollution from increased shipping, and the possible introduction of exotic pests or diseases.

Visits to Heard Island are infrequent, with only 202 tourists on six vessels between 1995 and 2004. There were no authorised visits in six of the last ten years, and the last visit was in 2002–03, involving one ship visiting for two days accompanied by an Australian Government Antarctic Division guide. One private visit to Heard Island is mooted for the 2006–07 summer. The low level of visitation is probably best explained by the substantial travel time and costs arising from the island's remoteness, rather than a lack of features of interest to tourists.

In the 18 years since 1987, 5180 tourists on 75 vessels have visited Macquarie Island. Tourist visits have been recorded at Macquarie Island every year since 1992–93.

Tourists have visited Macquarie Island at a relatively constant rate over the past ten years. To date the seasonal total has remained below the limit set by the Tasmanian management plan, which is currently 750 tourists per year. 2005–06 is expected to be the first season in which approvals exceed the limit. However, this is viewed as a one-off, and the Parks and Wildlife Service has no plans to change the overall limit or to modify site limits. In addition to its own attractions, Macquarie Island is a half-way point for voyages between Hobart and East Antarctica, most of which also use the ports of Lyttelton and Bluff in New Zealand.

## Government expeditioners

The Australian Antarctic program makes between five and seven voyages each summer: between 1987–88 and 2004–05, there were 147 voyages to the Antarctic, recording nearly 374 000 person-ship-days. RSV *Aurora Australis* is the main means of transporting Australian Antarctic personnel and has a maximum carrying capacity of 116 expeditioners.

Since 1987–88 Davis has had the largest aggregate population, with 251 294 person-days, followed by Casey with 221 200, Mawson with 202 574 and Macquarie Island with 162 362. Since 1994, there has been a decrease in the number of people travelling to Australia's Antarctic Territory and a decrease in average station population, and there is strong seasonal variation, with the summer station population two to four times that of the winter. The peak in continental station population in the 1980s and early 1990s was due to an increase in the number of trades personnel completing a major rebuilding programme. Although some replacement of buildings as a result of ageing and wear and tear will take place, it is not envisaged that the current stations will be expanded. The heritage values and conservation needs of structures from earlier years are being assessed under the *Environment Protection and Biodiversity Conservation Act 1999* and the heritage strategy of the Department of the Environment and Heritage (DEH 2005).

Davis is the base of investigations into the biology, geology and glaciology of the Prince Charles Mountains – Lambert Glacier – Amery Ice Shelf region, and the home of a major atmospheric physics programme using laser technology, radar and other equipment to investigate the stratosphere and mesosphere.

It is expected that the introduction of intercontinental air transport in 2007–08 will result in short-term increases in the population of Casey, which is the Antarctic terminus.

In the sub-Antarctic, the Commonwealth's management and research focus is shifting from Macquarie Island to Heard Island. The Australian Government Antarctic Division has reduced its ship visitation to Macquarie Island to one visit per year, and tourist vessels have been used to fill the gap.

There is expected to be a small increase in person-days on continental stations from 2007 as a result of the commencement of direct flights from Hobart to Antarctica: while more expeditioners will visit, the duration of their stay will be shorter.

## Wastewater

Wastewater is a source of local environmental pollution. Environmentalists, ecologists, wastewater specialists and others have been critical of the disposal of untreated sewage into the sea in Antarctica (Meyer-Rochow 1992). While the biological impacts are not well understood (Meyer-Rochow 1992), studies have noted:

- the potential for sewage microorganisms to remain viable in Antarctica's environment for prolonged periods (for example Meyer et al 1962, Hughes and Blenkharn 2003)
- that faeces in Antarctica's terrestrial environment may contain viable microorganisms some 30–40 years after deposition (Hughes and Nobbs 2004)
- that, along with contaminated food, the release of untreated sewage is the most likely risk factor for the introduction of pathogenic bacteria and viruses to Antarctica (Bonnedahl et al 2005).

At Casey and Mawson, sewage waste and grey water are processed through rotating biological contactors (RBCs), using a combination of mechanical and microbial action to treat sewage waste. Effluent is discharged into the sea adjacent to the stations, and sludge is removed to Australia for disposal.

When the RBCs are bypassed due to equipment failure, for annual maintenance or because the station population exceeds system capacity, waste is macerated by being passed through a pump, but is otherwise untreated before being discharged into the sea.

There is a strong correlation between the quality of the effluent and the annual summer population increase. This is evidenced by the spikes in the Casey and Davis graphs, where the station population tripled or quadrupled over the summer period. The relatively flat response on the Mawson graph further illustrates the correlation, as the station population only doubles over the summer period. The collection of effluent data has been intermittent during the summer periods at Casey and Davis because of the necessity to by-pass the RBCs when the stations' population exceeds the RBCs' capacity. The Davis RBC failed irreparably in 2004, and options are under development to improve sewage treatment at all Australian stations.

## Fuel usage of generator sets, boilers and incinerators

A co-generation system is used to provide both electrical and thermal energy to the Australian stations. Waste heat created by diesel generators heats water that is then pumped around the station to heat each building. This is usually only sufficient to heat the station for three months during summer, and fuel-fired boilers are used to boost the system during winter.

Annual fuel consumption for the production of thermal and electrical energy at the stations has been decreasing over the past 10 years as a result of an energy management program. The significant decrease in fuel consumption at Mawson is due to the introduction of large-scale wind turbines with sophisticated control systems, and a computerised building management and control system.

Each station has a high-temperature incinerator that is used to incinerate kitchen waste, some packaging waste, and other waste such as field waste that is not suitable for return to Australia. Incinerator waste is stockpiled until there is sufficient waste to warrant a burn. Over winter this can be weekly; over summer it is often daily. The quantity of fuel used provides some indication of the quantity of waste produced, which depends on the stations' population and the nature of the programs conducted.

In 2004–05 the Australian Antarctic stations incinerated a total of 56 190 kg of waste, which is 14 per cent of all waste produced by Australian Antarctic operations in that period. Most waste from Antarctic stations is returned to Australia where it is recycled, reused, or treated and disposed of to landfill. The total fuel used in incinerators has dropped by 10 per cent over the past five years.

The annual peaks and troughs in waste figures correspond to the stations' populations. The spike in the Mawson data in 2002–03 is due to a large field-based program.

The incinerators are quite old (over 20 years) and are rapidly approaching the end of their serviceable lives. Alternative methods of organic waste disposal and more efficient incinerators are being investigated.

The energy management strategies put in place by Australia's Antarctic Division over the past decade have been successful. Further significant reductions in fuel usage, however, will be difficult without a large investment in alternative energy systems.

## Potable water

Australia's stations have a reticulated water system which provides for all potable, cleaning, heating, domestic and industrial uses from one station source. Water consumption is regulated according to the abundance of supply, and also varies according to the nature of the activities being undertaken (such as construction and concrete mixing), the station's population, and, for the continental stations, the extent of the summer thaw.

Because of the high rainfall, catchment configuration and small station population, water use at Macquarie Island is not considered to have any negative environmental impacts.

Although freshwater in the Vestfold Hills is abundant in the summer months, Davis station is several kilometres distant from the nearest source. Potable water is produced by reverse-osmosis of saline water from a nearby tarn and stored in tanks with a total capacity of 1 430 000 litres, which is considered adequate for a maximum population of around 65 people. Brine from the reverse-osmosis plant is discharged to the sea. Increasing summer populations are stretching the station's water-making capacity, leading to regular summer water restrictions and the investigation of alternative water sources.

At Casey and Mawson, meltwater from the summer thaw is captured and stored in 270 000-litre tanks, and drawn from melt-lakes during the winter. Predicted future peaks in the Casey population due to the air transport system are expected to strain its water supply, and storage capacity may have to be increased.

The environmental aspects of water supply at the continental stations are the use of fuel to generate electricity to maintain the water in a liquid state, and at Davis to run the reverse-osmosis plant. These effects are not considered to be significant.

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# Glossary

**Biomass:** The total mass, at a given time, of living organisms of one or more species per unit area (species biomass)

**CCAMLR:  Convention of the Conservation of Antarctic Marine Living Resources:** The Convention on the Conservation of Antarctic Marine Living Resources came into force in

1982, as part of the Antarctic Treaty System, in pursuance of the provisions of Article IX of the Treaty. The Convention establishes a Commission to manage the marine living resources of the area for which it is responsible.

**Dobson Unit (DU)** is defined to be 0.01 mm thickness at STP (standard temperature and pressure). Ozone layer thickness is expressed in terms of Dobson units, which measure what its physical thickness would be if compressed in the Earth's atmosphere.

**Fast-ice:** This is sea-ice in the very early stages of formation. Sea-ice that forms in situ and attached to the coast is called "fast-ice", it is stuck fast. In this picture the surface of the sea is beginning to freeze as the temperature is dropping to -20C and below.

**Phytoplankton** = Free-floating flora that convert inorganic compounds into complex organic compounds. This process of primary productivity supports the pelagic food-chain. Phytoplankton vary in size from less than 1 to several hundred µm.
**Phytoplankton biomass:** The total weight of phytoplankton, a free-floating flora, at a given time per unit area.

**Rotating biological contactors (RBCs)** treat waste streams using a thin film of aerobic microorganisms on rotating cylinders. The rate of rotation is selected and controlled to provide optimum oxygen levels and contact with the waste stream. <http://flint.apogee.net/et/ewtwrbc.asp> includes a diagram.

**Southern Annular Mode:** The Southern Hemisphere annular mode is a large-scale see-saw in atmospheric pressure between the western and eastern hemispheres which fluctuates on a time scale of years. It has been also been referred to as the Antarctic Oscillation and the High-Latitude Mode.

**Ultraviolet radiation (UVR): Ultraviolet rays** that are part of the energy that comes from the sun. Ultraviolet radiation **(UVR)** which falls between x-rays and visible light on the electromagnetic spectrum, is divided into three types, according to wavelength. These are: **UVA** (320-400nm), **UVB** (290-320), and **UVC** (200-290nm).