Chapter 2
Human Impacts to Antarctic Wildlife: Predictions and Speculations for 2060

Eric J. Woehler, David Ainley and Julia Jabour

Abstract Four broad categories of human activities that presently threaten Antarctic wildlife in the Antarctic were identified: (1) tourism and non-governmental activities, (2) scientific research, (3) commercial fisheries and (4) whaling. Two further broad categories of threats that originate from multiple forms of human activities are: (1) shipping-related impacts and (2) the introduction of non-native species or disease-causing agents. These threats are not mutually exclusive, and there are various interactions and synergies present amongst them. We have not incorporated climate change into the assessment of each of these, but briefly assess the hierarchical contribution of climate change to other threats. We confidently expect an expansion of virtually all anthropogenic activities in the Antarctic (primarily tourism, research and fisheries) in the next 50 years. The threats will also increase in their complex synergies and interactions, giving further increasing urgency to adopting a more precautionary approach to managing human activities in the Antarctic. We present predictions for 2060 and list suggested proactive management and conservation strategies to address the predicted threats to Antarctic wildlife and their environment.

Keywords Antarctica • Conservation • Cumulative impacts • Threats • Wildlife

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E. J. Woehler (✉)
School of Zoology, University of Tasmania, Private Bag 05, Hobart,
TAS 7001, Australia
e-mail: eric.woehler@utas.edu.au

D. Ainley
HT Harvey and Associates, 983 University Avenue, Building D, Los Gatos,
CA 95032, USA
e-mail: dainley@penguinscience.com

J. Jabour
Institute for Marine and Antarctic Studies, University of Tasmania,
Private Bag 129, Hobart, TAS 7001, Australia
e-mail: julia.jabour@utas.edu.au

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2.1 Introduction

With no native human population in the Antarctic or on the peri-Antarctic islands, resident wildlife have evolved in the absence of human hunters, the pressures arising from habitat modification and the predation from domesticated vertebrates that are all common throughout the rest of the world. In this chapter, we aim to predict and speculate on potential direct impacts of human activities to Antarctic wildlife in 2060, based on our understanding of current impacts, and with a continuation of Business-As-Usual in the spectrum of existing anthropogenic activities; we do not examine the direct effects of climate change, but note its potential synergistic and hierarchical role with other impacts.

Our focus is on the areas south of the Antarctic Polar Front. We confine our discussions to those species for which contemporary data permit assessment of current and future threats and impacts, i.e. vertebrate species (seabirds, marine mammals and finfish), and include one invertebrate species for which there is a substantial commercial fishery, Antarctic krill (*Euphausia superba*).

2.2 Methodology, Qualifiers and Challenges

Our contemporary state of knowledge regarding human impacts on wildlife is based on three decades of studies on relatively few species that have generated widely disparate results (see de Villiers 2008, for a detailed review and list of the extensive literature). Predictions about threats and their impacts 50 years into the future, therefore, are substantially qualified. If researchers had been asked to undertake similar predictions in 1961—coincident with the Antarctic Treaty coming into force—for 2010, they would have been unlikely to predict the development of commercial tourism, the extent of research stations and the complexity of the associated and obligatory infrastructures, the scale of commercial krill and finfish fisheries, and the impacts from global warming.

The dramatic developments in technology and engineering since 1961 will be negligible compared to those advances that will occur in the next 50 years, so we may confidently predict unpredictable situations and circumstances that are beyond our current understanding or even our capacity to foresee. Clearly, lack of such foresight provides both a challenge to making predictions and an opportunity to speculate beyond what may appear likely today. To address the constraints, we incorporate results from reviews of human impacts to wildlife with observed and predicted trends in various human activities in the Antarctic and (where relevant, on the peri-Antarctic islands).

Our assessments are based on the available information in numerous wildlife impact studies (de Villiers 2008, lists well over 100 studies). Herein, we review studies on the efficacy of current Antarctic environmental regimes, examine trends of various human activities and draw upon our (EW: 32, DGA: 43 and JJ: 20) years of collective experience working in the fields of Antarctic and Subantarctic biology.

Since the 1980s, researchers have investigated the scale, duration and intensity of impacts to wildlife associated with human activities in the South Polar Region. A high number of studies examined physiological and behavioural responses by seabirds and seals in reaction to a range of human activities. Notable milestones include Benninghoff and Bonner (1985), Fraser and Trivelpiece (1994, seabird researchers), Kennicutt (1996, science and operations), Hofman and Jatko (2000, cumulative impacts from commercial tourism activities), United Nations Environment Programme (2002, persistent toxic chemicals) and Kerry and Riddle (2009, disease). Recent comprehensive reviews include de Villiers (2008), Tin et al. (2009) and Aronson et al. (2011). It is important to note that virtually all of the research on human disturbance has been limited to vertebrates, typically penguins (particularly Adélie penguins *Pygoscelis adeliae*) and seals at their breeding or haul-out sites. A greater range of species comprising procellarids, skuas and cormorants has recently been studied (de Villiers 2008), but little research has been undertaken on other taxa.

Headland (2009) provides a detailed listing of human activities in the Antarctic from the earliest records to the International Polar Year 2007–2009. Statistics in the public domain are available from the International Association of Antarctica Tour Operators (IAATO, commercial tourism since 1992), Commission for the Conservation of Marine Living Resources (CCAMLR: commercial fishing since 1970), and Council of Managers of National Antarctic Programs (COMNAP: infrastructure currently in use by National Antarctic Programs); see also Summerson and Riddle (2000).

A recent assessment of the functioning of the Committee for Environmental Protection (CEP) established under the Protocol on Environmental Protection to the Antarctic Treaty (also known as the Madrid Protocol) by Orheim et al. (2011) was complemented by that of Grant et al. (2012). Bastmeijer and Roura (2008) undertook a systematic examination of the strengths and weaknesses of the coverage and application of the Protocol's Annex I concerning Environmental Impact Assessments (EIAs). Hemmings and Kriwoken (2010) examined the limitations in coverage, compliance and effectiveness of high-level Antarctic Environmental Impact Assessments (EIAs), while Roura and Hemmings (2011) and Marsden (2011) each argued for Strategic Environmental Assessments. Annex II of the Protocol, dealing with the conservation of Antarctic flora and fauna was revised in 2009 but has yet to enter into force. Hughes and Convey (2010) examined the current practices to prevent the transfer and introduction of non-indigenous species to the Antarctic. Goldsworthy and Hemmings (2009) reviewed the efficacy of Annex V dealing with area protection and management. One weakness identified by them, that of the need to add Marine Protected Areas (MPAs) to the Antarctic Specially Protected Area (ASPA) network has seen some recent developments. A strategic overview of national, regional (i.e. Antarctic Treaty System, ATS) and global law touching on the Antarctic environment is provided by Hemmings (2011a).

We describe the intensities of a wide range of current anthropogenic activities that impact on Antarctic wildlife, and summarise the current efforts to minimise them. Based on current trends and impacts, we present predictions for 2060 and suggest proactive management and conservation strategies to address the predicted threats to Antarctic wildlife. While we are confident that all anthropogenic activities in the Antarctic will expand in the next 50 years, we are equally confident that the conservation and management of the Antarctic environment and the values of the people responsible for the task will also vary and evolve in the decades to come. As a result, some of our suggestions for conservation strategies may lose their relevance. We are also confident that climate change, globalisation and other global phenomena will have increasing effects on the Antarctic. In addition, in this chapter, we do not attempt to make value judgments of the significance of impacts or whether the benefits of an activity outweigh its impact. While a discussion of global influences on Antarctic wildlife deserves a more in-depth treatment than we can afford in this chapter, we dedicate Sect. 2.4.1 for a discussion of the synergies that climate change is likely to have with the threats associated with human activities taking place in Antarctica.

In this chapter, we adopt the term 'threat' to identify anthropogenic activities that may adversely affect the distribution and abundance of a taxon between the present and 2060. This includes activities that can cause a significant decrease or loss in the quality and quantity of required habitat, disrupt ecosystem services and functions, or result in a significant decrease in population sizes (e.g. by affecting breeding success and/or survival).

2.3 Contemporary Impacts to Antarctic Wildlife from Human Activities: Management and Gaps

Based on information from wildlife impact studies, we identify four broad categories of human activities that presently threaten Antarctic wildlife and two broad categories of threats that originate from multiple forms of human activities in the Antarctic. In no particular order or ranking, they are:

1. Tourism and non-governmental activities

Began in the 1960s and increasing significantly in the last two decades, commercial tourism now brings the highest number of people to the region. During the 2010/2011 season, just under 34,000 paying tourists travelled to Antarctica; more than 95 % of them travelled on cruise ships. About 40 % of the tourists stayed onboard their ship or aircraft during the entire voyage. Over 18,000 cruise ship passengers landed and visited tourist sites on the Antarctic Peninsula (IAATO 2012a). In general, the majority of tourist visits take place on the Antarctic Peninsula and adjacent localities, primarily between October and March, but all areas of the Antarctic Continent and many peri-Antarctic islands are visited and some sites are visited at other times of the year (Jabour 2009).

Travelling with the paying passengers are also approximately 10–20,000 staff and crew members (Tin et al. 2013), with a typical guide to tourist ratio of 1:20 while onshore, although this may vary amongst operators (IAATO 2012b).

Primary destinations are wildlife concentrations (seabird colonies and seal haul-outs), with multiple groups of tourists walking to the vicinity of the animals. The arrival of several cruise ships at the same site on the same day is possible at frequently visited sites, although under industry (IAATO 2012b) and site-specific guidelines (ATS 2012a), this practice is discouraged. However, no such guidelines or rules exist for private, independent expeditions to Antarctica. These are possibly of greater concern because of the lack of controls on their activities (Murray and Jabour 2004; Sandelson 2011).

Possible impacts of tourism on wildlife include disturbance of animals as a result of frequent visit on foot, introduction of diseases and non-native species and disturbance and pollution linked to ship and aircraft operations (e.g. Hofman and Jatko 2000; Stewart et al. 2005; de Villiers 2008; Australia 2009). However, little coordinated long-term monitoring and research exists, available data are at least partly contradictory (de Villiers 2008) and consequently our current understanding on long-term population effects and comparison to disturbances caused by intra- and inter-species interactions are minimal. Tourism activities are diversifying and the development of permanent, tourism-dedicated land-based infrastructure has been considered, although it is not supported by the Antarctic Treaty Consultative Parties (Bastmeijer 2007; Bastmeijer et al. 2008; IAATO 2008).

2. Scientific research activities, including infrastructure construction, support operations and logistics

Scientific research efforts and the construction of permanent research stations accelerated during and following the International Geophysical Year in 1957/58 (Tin et al. 2013). According to the Council of Managers of National Antarctic Programs (COMNAP 2012a), there are currently approximately 100 active research facilities (all-year and summer stations, field camps and refuges) in the Antarctic Treaty area.

Station footprints encompass a wide range of facilities and evidence of their use (e.g. runways, fuel storage and roads/tracks and exhaust from diesel power stations). Most stations are built on ice-free areas, in many cases occupying areas previously used for nesting and moulting seabirds, and for pupping and moulting by fur seals and seals. All stations combined, it is estimated that there is a maximum simultaneous accommodation capacity for 5,000 people during summer (October to March) and 1,000 during winter (cf Jabour 2009). Stations built since the Madrid Protocol came into force will have had some form of a national EIA undertaken for their construction and operation (see http://www.ats.aq/devAS/ep_eia_list.aspx?lang=e for all such assessments in the public domain). These assessments determine the scale and intensity of any environmental impacts, including those on local wildlife in the proximity of the station.

Stations have typically served as foci for local and regional research activities, acting as logistic hubs for fieldwork farther into the Antarctic wilderness. Almost all stations have a highly localised impact on their immediate environment, especially before the entry into force of the Madrid Protocol (Bargagli 2008). Since then, the footprints of some stations have stabilised while others have expanded or intensified (e.g. Peter et al. 2008; Kennicutt et al. 2010; Chwedorzewska and Korczak 2010; Klein et al. 2013). Joint facilities are rare, despite the seeming benefits in reducing human footprint (Hemmings 2011b). As noted, field research activities will also make use of temporary or permanent field camps away from stations. Data on the locations and use of field camps or the environmental guidelines that are applied to their operations are sparse and not regularly updated.

Fuel spills are one of the most widespread sources of contamination near research stations and refuelling areas (Bargagli 2008). Sewage discharged from stations is in most cases only lightly treated. High levels of polybrominated diphenylether (PBDE) have been found in fish living near a sewage outlet (Hale et al. 2008). Untreated sewage and other discharges from stations may introduce potential for disease transfer to environment (Barbosa and Palacios 2009; Kerry and Riddle 2009; Grimaldi et al. 2010; Hughes et al. 2013). Toxins such as asbestos and polychlorinated biphenyls (PCBs) are being released from decaying infrastructure and disused waste dumps with unknown impacts on wildlife and ecosystems (Tin et al. 2009). Construction has damaged breeding and roosting habitats (e.g. Wilson et al. 1990; Micol and Jouventin 2001; Woehler 2006; Braun et al. 2013).

Wildlife living in proximity to stations may become disturbed by interactions with humans while others have developed some habituation. Use of ships, zodiacs, aircrafts and other machinery can disturb wildlife (de Villiers 2008 and references therein). Research activities that involve banding, tagging, instrument attachment or handling of animals (primarily seabirds and seals) may stress the animals, though in most cases, relatively few individuals are involved and population-level effects have not been documented (Tin et al. 2009 and references therein).

Marine acoustic research and underwater construction activities can generate underwater noise at levels that disturb marine mammals, adversely affect hearing of diving seabirds (Cooper 1982; Woehler 2004), disturb birds foraging near breeding sites, and disperse prey in water, potentially reducing foraging efficiency.

3. Commercial fisheries

(a) Regulated fisheries and general fisheries impacts

Extensive fisheries were once present on the insular shelves of peri-Antarctic islands and the northern Antarctic Peninsula, but after overfishing destroyed many stocks, these were shut down (Koch 1992). Now only limited to small finfish fisheries for Patagonian toothfish (*Dissostichus eleginoides*) and mackerel ice fish (*Champsocephalus gunnari*) that remain in those areas, replaced to some degree by a burgeoning Antarctic krill (*Euphausia superba*) fishery centered in the Scotia Sea region. New ‘exploratory’ fish–fish fisheries for Antarctic toothfish (*D. mawsoni*) have begun to operate increasingly farther south, extending into the Ross Sea and elsewhere along the continental slope (CCAMLR 2010). Fishery operations occur year-round, depending on area closures, target species and sea ice presence and conditions. The total reported catches for 2010/11 were 179,131 tonnes of krill, 11,254 tonnes of toothfish and 11 tonnes of icefish within the CCAMLR area (CCAMLR 2011a). Improper fisheries management is a major challenge to the Antarctic marine ecosystem’s integrity (Miller 2013).

Bycatch species comprise seabirds, Antarctic rock cods, macrourid fish, skates and rays, sponges, corals and other benthic invertebrates. The most direct impacts have arisen from harm to the seabed by long lines, in some cases scraping clean several sea mounts, and over-fishing, with corresponding alteration of food webs. Depleted fish stocks have failed to recover even after 20 years of no fishing (Marschoff et al. 2012). CCAMLR practices a form of ecosystem based management for species it views as 'forage', e.g. krill, and employs an Ecosystem Monitoring Programme (also known as CEMP) to help inform management (Constable et al. 2000). However, CCAMLR resorts to a single-species maximum sustainable yield (MSY) strategy for finfish, which it views as 'predatory', but with no monitoring programme in place (Constable et al. 2000). CCAMLR introduced Conservation Measures to protect shallow habitats (<550 m) from long-lines and trawls in 2008 and restricted fishing in areas of high concentration of what it calls, 'vulnerable marine ecosystem' species (corals etc.) in 2009, 30 years after the Convention came into force. Therefore, further damage to what is left should be minimal hereafter. Recovery of damaged stocks is at best uncertain.

Drawing on results elsewhere (e.g. Baum and Worm 2009), effects on top predators from fishing may come from competition for and reduced availability of preferred prey species, and altered ecosystem structure and functions, with concomitant cascading effects of reduced top predator species as seen in bank and reef ecosystems (Ainley et al. 2012). Almost all krill fishing occurs where land-based and marine-based predators forage or used to forage (ASOC 2010). Thus, while the overall take of krill may be relatively low from a Southern Ocean stock-size perspective, the spatial and temporal concentration in these important predator foraging areas can have disproportionately high effects, competing with predators for prey at critical periods during the year. Fishing operations are a key source of plastic debris in the Southern Ocean (Ivar do Sul et al. 2011). Loss and discard of fishing gear results in marine debris that can entangle wildlife (e.g. Ainley 1990; Auman et al. 2004; Hofmeyr et al. 2006). Shipping operations can also disturb wildlife nearby (see item 5).

(b) Illegal, unreported and unregulated (IUU) fisheries

IUU fisheries do not comply with established conservation measures, greatly exacerbating the general impacts arising from fishing operations described above. IUU fisheries operate throughout the Southern Ocean and extend northward into subantarctic and temperate waters. By the early 2000s, the total IUU catch for Patagonian toothfish was estimated to be at least double the legal catch, and exceeded the aggregate global limit recommended for regulated fisheries in all CCAMLR waters (Tin et al. 2009). Through CCAMLR's efforts, IUU fishing has decreased in recent years. In 2009/2010, total IUU catches were estimated to be just over 10 % of total reported catch. However, IUU operations also appear to have shifted southwards and in some areas, catches were estimated to be up to 10 times that of reported legal catches. There is concern that CCAMLR appears to be unable to control further IUU fishing in the Southern Ocean (CCAMLR 2011c).

4. Whaling

The International Whaling Commission (IWC) established a global moratorium on commercial whaling in 1986 and the Southern Ocean Whale Sanctuary in 1994. Between 1987 and 2009, Japanese vessels took over 9000 minke (*Balaenoptera bonaerensis*) and 14 fin (*B. physalus*) whales in the Southern Ocean Whale Sanctuary under scientific 'Special Permits', despite widespread criticism of the validity of the science being used as justification (Gales et al. 2005; Clapham et al. 2007). All sampled animals have been killed.

The direct effect of past commercial whaling and sealing has had major impacts to the Southern Ocean ecosystem, including impacts on ecosystem productivity (e.g. increasing ocean productivity by recycling iron, Nicol et al. 2010) and cascading effects on food webs (Emslie and Patterson 2007; Baum and Worm 2009). Recovery of fur seals (*Arctocephalus* spp.) and humpback whales (*Megaptera novaeangliae*) is having complex effects on trophically competing species, obscuring other effects from climate change (Ainley et al. 2010a; Trivelpiece et al. 2011; Trathan et al. 2012). While current Special Permit whaling removes a relatively low number of whales, its concentration along continental shelf-breaks along just one-third of the Antarctic circumference amplifies the ecological impact.

Recent proposals to increase the take to 1,000 minke whales per year, in conjunction with an expansion to take humpback whales, has been met with intense public outcry and vigilante action, causing even governments to voice opposition (McCurry 2012; Rothwell 2012). Other than hesitance to take humpback whales, the whalers have not responded. In addition, uncertainties exist as to the future of the global moratorium on commercial whaling and Special Permit whaling, which is the subject of a case currently before the International Court of Justice (ICJ 2012).

We have also identified two broad types of threats to wildlife that arise from multiple activity types:

5. Shipping-related impacts

Ships are used extensively by tourism operators, fishing operations and National Antarctic Programs to access and to work in the Antarctic and surrounding waters. Fuel spills from ships that run aground or sink can have severe and long-lasting impacts on marine wildlife (e.g. Eppley and Rubega 1989, 1990; Kennicutt and Sweet 1992; van den Brink and de Ruiter-Dijkman 1997; Ruoppolo et al. 2012). Bird strikes with vessels and ship collisions with cetaceans can cause injury and mortality (Black 2005; van Waerebeek et al. 2007). Ships' hulls, ballast water and sea chests are the primary means of introducing non-native marine organisms (Lee and Chown 2007, 2009).

Anti-fouling toxins applied on ship hulls may have adverse effects on marine species and ecosystems that are as yet unknown for the Southern Ocean. Ship traffic creates underwater noise that is likely to be audible to animals under the sea surface. The severity of impacts is related to the species concerned, the timing of the shipping activity relative to the breeding season of the species, and the distance from wildlife concentrations (de Villiers 2008).

Fishing vessels are the primary source of marine plastic debris within the Antarctic region. Fishing materials are generally not biodegradable and consequently are present in the ocean year-round and may persist for decades, leading to mortality and morbidity of relatively low numbers of seals and birds from ingestion and entanglement (Ainley 1990; Auman et al. 2004; Ivar do Sul et al. 2011). Marine debris can also serve as substrate for the transfer and introduction of non-native organisms that have the potential to alter ecosystem structure (Barnes and Fraser 2003; Gregory 2009).

6. Introduction of non-native species or disease-causing agents

While it is unlikely that unintentional introduction would lead to establishment of non-native vertebrates in the Antarctic because of the harsh climate (but see Headland 2012), the transport and dissemination of micro-organisms is an inevitable consequence of human presence in the Antarctic (Cowan et al. 2011). Visitors' clothing and personal belongings, vehicles, aircraft and ship holds, imported food, cargo and building materials are all viable pathways of transportation of non-native plant propagules (Hughes and Convey 2012 and references therein). Untreated sewage and other discharges from stations and ships may introduce pathogens to which native species have never been exposed and have developed no immunity (Smith and Riddle 2009). Researchers who come in contact with wildlife may carry and transfer disease-causing agents (Grimaldi et al. 2010).

It is important to note that these threats are not mutually exclusive, and there are various interactions and synergies present amongst them. We have not incorporated climate change into the assessment of each of these, and confine our predictions and discussions regarding this issue to Sect. 2.4.1.

Current terrestrial threats to Antarctic wildlife are largely confined to the ice-free areas around the periphery of Antarctica, which represent approximately 0.3 % of the surface area of the continent (Tin et al. 2009). Impacts also largely occur during the summer months, October to March, inclusive. The breeding seasons for most seabirds (excluding king *Aptenodytes patagonicus* and emperor penguins *A. forsteri*) and marine mammals that breed ashore coincide with the peak in human activities, human visitor numbers and associated logistic support efforts. The logistical support from research and supply vessels is largely confined to the summer months, being dependent on the break-up of the winter sea-ice before most vessels can approach the Antarctic continent. Thus, any adverse effects associated with vessels (bird strikes or noise, for example) are confined to the summer months.

Table 2.1 summarises some of the current management and conservation strategies that seek to minimise or mitigate these six selected threats. In the following Sects. 2.3.1–2.3.6, we describe current trends and our predictions for 2060 based on a Business-As-Usual scenario. Finally, a number of proactive management and conservation strategies are listed to address, minimise or prevent our 2060 predictions.

Table 2.1 Selected strategies in place in 2012 aimed at managing impacts of human activities on Antarctic wildlife

Activity	Selected 2012 strategies aimed at managing impacts on Antarctic wildlife
Tourism and non-governmental activities	• Madrid Protocol applies • Largely self-regulated by IAATO members through expedition leader instructions, Guidelines for wildlife watching, special activity guidelines, etc. (IAATO 2012c) • ATCM site guidelines for visitors for the 35 most-visited sites in the Antarctic Peninsula (ATS 2012a) • ATCM resolutions on tourism that recommend guide-to-passenger ratio, maximum ship capacity, etc. (ATS 2012b) • Varying and contradictory wildlife approach distances implemented by IAATO and various National Antarctic Programs (de Villiers 2008) • Protected Area network protects some wildlife values (New Zealand 2005, 2009) • Aircraft operation guidelines (Harris 2006)
Scientific research	• Madrid Protocol applies. Specifically: – Annex I requires EIAs prepared before all activities – Annex II requires special permits for research involving the killing, collection, capture, handling and tagging of birds and mammals – Annex III details requirements for waste and sewage disposal at field camps and research stations and clean-up of old and abandoned disposal sites – Annex IV prohibits the discharge of oil, chemicals and garbage into the marine environment – Protected area network, including marine reserves established under Annex V protect some wildlife values – Annex VI details liability arising from environmental emergencies (not yet ratified) • Scientific Committee on Antarctic Research (SCAR 2009, 2011a, b) non-mandatory codes of conduct for animal research, terrestrial field research and exploration of sub-glacial lake environments • Council of Managers of National Antarctic Programs (COMNAP 2012b) guidelines, manuals and handbooks that share best practices on energy, fuel and waste management, establishment of protected areas, etc • Practices vary amongst National Antarctic Programs, e.g. in quarantine and biosecurity protocols, sewage treatment, deployment of renewable energy and energy efficiency applications and oil spill response plans (e.g. Hughes and Convey 2010; Gröndhal et al. 2008; Shears et al. 2007; Tin et al. 2010)

(continued)

Table 2.1 (continued)

Activity	Selected 2012 strategies aimed at managing impacts on Antarctic wildlife
Commercial fisheries	• CCAMLR entered into force in 1982 to manage fisheries south of the Antarctic polar front. Science is a key component that underlies decision making that is aimed at ecosystem-based management, taking into account the precautionary approach. Conservation measures have included mesh size regulation, fisheries closures, bottom trawl and gillnet prohibition, longline prohibition in waters <550 m, and bycatch limits for some elasmobranches and vulnerable benthic invertebrates (e.g. Constable et al. 2000; CCAMLR Performance Review Panel 2008; Miller 2011) • Since 1985, CEMP monitors effects of krill fishery on land-breeding seals and seabirds. Other than some degree of spatial limits to catch, the data have not yet been used to adjust catch levels to avoid effects on krill-dependent or associated species, nor does it include monitoring of ecosystem effects by non-krill fisheries (CCAMLR Performance Review Panel 2008) • Seabird bycatch mitigation measures first introduced in 1992, result in significant decrease of seabird bycatch where enforced for regulated longline fisheries (Melvin and Baker 2006). Development or implementation of several international policies to reduce seabird bycatch, e.g. FAO's International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries, CCAMLR's *Ad-hoc* Working Group on Incidental Mortality Associated with Fishing (WG-IMAF) and Agreement on the Conservation of Albatrosses and Petrels' (ACAP) Seabird Bycatch Working Group • Establishment of first MPA in Southern Ocean, though applicability to fishery management appears to be minimal (CCAMLR 2009) • Effort to reduce bycatch in IUU fisheries progressing but with much further work needed (CCAMLR 2011c) • Other than unverified 'precautionary' measures, limited effort ensures that fisheries do not collectively have adverse population and ecosystem effects (Ainley and Brooks 2012) • Improved monitoring of IUU imports and exports through catch documentation schemes, and FAO's IPOA-IUU provides diplomatic and legal measures to diminish IUU fishing (Tuck et al. 2003)

(continued)

Table 2.1 (continued)

Activity	Selected 2012 strategies aimed at managing impacts on Antarctic wildlife
Shipping	• Annex IV of the Madrid Protocol prohibits discharge of oil, chemicals and garbage into the marine environment • International Convention for the Prevention of Pollution from Ships (MARPOL) applies and regulates atmospheric emissions, garbage and sewage discharges. August 2011 amendment prohibits use of heavy and intermediate fuel oils in Antarctic waters (Ruoppolo et al. 2012) • IMO member states adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments in 2004 (not yet in force) • COMNAP oil spill response plans and shipping guidelines (COMNAP 2012b) • Guidelines for reducing bird strikes on vessels (IAATO 2010) • Incomplete reporting of accumulation, ingestion and entanglement data required by CCAMLR. *Ad-hoc* reporting by tour operators, scientists and station personnel • CCAMLR has developed an education programme to encourage fishermen not to discard damaged fishing gear and other potentially harmful materials at sea. IAATO likewise has taken steps to ensure that tourists do not discard potentially hazardous materials at sea or on land in the Treaty Area (IAATO 2012c) • IMO efforts underway to increase safety of ships but so far do not apply to fishing vessels (ASOC 2011b)
Whaling	• Diplomatic pressure at meetings of the International Whaling Commission • Legal action in International Court of Justice by Australia (ICJ 2012) • Efforts by environmental groups to raise public awareness of whaling, subsidies involved and health hazards related to eating whale meat, and to intercept whaling vessels in the Southern Ocean to prevent operations (Roeschke 2009; WWF and Whales and Dolphins Conservation Society 2009)
Non-native species or disease-causing agents	• Annex II of Madrid Protocol prohibits deliberate imports of non-native species and requires imported poultry products to be inspected for evidence of diseases • CEP Non-native species manual provides information and non-mandatory guidelines on prevention, monitoring and response (CEP 2011) • Implementation of quarantine and biosecurity measures varies amongst countries and operations (e.g. IAATO 2012c; Grimaldi et al. 2010; Kerry and Riddle 2009) • Some development of disease response strategies and practical measures to diminish risk of spreading diseases amongst Antarctic wildlife with little adoption or implementation (Kerry and Riddle 2009)

2.3.1 *Tourism and Non-governmental Activities*

2.3.1.1 Current Trends and Impacts Predicted for 2060

Commercial tourism has been increasing in spatial and temporal extent over the last three decades, with a concomitant increasing spectrum of activities, increasing number of wildlife species exposed to, and potentially disturbed by tourism activities. Since 2008, the number of tourists travelling to Antarctica decreased as a result of the global financial crisis. In 2009, IAATO projected that the increase would resume. Nonetheless, there was still a 30 % decrease in tourist numbers between the 2008/2009 and 2010/2011 seasons (IAATO 2012a).

There have been few programmes of comprehensive and long-term research and monitoring of environmental impacts of Antarctic tourism (e.g. Naveen 1996; Lynch et al. 2010). In the face of this lack of conclusive evidence, some Antarctic Treaty parties are not willing to take precautionary action to minimise tourism impacts, nor are they investing the requisite resources in monitoring programmes that could provide these fundamental scientific data necessary to inform management decisions (ASOC 2011a).

Based on current trends, we conservatively project that there will be 120,000–160,000 visitors to Antarctica annually by 2060. This projection may appear high, but it is barely twice the peak of visitors to the Antarctic before the most recent financial crisis. A recovery to double the previous peak over the next 50 years is realistic in light of the previous growth in Antarctic tourism. We also forecast that there will be an increasing number of vessels. Large vessels may have an advantage as a result of economy of scale as costs of compliance with international law increase (Jabour 2013). However, the ban on the use of heavy fuel oils by ships transiting the Antarctic area is likely to reduce the number of very large (500 + passengers) vessels.

We further expect that there will be increased numbers of tourist flights to more areas over greater periods of each year and not primarily confined to summer months, as is the current situation. It is possible that land-based tourism will also develop, leading to increased permanent infrastructure, with concomitant increase in risk of pollution and damage to wildlife habitat (Bastmeijer et al. 2008). In general, we project there to be an increasing range and spectrum of human activities that would increase the potential for disease and other species' introductions due to rapid transit of tourists and their gear from elsewhere on the planet (e.g. Curry et al. 2002; Frenot et al. 2005; Bergstrom et al. 2006 and references therein; Frenot et al. 2008).

2.3.1.2 Management Needs for 2060

Many suggestions on how to manage Antarctic tourism have been proposed (e.g. Hemmings and Roura 2003; Bastmeijer and Roura 2004; Liggett et al. 2010; Jabour 2013). In our opinion, in order that commercial tourism activities do not result in harmful interference on Antarctic wildlife and ecosystems, it would be necessary to manage tourism proactively, and to a greater extent than currently. There needs to be more active involvement by the Antarctic Treaty Consultative Parties in the regulation of the tourism industry, starting with the development of a strategic vision on tourism in Antarctica (sensu Amelung and Lamers 2006). Greater constraints need to be established to reduce the number of sites visited, the number of visitors ashore and the ratio of tourists to guides ashore. At all wildlife sites, site-specific and species-specific guidelines for visitors need to be adopted, implemented and enforced. Resources need to be made available in order that the impacts of all aspects of commercial tourism can be assessed objectively and independently.

The Madrid Protocol requires that EIAs are undertaken before the start of any activity, and that cumulative impacts (temporal and spatial) and other ongoing and future activities (including research) need to be incorporated into management considerations. This requirement needs to be implemented. Where it is not possible to predict cumulative impacts a priori with reliability, monitoring programmes need to be established in order to detect impacts in time and space so that remedial action can be taken (Hofman and Jatko 2000). Until scientifically valid and independent data are available, tourism activities need to be managed with a precautionary approach, e.g. by increasing minimum approach distances to wildlife from 5 to 20 m to allow for the current uncertainty. Tighter biosecurity protocols need to be adopted, implemented and legally enforced (see Sect. 2.3.6). In addition, regional zonation with specified inviolate (i.e. no-research, no-tourism, no-entry) sites needs to be used to protect wildlife and other environmental values (e.g. wilderness and aesthetic: Summerson and Riddle 2000).

2.3.2 Scientific Research and Associated Logistics

2.3.2.1 Current Trends and Impacts Predicted for 2060

The Madrid Protocol entered into force in 1998 and has significantly reduced the environmental impacts of scientific research and the activities of National Antarctic Programs (e.g. Bargagli 2008; Kerry and Riddle 2009). More than a decade later, gaps in its implementation still remain—e.g. no EIA appears to have prevented or modified any proposed activity (Hemmings and Kriwoken 2010), only a few abandoned sites have been cleaned up, with only a few of them involving the full remediation of contaminated soils and sediments (Tin et al. 2009) and there is a general lack of compliance at some locations (e.g. Peter et al. 2008; Braun et al. 2012). Concomitant with these gaps in implementation, has been the increasing human presence in the Antarctic.

Following current trends, we forecast that there will be increasing numbers of year-round and summer stations, researchers and support staff, support vessels and flights and all forms of vehicular traffic and subsequently, increasing volumes of fuel consumption and storage requirements. These will all contribute to greater spatial footprints of research stations and activities, increased local pollution and disturbance from station and operations and greater realised and potential disturbance to wildlife, assuming that no additional steps are taken to minimise their effects. There will also be associated deterioration of the wilderness values of areas close to these stations.

Chemical contamination from past decades is likely to continue to adversely affect the environment. We expect an increased potential for disease and other species introductions due to the rapid transit of researchers and their field equipment and personal gear (Frenot et al. 2005, 2008; Bergstrom et al. 2006 and references therein; Grimaldi et al. 2010). National Antarctic operations may be subject to future budget cuts, which could lead to varying reductions in construction and logistics activities, however, a wide range of effects (comprising reductions in scientific research, logistics, environmental management or construction and new facilities) remain possible (Sánchez and Njaastad 2013).

2.3.2.2 Management Needs for 2060

Many suggestions have been proposed on how to improve the implementation and compliance to the Madrid Protocol (e.g. Hemmings and Roura 2003; Bastmeijer and Roura 2008; Tin et al. 2009; Roura and Hemmings 2011). In our opinion, to minimise the potential that scientific research and its supporting logistics will result in harmful interference on Antarctic wildlife and ecosystems, it would be necessary that all aspects of station activities and operations are managed proactively, with a greater integration of the impacts from commercial tourism activities (where present) to more appropriately assess cumulative impacts over time and space of all human activities in an area, past, present and future. This would ensure that impact assessments address cumulative impacts (temporal and spatial) and include commercial tourism activities where relevant in order that the EIA process can work effectively as a gatekeeper. As Hemmings and Roura (2003) noted, 'Impact assessments should identify any uncertainties and assumptions concerning possible temporal and spatial impacts, and describe the research or monitoring that will be done to resolve the uncertainties and validate the assumptions. If other activities are occurring or likely to occur where they could have additive effects, the impact assessment should reference those activities and describe the research and monitoring that will be done to be able to distinguish those effects from the effects of the activity for which the impact assessment was done'. A standardised understanding and measurement of stations 'footprint' would assist in impact assessments and management implications.

Objective assessments of the threats and cumulative impacts to Antarctic wildlife from all aspects of research programmes must be more fully incorporated into research protocols, and station and local protected area(s) management plans. Additional long-term population studies to assess long-term trends and to distinguish the effects of climate change, fisheries, tourism and other activities in the Southern Ocean should be established to complement existing decadal-scale seabird and seal studies. Such long-term studies could contribute to regional zoning for wildlife and other values, with some high-conservation value sites off-limits to all visits from both research and tourism. Remotely sensed data could be used to facilitate monitoring of wildlife populations inside these restricted areas.

The Antarctic Treaty Consultative Parties conduct site and compliance inspections in accordance with Article VII of the Treaty and Article 14 of the Madrid Protocol (Sánchez and Njaastad 2013). A recent preliminary evaluation of the value of these inspections in fostering protection of Antarctic values has found that while the number and scope of inspections was adequate, the process was fundamentally flawed without a mechanism for applying sanctions for poor environmental compliance (Jabour 2012a). The so-called 'no-blame policy' may be ideal diplomatically for keeping the peace amongst parties, but it is unhelpful environmentally. To make a real difference to environmental protection, this approach must change.

More countries should investigate the potential for greater use of renewable energy sources. Examples include hydroelectric power at Grytviken, South Georgia (Morrison 2006), wind turbines at Mawson Station (Australian Antarctic Division 2011), McMurdo-Scott Base (Antarctica New Zealand 2011) and at various field sites (Tin et al. 2010; Sánchez and Njaastad 2013). Wind energy will reduce the volume of fuels required for station operations and may reduce the likelihood of fuel spills, but must be considered in the light of potential for bird-strikes. It would be very useful to obtain objective risk assessment information for future clean-up and remediation programmes that is specifically relevant to the Antarctic environment (Tin et al. 2009). Because the Madrid Protocol allows that clean up efforts only take place if in doing so, they do not create, 'greater adverse environmental impact' [Annex III, Article 1.5(b)], it will not be possible to remediate all past and current waste disposal and abandoned work sites.

2.3.3 Commercial Fisheries

2.3.3.1 Current Trends and Impacts Predicted for 2060

Longline fishing effort has increased markedly in the Southern Ocean during the last 20 years. The average effort between 2000 and 2009 is more than 300 % that of the previous decade (CCAMLR 2011b, 2012). There has been a dramatic increase in the mean depth of the fish catch which has recently stabilised, clearly reflecting the collapse and the implementation of fisheries restrictions for some shallower water fishes in the late 1980s, and increased landings of the deep-water toothfish (*Dissostichus* spp) during late 1980s (Morato et al. 2006; Ainley et al. 2012).

The krill catch has remained relatively stable for 17 years until 2009, at which time it nearly doubled (Nicol et al. 2012). While CCAMLR's efforts have reduced

IUU catches markedly since the early 2000s, IUU operations continue to evolve despite CCAMLR's controls. IUU operations are moving farther south, fishing in areas where little or no regulated fishing occurs. Gillnets are used and the extent of by-catch of fish and seabirds and the impact on benthos are unknown (SC-CAMLR 2010a).

We forecast that regulated fisheries will continue to expand, although rising fuel costs may reduce some fishing effort (Pauly et al. 2003; Fabri and Gascón 2008). IUU fishing will not be eradicated. Combined IUU and regulated fisheries will be unsustainable for long-lived demersal species, resulting in some current target species being unable to remain commercially viable (Briggs 2011). Long-term viability of many seabird species and some killer whale ecotypes may be jeopardised (Tuck et al. 2003; Guinet and Tixier 2011). Novel species, e.g. myctophids or silverfish (*Pleuragramma antarcticum*), are likely to be targeted or subjected to increased fishing pressure as currently targeted species and populations are overfished, protected or become economically unviable.

The krill fishery is likely to expand as more efficient krill fishing technology and more lucrative krill products are developed (Nicol et al. 2012). If the krill fishery does expand substantially beyond its present level, we forecast that there will be more general and substantial population and ecosystem effects on its predator and associated species. These effects are likely to be exacerbated by the effects of climate change (Atkinson et al. 2008; Kawaguchi et al. 2009, 2011) and the recovery of depleted whales (Ainley et al. 2010a; Leaper and Miller 2011; Trivelpiece et al. 2011). Recovery of depleted fish stocks is likely to be slow (Marschoff et al. 2012), especially in the face of a rapidly changing Southern Ocean, and at best will attain levels well below pre-exploitation levels. Benthic communities, once populated by 1,000-year old organisms, but destroyed by long-lines will not fully recover. Food webs and ecosystem structure will remain altered.

2.3.3.2 Management Needs for 2060

First and foremost, the broad consensus amongst fishery biologists and managers is that spatial management of fisheries, e.g. the designation of ecologically meaningful MPAs, is required for effective management of live-capture marine fisheries (Fosså and Skjodal 2009; Clark 2009; Kompas et al. 2009; Longhurst 2010). While CCAMLR currently is absorbed in designating a network of MPAs in the Southern Ocean, thus in keeping to Article IX 2(g) in its charter, it remains to be seen how many will actually be useful in fishery management rather than protecting areas where industry has no interest.

In our opinion, more robust and fishery-independent data needs to be incorporated into fishery models, and used to verify model assumptions and catch rates that are considered as precautionary. Until the validity of the data, models and assumptions used to estimate sustainable catch levels can be confirmed, quotas for target and bycatch species need to be more conservative. CCAMLR's CEMP needs to be expanded to include research and monitoring that are capable of detecting and providing feedback to manage the toothfish and other finfish fisheries. The current CEMP effort which focuses on krill needs to be maintained and expanded to concentrate on areas that are smaller than the current regional harvesting units in order to better assess and minimise effects on krill-dependent predators.

CCAMLR allows a 50 % reduction in spawning biomass of so-called 'predatory' species (e.g. toothfish) and 25 % reduction in the case of forage species (e.g. krill; cf Constable et al. 2000; Croxall and Nicol 2004). While the 25 % rule, which includes ecosystem monitoring through CEMP and spatial management of take, is consistent with the Precautionary Principle (Constable 2011), CCAMLR's admitted application of the single-species MSY principle (cf Constable et al. 2000; Longhurst 2010) was not what was originally envisioned in the founding principles of CCAMLR and cannot be construed in any way as 'rational use' (Ainley et al. 2012; Ainley and Brooks 2012). Efforts should be coordinated at the global scale, providing for the development and implementation of best management practices to further reduce seabird bycatch (Melvin and Baker 2006).

2.3.4 Whaling

2.3.4.1 Current Trends and Impacts Predicted for 2060

Japanese scientific whaling in the Southern Ocean has decreased in recent years partly due to non-governmental organisation activities that have drawn the attention of governments. Some whale populations are increasing rapidly, e.g. humpback whales (*Megaptera novaengliae*), others remain far below population levels before industrial whaling of the 1900s, e.g. blue (*B. musculus*) and fin whales, others may be decreasing (e.g. Antarctic minke whales), and insufficient data exist to assess other species, e.g. sei *B. borealis* whales) (IWC 2012).

Changes in attitudes towards whaling and eating whale meat may combine with increasing fuel costs and compliance costs for vessels going into Antarctic waters to end government-subsidised whaling in the Southern Ocean (Hoek 2010). While full recovery of whale populations is doubtful in the face of climate change, any increase in whale populations will continue to result in alteration of food web dynamics (Ainley et al. 2010a; Trivelpiece et al. 2011; Trathan et al. 2012). Only large MPAs, that prohibit fishing and whaling, will reveal the recovery potential. However, uncertainties exist as to the future of the global moratorium on whaling activities, and on the form of regulations of any future commercial whaling (Leaper and Childerhouse 2013).

2.3.4.2 Management Needs for 2060

In order to allow for recovery of whale populations to the extent that climate change allows, large MPAs need to be designated and the existing global moratorium on commercial whaling needs to continue. Non-complying nations need to be convinced to comply with the moratorium. The Southern Ocean Sanctuary needs to be universally adopted and recognised. Management needs for the future will hinge to a great degree on the decision of the International Court of Justice (ICJ 2012). If the ICJ finds that Japanese Special Permit whaling is in fact commercial whaling, a whole regime change will occur. But it is noted that this will involve the International Convention for the Regulation and Whaling and the IWC, neither of which are Antarctic-specific.

2.3.5 Shipping-Related Impacts

2.3.5.1 Current Trends and Impacts Predicted for 2060

With the expected increase of tourism, fishing and National Antarctic Program activities, we forecast shipping activities to increase correspondingly. As the amount of marine traffic increases, there will be increased discharges of sewage, sewage sludge, grey-water and ground food wastes, increased undersea noise and higher likelihood of shipping accidents, fuel spills and ship strikes on marine mammals (e.g. Ruoppolo et al. 2012). Worldwide, the quantity of persistent debris in the marine environment is increasing. In the Southern Ocean, increasing marine traffic, especially IUU fishing vessels, in combination with greater quantities of waste produced and transported from north of the Antarctic Polar Front, from population centers in the Southern Hemisphere are likely to increase the quantity of persistent marine debris.

2.3.5.2 Management Needs for 2060

The International Maritime Organisation (IMO) is presently developing a mandatory polar shipping code that needs to be adopted and implemented. This Code must include fishing vessels, which are currently excluded in IMO deliberations. Ideally the Code needs to ensure that only properly equipped ice-class vessels should enter into Antarctic Treaty waters and that the disposal of operational wastes from vessels are regulated under more stringent requirements than at present (ASOC 2011b). However, the Code is likely to employ a new ship classification system to rate the ability of any ship to operate safely in a range of different ice conditions. In tandem, an up-to-date map of conditions—zoned according to the prevailing ice regime—will be required. Progress is slow on both of these developments. The Code will not prevent any vessel from entering Antarctic waters. It will only prescribe areas of safe operation. As enforcement of IMO conventions is a flag state responsibility, implementation will rely heavily on support from ship insurers and classification societies (Jabour 2012b).

The EIA process, as stipulated under the Madrid Protocol, needs to recognise the potential and actual impacts of undersea noise on marine mammals. Undersea noise, while on its own may be a relatively minor threat to wildlife, will interact synergistically with other concurrent threats, such as climate change and alterations in ecosystem structure, and contribute to significant cumulative impacts. Currently, basic data are lacking on the marine acoustic environment of the Southern Ocean and research needs to be initiated in the Southern Ocean into acoustics and marine mammals if a sound scientific basis is to underpin any future management of ocean noise (SCAR 2006).

More scientific data and continued monitoring are also needed to better document the rates and levels of wildlife entanglement and ingestion of marine debris, and the accumulation rates of marine debris on Antarctic shores. Improved education, and where possible, promulgation of regulations and monitoring programmes, can also contribute towards reducing sources of marine debris from vessels and from population centers in the Southern Hemisphere. Section 2.3.6 further discusses the need for sound biosecurity and quarantine measures to reduce the risk of introduction of non-native species.

In general, MPAs can be created to protect biologically sensitive species, communities and areas from the impact of shipping activities. IMO's polar shipping code may assist here, with regulations proscribing shipping activities in areas of high ice concentration, corresponding with areas of high productivity. Furthermore, in the event that migration routes of marine mammals vulnerable to ship strikes can be charted, additional safety regulations could be imposed on ship operators to reduce pressure during times of heavy traffic.

2.3.6 Introduction of Non-native Species or Disease-Causing Agents

2.3.6.1 Current Trends and Impacts Predicted for 2060

There are currently relatively few established introduced species on the Antarctic, none of which are vertebrates (Headland 2012; Frenot et al. 2005). On peri-Antarctic islands, however, introduced rodents and cats have led to predation of native birds, and the number of species introduced has been found to be related (amongst other things) to the number of human visitors to the site (Johnstone 1985; Chown et al. 1998; Jones et al. 2008; Jones and Ryan 2010; Headland 2012).

Introduced species have the potential to alter breeding habitat of native species (Bell and Dieterich 2010). Seabirds and seals will be the most likely taxa to face threats from any introductions to the Antarctic, due largely to their proximity to stations, their close relationships with species elsewhere and from their prevalence in numbers and biomass. Local cases of unusual disease-associated die-offs of wildlife have been observed. Most events have unknown origins, but human activities have been implicated in some instances, although to date there has been no evidence of any direct human-mediated pathogen introduction (Kerry and Riddle 2009).

Greater human presence, in combination with more amenable conditions, will increase the probability of introductions (Hughes et al. 2013). Increased mobility within Antarctica will also increase the potential for inadvertent transfer of native biota from one part of Antarctica elsewhere where they are alien (Frenot et al. 2005; Hughes and Convey 2010). Warming associated with climate change will increase the likelihood of establishment and expansion of non-native species (Turner et al. 2009a; Grimaldi et al. 2010) and the possibility of mutation of disease-causing agents currently present in Antarctic flora and fauna to more virulent forms. Increased use of aircraft to bring people to Antarctica will exacerbate the potential threat of introductions, including infectious disease-causing agents. It is likely that a greater range of species and areas will be impacted as longer periods of milder conditions and greater extents of ice-free areas with greater inter-connectivity (Cook et al. 2010) become available for colonisation and establishment.

2.3.6.2 Management Needs for 2060

Existing quarantine and biosecurity measures, both inward and outward for all human visitors and equipment to the Antarctic, whether there is close approach and/or contact with wildlife or not, need to be increased from the existing protocols (COMNAP/SCAR 2010). Other pragmatic measures reducing the risk of non-native introductions through non-human vectors also need to be implemented, e.g. fresh food checks, cargo sterilisation (Hughes et al. 2011, 2013). All measures must be efficient and effective, and standardised at all gateway ports and at all landing sites/destinations. Ideally measures would include redundancies to minimise the risks of introductions—e.g. prophylactic measures that are implemented at departure and at arrival points.

Long-term investments in biosecurity measures and environmental monitoring are needed in order to reduce the risk of introductions, and manage and monitor introductions and established species when they occur. At the same time, more research is needed to create an inventory of natural biodiversity in the Antarctic and to develop techniques in order to identify and remove newly established non-native species (SCAR 2010; Hughes and Convey 2012).

Similar research and policy needs exist for the issue of wildlife diseases in the Antarctic. Inventories of endemic diseases and infectious disease-causing agents are urgently needed. Current background levels of diseases and agents need to be quantified in order to provide a baseline for future assessments. Research is also needed to identify the opportunities that exist for introductions and establishment of novel diseases and agents or mechanisms of contagion, and universal disease surveillance and reporting procedures need to be implemented (Kerry et al. 1998). Disease outbreak contingency plans also need to be developed and adopted (Kerry and Riddle 2009).

2.4 Antarctica 2010–2060: Conservation Needs and Challenges

2.4.1 Contribution of Climate Change

Predictions as to how climate change will affect the Antarctic and Southern Ocean vary in their estimates of magnitude, intensity and imminence (e.g. Turner et al. 2009a, b; ACE CRC 2011). Concomitant with these predictions are various estimates of the changes and adaptations required of Antarctic wildlife, particularly those species that are closely associated with sea ice, such as emperor penguins and Weddell seals (*Leptonychotes weddellii*) (e.g. Siniff et al. 2008; Jenouvrier et al. 2009; Ainley et al. 2010b). Unfortunately, many of the predictions and their various assumptions can only be tested post hoc. Rather than predicting a particular state in 2060 (or at any other year–the most common being 2100: Turner et al. 2009a; Jenouvrier et al. 2009), Ainley et al. (2010b) described the qualitative changes to populations, abundances and distributions of Adélie and emperor penguins to modelled habitat changes as the mean tropospheric temperatures reached 2 °C above pre-industrialised levels. They noted that significant changes will be evident when that criterion is reached well before 2060. Similar analyses may provide models for other vertebrate species in the Antarctic, and serve to develop proactive and holistic conservation and management strategies that incorporate and implement a precautionary approach embodying the Precautionary Principle.

Irrespective of the rate of climate alteration, there can be no doubt that climate change will act hierarchically (i.e. top-down) and synergistically with existing anthropogenic threats to the marine and terrestrial wildlife and environments of the Antarctic, potentially realising additive or multiplicative responses from the existing threats (e.g. Halpern et al. 2008a, b; Hoegh-Guldberg and Bruno 2010). It is apparent that the threats will increase in their intensity, frequency and spatial extents into the future. In addition, novel pressures will emerge, including ocean acidification (Kerr 2010), and there will likely be an increase in the frequency and severity of extreme weather events. The effects of these synergistic and cumulative impacts on the resilience of the Antarctic marine and terrestrial ecosystems are presently unknown, but are highly likely to reduce the resilience to further anthropogenic threats and pressures, and exacerbate the existing threats, placing greater stress on ecosystem functions, tropho-dynamics and ecosystem services than present (Ainley and Tin 2012). A comprehensive and integrated understanding of how climate change will affect Antarctic ecosystems is currently lacking, and more research into climate change impacts is urgently needed (Hoegh-Guldberg and Bruno 2010; but see Turner et al. 2009a).

2.4.2 Gaps, Uncertainties and Opportunities

The present lack of quantitative data on the relative impacts to Antarctic wildlife prevents a ranking of the threats discussed here. Were such data available, analyses could identify spatial and temporal patterns, extents and trends in each threat discussed to generate holistic, regional and whole-of-ecosystem threat assessments that could be used to direct research efforts and resources in a pro-active, adaptive conservation management framework.

However, some preliminary contemporary assessments are possible. More than 90 % of the commercial tourist activities visit sites in the Scotia Arc/Antarctic Peninsula (Jabour 2009), an area with the greatest number and concentration of summer and winter research stations (Headland 2009). The greatest pressures on the Antarctic environment and its wildlife are presently occurring in this area during the summer months with the greatest intensity and diversity of human activities. In addition, fishing efforts for Antarctic krill are concentrated in this region (SC-CAMLR 2010b), placing further pressure on the region's wildlife.

We note that there is a wide-range of efforts presently underway to improve the conservation status of Antarctic wildlife (e.g. the designation of MPAs, the implementation of international regulation to reduce seabird bycatch, and the priority given to the consideration of climate change and non-native species by the Antarctic Treaty Consultative Parties) in recognition of the increasing spectrum of threats to the region and we expect them to continue to evolve and expand. However, the lack of quantitative data prevents an objective assessment of the efficacy of existing management frameworks and the claimed sustainability of various activities, including commercial fisheries. Meanwhile, it is very clear that the vast majority of the contemporary threats to Antarctic wildlife are increasing in their spatial and temporal extents and in their intensities, and thus can be expected to increase further by 2060, assuming a Business-As-Usual approach for the next 50 years. Just how realistic this assumption is is certainly debatable, but comparing the rate at which other conservation strategies are adopted and implemented, and the rate of expansion of human activities and appearance of new threats, we see that a reactive, *ad-hoc* approach to conservation and management of the Antarctic environment is unlikely to be able to keep up with the demands of human use of the Antarctic in the twenty-first century.

It is very likely that there are other threats to wildlife resulting from interactions and synergies amongst and between the threats listed above in Sect. 2.3, particularly in association with climate change (see Sect. 2.4.1). These interactions are likely to generate cumulative impacts beyond our contemporary assessment protocols, and are thus beyond our ability to predict. They are, however, likely to be greater than the sum of their parts. In an overwhelming majority of cases, it is currently impossible to quantify the effects or impacts of various human activities on Antarctic wildlife, despite the extensive research undertaken to date (see de Villiers 2008; Tin et al. 2009 for reviews). To overcome this, greater efforts must be made in the future to collect quantitative data that can be used to assess threat levels and impacts to wildlife and to the environment. Until then, a greater level of adoption and application of the Precautionary Principle is warranted in light of the increase in threats to Antarctic wildlife predicted here.

2.4.3 Strategic Conservation Needs

To close, we take a step back from the discussion of specific activities and threats and propose a number of strategic actions that address the overarching context in which Antarctic wildlife—and indeed, the Antarctic environment—can be appropriately protected into the future. While activity-, threat- or species-specific management actions are necessary (and are typically the initial response), it is important not to lose sight of the large-scale strategic context that has the ability to influence the effectiveness of any individual decision or action.

- A holistic and proactive approach, recognising and incorporating cumulative impacts, needs to be adopted for the management of the Antarctic and its wildlife (e.g. Halpern et al. 2008a). The Precautionary Principle needs to be adopted and implemented in the management of all aspects of human activities in the Antarctic in recognition of the substantial data gaps that exist in relation to the impacts of existing human activities in the Antarctic. Proactive measures will provide greater capacity to distinguish between natural and anthropogenic forcing of populations and environmental changes. Concomitantly, criteria for the identification of cumulative impacts to wildlife are required to reduce their occurrence and frequency in the region. Where a meaningful assessment of cumulative impacts is not possible, monitoring programmes need to be established as a matter of priority in order to resolve uncertainties and validate or repudiate assumptions.
- Efforts to obtain baseline data for key, 'indicator' species of wildlife need to be increased substantially. Potentially following the example of the Census of Antarctic Marine Life (CAML), fundamental ecological and biological data on the distributions and abundances for many Antarctic terrestrial species urgently need to be collected. Very few biogeographical studies of the biota on the Antarctic continent exist (but see Howard-Williams et al. 2006 and following, Bergstrom et al. 2009; Terauds et al. 2012) and the various data gaps reduce the scales and extents of current EIAs, and prevent quantitative ecological risk assessments for existing or planned human activities. The data gaps also prevent the adoption and implementation of holistic and pro-active conservation and management strategies and the full description of ecosystem services and functions.
- In the face of climate-generated uncertainty, the potential for managing Antarctica, the peri-Antarctic islands and adjacent seas under frameworks similar to those used for National Parks and Marine Sanctuaries should be investigated (e.g. Bastmeijer and Roura 2004). Approaches adopted and implemented elsewhere where wildlife and environmental values are protected from intensive human visitation (e.g. seasonal access restrictions, including visitor quotas) could be readily adopted within a future management framework for the Antarctic. No-take marine protected areas need to be used more widely to minimise the risks of overfishing and increasing shipping traffic. Types of protection include: species being fished along with related and dependent species, critical

life history stages or habitats, such as spawning seasons and areas, or establishment of reference or study areas to partition effects of climate from fishing on the structure and function of ecosystems. Further, no-take marine reserves are required to allow benthic communities to, if possible, recover. In fact, these benthic communities provide habitat for fishes.

- Develop continental- and ocean-wide monitoring programmes in order to assess the long-term effects of persistent contaminants in Antarctic organisms and food chains and to predict possible responses of terrestrial and marine ecosystems to climate changes and anthropogenic activities.
- Promote international agreements and the transfer of financial aid and technologies from rich countries to developing countries in the Southern Hemisphere in order to address global environmental threats (Bargagli 2008). Educate and raise public awareness on environmental issues on a global scale in order to contribute towards climate change mitigation and reducing global consumption and waste production.
- Acknowledge the potential for mineral extraction in the Antarctic and its potential substantial environmental impacts. Recent claimant state interest in their supposed rights as coastal states under the United Nations Convention on the Law of the Sea has reflected a clear intention to reserve positions about the Antarctic continental shelf, revealing a real and ongoing interest in resource realisation in both the Antarctic Treaty Area and the peri-Antarctic islands subject to national jurisdiction (Hemmings and Stephens 2010). This suggests a tension between national commitment to environmental protection in Antarctica and an interest in realising potential economic benefits from resources such as hydrocarbons and living resources.

2.5 Conclusions

Clearly not all of our proposals can be implemented immediately or simultaneously, but strategic adoption is necessary to address the ever-increasing spectrum and intensity of threats to Antarctic wildlife from the consistently increasing number of people in the Antarctic each year. These threats will also increase in their complex synergies and interactions, giving further increasing urgency to adopting a more precautionary approach to managing human activities in the Antarctic. Failure to act now may well see future generations managing an Antarctic region with degraded environmental values and ecosystem functions, more typical of the rest of the planet. Such an outcome is indefensible and unacceptable in light of our current knowledge and our ability to mitigate the worst of the potential impacts with considered and effective measures.

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