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Considerations for minimising the spread of infectious disease in Antarctic seabirds and seals

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ABSTRACT. Before 1998, concern was raised over the potential for human activities in Antarctica to introduce infectious disease organisms to native wildlife. A workshop was held that year to address this issue. In the last decade, there has been a dramatic increase in human traffic to the Antarctic and the number of commercial tourists visiting the Antarctic has steadily risen. Personnel of national science programmes, though relatively few in numbers, have the most intimate contact with wildlife and thus the greater potential to introduce organisms through their research activities. Many visitors are now able to arrive in the Antarctic from temperate regions within hours by aircraft, and from northern polar regions within 24 to 36 hours. Tourists, by their high numbers, also have the potential to transfer infectious disease agents among commonly visited sites. As of 2009, no outbreaks of infectious diseases in the Antarctic reported in the literature have been directly attributed to human activity, but the ameliorating climate may break down the barriers that have kept Antarctic wildlife relatively free of infectious diseases. Several agents of infectious diseases reported in Antarctic seabirds and seals are assessed for their likelihood to occur more frequently in terms of the characteristics of the agent, the behaviour of Antarctic wildlife, and the effects of an ameliorating climate (regional warming) in conjunction with continued increasing human activities.

Contents

Introduction

In 1993, Clarke and Kerry reported that, 'there appear to be few studies and no statistics on the incidence of disease among penguin populations in the wild despite extensive biological studies.' Since the 1998 workshop on diseases of Antarctic wildlife hosted by the Australian Antarctic Division in Kingston, Tasmania, the number of infectious diseases reported has remained low. Following a contemporary review by Barbosa and Palacios (2009) the information on infectious diseases of penguins and other Antarctic fauna was considered to be inadequate.

While at present the probability of direct human activity resulting in disease outbreaks among Antarctic wildlife is low, there is however the possibility that this could occur in the future. This may be especially relevant for diseases for which sporadic outbreaks have been previously reported in the Antarctic. With the documented rapid warming trend on the Antarctic Peninsula, the ever increasing numbers of human visitors to Antarctica, mostly concentrated along the Antarctic Peninsula, and enhanced capabilities to arrive there from all areas of the globe, this probability may increase over time.

There is a legal responsibility arising from the 1991 Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol) on all visitors to the Antarctic Treaty area to prevent the introduction of infectious agents into the treaty area. There is an additional responsibility to take measures to prevent outbreaks of previously reported diseases from recurring and spreading within wildlife populations. Furthermore, there is a need to prevent disease causing agents that may be present in the environment from being transmitted not only to the animals living in the Antarctic but to the researchers who may come in contact with these animals.

Grimaldi (2008) examined selected agents that have previously been reported in Antarctic animal populations and have the potential to become established there under changing environmental conditions. Consideration was given to the natural and anthropogenic mechanisms that may transport and/or spread these agents, and how the effects of the documented rapid regional warming (specifically over the Antarctic Peninsula) may increase the potential for disease outbreaks.

The objectives of the present study were first, to provide an overview of some of the disease agents reported in the Antarctic Treaty area; second, to review the behaviour of the wildlife and how it might influence disease outbreaks; and then to assess the likelihood of infectious disease outbreaks within Antarctic wildlife populations in view of the predictions of how climate change might affect infectious diseases. Given that there is only one vector that can be managed to any degree, we also sought to determine the types of human activities that may increase the risk of transferring disease agents and/or causing infectious diseases to Antarctic wildlife. Finally, we propose suggestions for strengthening biosecurity weaknesses or lapses found.

Diseases

Because of Antarctica's geographic isolation, infectious disease outbreaks in Antarctic wildlife have been infrequently reported. The number of documented disease outbreaks in Antarctic wildlife has been low since the first reported mass mortality event of crabeater seals *Lobodon carcinophagus* in the Crown Prince Gustav Channel in 1955 (Laws and Taylor 1957; Barbosa and Palacios 2009 and references therein).

Disease outbreaks resulting in many deaths where a pathogen has been isolated are limited: only outbreaks involving the agents of avian cholera and avian pox have to date been documented in the treaty area (for example Parmelee and others 1979; Leotta and others 2003; Weimerskirch 2004; GSGSSI 2005; Leotta and others 2006b; Munro 2007; Shearn-Bochsler and others 2008). Antibodies to the agents of various infectious diseases against a number of viruses (for example Morgan and others 1981; Baumeister and others 2004; Miller and others 2008) and bacterial agents (Gauthier-Clerc and others 1999; Retamal and others 2000) have been detected (see also generally Kerry and Riddle 2009 and references therein). In most of these reports, signs of illness were not observed. Isolates of human enteric pathogens such as *Campylobacter* spp. (Broman and others 2000; Bonnedahl and others 2005), *Escherichia coli* 0157 (*E. coli* 0157; Hernandez and others 2007), and *Salmonella* species (Oelke and Steiniger 1973; Olsen and others 1996; Palmgren and others 2000) have been recovered but have not been implicated in diseases of Antarctic wildlife.

Three infectious disease agents or groups that have been previously isolated and have the potential to become established in the Antarctic. They are described and briefly examined below.

Avian cholera

Avian cholera, caused by the bacterium *Pasteurella multocida*, has been implicated in five disease outbreaks (Parmelee and others 1979; Leotta and others 2003; Weimerskirch 2004; GSGSSI 2005; Leotta and others 2006b). Three of these outbreaks occurred on the Antarctic Peninsula within a two year period. This suggests a local reservoir, though it is still not proved how this organism is maintained in bird populations from year to year in other parts of the world experiencing extensive die offs (Samuel 2002). One hypothesis states that some infected birds survive infections and become carriers. These birds are still able to migrate and then infect other susceptible birds (Samuel 2002). It is believed that explosive mortality events occur when sick birds die in water, dispersing the bacteria that can then be aerosolised and inhaled or ingested. Bird density is thought to be one of the contributing factors in the intensity of avian cholera outbreaks (Rosen 1969).

Avian pox

Only two reports of this viral disease have been documented in the Antarctic Treaty area (Munro 2007; Shearn-Bochsler and others 2007). This disease typically affects chicks and it is usually not fatal. However, the outbreak that occurred on the Falkland Islands in 2006 involved gentoo penguins *Pygoscelis papua* with high adult and chick mortality (Munro 2007). It was noted that other bird species in the vicinity were not affected and the five gentoo penguin colonies that were affected were situated on the southern or southwestern beaches of West Falkland (Munro 2007). In 1987, there were suspected cases of avian pox in domestic fowl and avian pox was confirmed in a black-browed albatross *Thalassarche melanophrys* in the Falkland Islands (Munro 2007), but no details of this report were found.

The avian pox virus is large compared to other viruses. It is able to survive many years in the environment on dust particles or on pieces of scabs, and resists drying; birds can become infected by direct transmission from other birds (van Ripper and Forrester 2007). This organism might survive in the Antarctic environment and become more widespread in the future under predicted milder climatic conditions.

Enteric pathogens

A variety of human enteric pathogens have been recovered from Antarctic species of birds and seals. Numerous species of *Salmonella* have been isolated from different parts of the Antarctic Treaty area (for example Oelke and Steiniger 1973; Olsen and others 1996). Enteropathogenic *E. coli* has been recovered from Antarctic fur seals *Arctocephalus gazella* (Hernandez and others 2007). In one study, *Campylobacter lari* was recovered from a variety of seabirds that had died of avian cholera near Hope Bay (Esperanza Station) (Leotta and others 2006a) and *C. jejuni* has been isolated from macaroni penguins *Eudyptes chrysolophus* on Bird Island (Broman and others 2000). The recently reported occurrence of an intestinal protozoan, *Cryptosporidium* spp. in gentoo penguins suggested it may be present because of either increased human activities or milder climatic conditions that now favour this organism, or a combination of both (Fredes and others 2008). In none of these reports was there mention of signs of disease in the animals from which these isolates were recovered.

Wildlife considerations

The breeding colonies of most seabird and some seal species are established in the relatively few coastal ice free areas. Courting, breeding and chick or pup rearing take place within a short time closely linked to cycles of the loss of sea ice and food production. Some of the characteristics of the colonies and activities of birds and seals can be conducive to the establishment of disease outbreaks. Different species vary in their susceptibility to certain diseases and the activities of these animals and the conditions of the colonies could contribute to disease exposure (Rosen 1969). The natural behaviours of some species of birds and seals of the Antarctic afford opportunities to spread pathogenic organisms. The natural migration to other geographic regions increases the risk of exposure of these birds and seals to disease causing agents. Disease agents on distant shores may return with them. It is possible that changing climatic conditions may alter the balance between arrival and establishment of an invasive agent in conjunction with these behaviours.

For colonial species such as Adélie (*P. adeliae*), gentoo and chinstrap (*Pygoscelis antarctica*) penguins, the close proximity of nesting birds to one another enhances the likelihood of the rapid passage of a pathogenic organism to sweep through a colony.

Birds using small ponds in which to bathe could come in contact with pathogens in contaminated water. If contaminated faeces or the carcass of an animal that had died of an infectious disease were in the water, birds could transfer pathogens to other areas by walking through them or flying to another site, or to nearby birds by shaking off the water creating an aerosol.

Many Antarctic seabirds are scavengers and/or predators. Skua *Catharacta* spp. feed on other flying birds, the eggs and chicks of penguins, small mammals, fish, marine invertebrates, and garbage (Reinhardt and others 2000). Sheathbills *Chionis* spp. pilfer food from penguins and shags but will also eat eggs and small chicks. Their diet includes, among other things, algae, seal and bird faeces, carcasses, and garbage (Parmelee 1992; Shirihai and others 2002). Southern giant petrels *Macronectes giganteus* are scavengers (Marchant and others 1996). Flying birds might easily transfer a contaminated piece of food to another location. Scavenging from an animal that had died from an infectious disease would allow further spread of disease. The highly gregarious nature of crabeater seals, southern elephant seals, and Antarctic fur seals (King 1983) would also increase the potential for spreading pathogens especially as they snort or vocalise. Aerosolisation of viral and bacterial agents by both birds and seals could contribute to disease mortality. Ingestion of certain infectious disease organisms, the faecal–oral route, particularly by bird species, must be considered as a pathway to the spread of diseases.

Migration and movements of species within the Antarctic Treaty area

Migration has been offered as a means of explaining the presence of antibodies in some Antarctic bird species (Palmgren and others 2000; Gauthier-Clerc and others 2002; Baumeister and others 2004; Weimerskirch 2004; Wallensten and others 2006; Miller and others 2008; Barbosa and Palacios 2009).

There are a number of bird species that migrate from the Antarctic to South America and beyond. These include southern giant petrels, Wilson's storm petrels *Oceanites oceanicus*, Cape petrels *Daption capense*, sheathbills *Chionis* spp., skua *Catharacta* spp., jaegers *Stercorarius* spp., and kelp gulls *Larus dominicanus* (Shirihai and others 2002; Olsen and others 2006). The Arctic tern *Sterna paradisaea* is one of the species that migrates between the Arctic and the Antarctic (Shirihai and others 2002). Southern giant petrels have been seen scavenging in areas with significant human sewage pollution and are likely to have exposure to pathogens outside of the Antarctic (Hughes 2005).

Infrequently, individuals of various Antarctic seal species have been observed on the coasts of South America, South Africa, New Zealand and Australia (Bengtson and others 1991; Reeves and others 2002). Some vagrant Weddell seals have been seen in South Australia, and at Heard and Macquarie Islands (Reeves and others 2002). Kooyman (1981a) noted that crabeater seals are occasionally seen in Tasmania (approximately 41°S) and New Zealand and in South America and South Africa. Leopard seals have also been reported along the New Zealand and Australian coasts (Kooyman 1981b; EJ Woehler unpublished data). Southern elephant seals have a wide circumpolar range, while found mostly in the sub-Antarctic, they can also occur anywhere from 16°–78°S with breeding sites between 40°–62°S in the South Atlantic and South Indian Oceans (Ling and Bryden 1981). Elephant seals and Antarctic fur seals may swim in sewage-contaminated waters off South America while foraging (Hughes 2005).

Climate change

Global surface temperature has risen 0.74°C (range: 0.56 to 0.92°C) since the beginning of the 20th century (IPCC 2007). Predictions from climate models estimate that the average global temperature will be between 1.5 and 4.5°C higher if the current levels of greenhouse gases double (Robinson and others 2003). One of the predictions from these models is that the polar regions will experience the greatest increase in winter time temperatures. A summary of the impacts on the polar regions due to increasing temperatures if the present trend continues was presented by the IPCC (2007). The main projected biophysical effects will be reductions in thickness and extent of glaciers, ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators (IPCC 2007; Allison and others 2009). Furthermore, in both polar regions, specific ecosystems and habitats were predicted to be vulnerable, as climatic barriers to species invasions are lowered (IPCC 2007).

Changes within the Antarctic Treaty area

The most dramatic warming trend has been taking place along the length of the Antarctic Peninsula. On its western coast, the increase in temperatures over the last 50 years is

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the greatest recorded anywhere (Turner and others 2005). At Palmer Station, the average midwinter temperature has increased by 6°C since 1950 and has, 'the highest rate of warming anywhere on the planet, five times the global average' (McClintock and others 2008).

The geography and topography of the Antarctic Peninsula may be partly responsible for where these changes in increasing temperatures are being observed. The backbone of the Antarctic Peninsula is a continuous chain of mountains 1400–2000 m above sea level that are known to be much more sensitive to atmospheric warming than the ice sheets that cover continental Antarctica (Chen and others 2008). One of the most obvious effects of this warming has been the retreat or collapse of several ice shelves in the northern Antarctic Peninsula (Scambos and others 2000; Vaughan and others 2003; Cook and others 2005). This region has experienced near surface temperature increases of more than 2°C since the mid-1960s (Marshall and others 2006). All along the Antarctic Peninsula, the Prince Gustav, Larsen Inlet, Larsen A, Larsen B, Wordie, and George VI ice shelves have experienced either rapid retreat or disintegration (Scambos and others 2000; Scambos and others 2009). These collapses are due in part to a southward migration of the 0°C surface isotherm during summer (Marshall and others 2006).

Vaughan (2006) has described an overall positive trend in the increase in the duration of above freezing conditions over the Antarctic Peninsula after analysing data from the last 50 years. This warming trend is also allowing some areas on the Antarctic Peninsula that have been covered by snow pack or glaciers to become ice free (Vaughan and others 2003). This is having a dual effect. It is making water more available for existing terrestrial habitats, and exposing the substrate. Two fundamental factors that restrict organisms being able to live successfully in the Antarctic are the availability of free water and suitable ice free substrate (Kennedy 1995; Bergstrom and others 2006). These enhancements will accelerate the formation of soils and be conducive for secondary communities to become established (Kennedy 1995). Robinson and others (2003) and Frenot and others (2005) predict that as the temperature continues to increase, native species and the successful anthropogenic introduction of non-native species to the Antarctic will likewise increase. Convey and Smith (2006) suggest that even, 'a small temperature increment has a potentially greater biological impact than one of similar scale in a less extreme environment' when referring to the extremes of the Antarctic environment and the impact of these on physiological limits of organisms.

This rise in regional temperature has also had an effect on animals. Adélie penguin populations around Palmer Station have decreased while those of gentoo and chinstrap penguins have risen dramatically (McClintock and others 2008). Adélie and emperor *Aptenodytes forsteri* penguins have life histories closely associated with the availability of sea ice and are considered true Antarctic species (Ainley 2002). In contrast, ice avoiding species such as gentoo, chinstrap and macaroni penguins are categorised as sub-Antarctic (Ducklow and others 2007). It is generally accepted that these population shifts are correlated with the noted gradual decrease in winter sea ice (McClintock and others 2008). Adélie penguins were found to use 'hot spots' in the winter sea ice where upwelling promotes concentrations of fish and krill. As these hot spots have disappeared due to the loss of sea ice, Adélie penguins have lost these prime foraging areas (McClintock and others 2008). Another factor working locally against Adélie penguin populations is that the increase in the accumulation of snow in breeding colonies reduces reproductive success (Ducklow and others 2007). However, researchers have noticed that the Adélie penguin populations 400km farther south of Palmer have increased threefold since the 1950s in response to more favourable ice conditions (for example Fraser and Ainley 1986; Fraser and Hoffman 2003; Stokstad 2007; Ainley and others 2010).

Antarctic fur seals and southern elephant seals have exploited this temperature rise. While only a few small fur seal colonies existed around Palmer in the 1990s, there has been an increase in their numbers. Since that time, one colony that began with six seals now has more than 5000 individuals (Stokstad 2007). These shifts may again reflect species preferences for open water but may also represent recovery from excessive hunting (Ducklow and others 2007).

The effects of the increasing temperatures, mostly along the Antarctic Peninsula, are both physical and biological. The current trend of a relatively more moderate climate in this region is likely to enhance conditions which will allow alien species, including pests and diseases, to become established (CEP 2006; Bergstrom and others 2006). Higher than long term mean temperatures may produce thermal stress in animals, increasing their susceptibility to disease (Lafferty and others 2004) while the milder conditions may facilitate or encourage the establishment or presence of disease agents. One consequence may be, therefore, a much higher incidence of infectious diseases in Antarctic wildlife.

Yergeau and others (2007) concluded that the severity of the Antarctic climate on soil microhabitats is decreased in the presence of vegetation. When compared to bare soils, vegetation enhanced thermal and moisture retention. Vegetation should be expected to increase in abundance, if not expand in range, with the increase in temperature (Robinson and others 2003). Hardy agents such as the avian pox virus and enteric bacteria could become established in soils and plant debris if brought in by either human or animal vectors. Emerging infectious diseases have been described as being similar to weeds (Dobson and Foufopoulos 2001). They have broad requirements for hosts, vectors and habitat. This 'weediness' or, 'biologic flexibility. . .makes certain pathogens adept at taking advantage of new epidemiologic opportunities' (Woolhouse and Gowtage-Sequeria 2005). This may

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increase the threat to both the health of individuals and to colonies, especially seals and ground nesting species of seabirds. This could become heightened when other stressors compromise their immune system such as extreme weather or poor food availability. Suppression of the immune response facilitates the emergence of a disease (Brown 1997).

Human activity

The surface area of continental Antarctica is approximately 45 million km^2, of which less than 0.35% is ice free when the areas of ice free islands are included (Bergstrom and others 2006). The same ice free areas favoured by humans are also the habitats for much of the terrestrial fauna, thus increasing the potential for contact between humans and animals in relatively small and concentrated areas. This contact, if improperly or carelessly undertaken, could have adverse effects on the wildlife. One of these adverse effects taken into consideration by the Madrid Protocol is the introduction of infectious disease. The Madrid Protocol regulates tourism as one of the legitimate ('authorised') activities under the general banner of its environmental evaluation and liability provisions. Despite the protocol's provisions to prevent the spread of disease, there is little actual direction on biosecurity within it. Notwithstanding, article 4 of annex II, introduction of non-native species, parasites and diseases is specifically concerned with this issue, and applies to all human activity, thus not excluding the potential for any human visitors to the Antarctic to be the vector (Madrid Protocol 1991).

It was recognised more than 20 years ago that the movement of people between temperate latitudes and sites throughout the Antarctic, especially with the increasing amount of air service, was allowing this traffic to act as potential vectors (Vincent 1988). More recently, the Madrid Protocol's Committee for Environmental Protection (CEP) stated, 'increasing travel and transport of goods and people, together with shorter transport times and increasingly direct links between sub-Antarctic and Arctic areas and the Antarctic, increase the likelihood of introductions and risk to Antarctic values' (CEP 2006**).** Globally, this idea is being supported by incidents involving transportation. The outbreak of foot and mouth disease in the United Kingdom in 2001 was the result of the importation of contaminated meat (Thompson and others 2001, cited in Brown 2010). The outbreak of West Nile Disease in New York City was believed to have been due to the introduction of an infected mosquito arriving on a cargo plane from Israel (Randolph 2010). In the 10 years since the initial onset, West Nile Disease is now found as far south as Argentina. Another mosquito introduced into the United States, the tiger mosquito *Aedes albopictus*, was imported from Japan in water within used tyres (Randolph 2010). This mosquito is the vector for twenty-two arboviruses (Brown 2010). Another example is the BTV-8 strain of the bluetongue virus. This came into the Netherlands from South Africa in 2006 (Saegerman and others 2008, cited in Randolph 2010).

Scientific personnel and support staff

Nearly all the Antarctic stations were established in the mid– to late–1950s for the 1957–1958 International Geophysical Year. Many of these stations have been continuously occupied ever since (McGonigal and Woodworth 2003). Scientific studies conducted in Antarctica require a flux of scientists and support staff that go to a number of stations and field sites located on the continent and the peninsula. Most of these personnel arrive during the summer, though many stations have overwintering staff. Aircraft move people and supplies much more quickly between source bases and the Antarctic. The air link between Christchurch, New Zealand and Antarctica brings in the greatest number of personnel (COMNAP 2009). In 2007, Australia started an air service to Casey, linking Australia with Antarctica. There are at least 30 airstrips in Antarctica of varying sizes; smaller aircraft and helicopters are used to shuttle personnel and equipment to various sites along the coast and to the interior of the continent (COMNAP 2009).

The nearly 4000 summer personnel connected to national programmes (COMNAP 2009) is possibly an underestimate, as there is turn over in human populations at many stations (Frenot and others 2005). It was estimated that there are approximately 50 people involved in biological research studying seabirds and seals in any season (K. Reid, personal communication, 1 October 2008). This may also include researchers who are not necessarily having actual physical contact with wildlife. There are, therefore, relatively few people working directly on animals during the year, though the interaction of researchers and animals is more intimate than that occurring between tourists and animals, and therefore poses a greater risk of spreading disease causing agents to the animals.

Commercial tourists

Expedition style trips to the Antarctic started in 1966 (Snyder 2007) and this industry continues to increase (Jabour 2009). In 1991, tour companies formed the International Association of Antarctica Tour Operators (IAATO). Its mission is to, 'advocate, promote and practice safe and environmentally responsible private-sector travel to the Antarctic' (IAATO 2009). Ship borne tourists now make up the highest numbers of travellers to the Antarctic, predominantly on IAATO member vessels (IAATO 2009). The majority of tourists arrive by ship between November and March each season. A recent innovation in travel to the Antarctic is provided by tourist operators who have flight services to King George Island using Punta Arenas, Chile as their home airport. IAATO has been aware of the potential to introduce and spread disease since 2000, and established mandatory guidelines for its members (IAATO 2009). It is the responsibility of the individual tour operator to inform its passengers of these guidelines. It is noteworthy that these are only guidelines and there is no uniform way to enforce them.

Discussion

Biosecurity in its simplest form is defined as the measures used to prevent the spread of disease (Wenzel and Nusbaum 2007). Basic cleaning and disinfection of clothing, equipment and hands are the most common means of preventing the spread of disease agents (for example Wenzel and Nusbaum 2007). Neither tourism nor research on Antarctic wildlife is exempt from these universal biosecurity measures.

Tourists' boots could be vectors in the transfer of disease causing organisms within the Antarctic Treaty area (Curry and others 2002, 2005). Initial studies showed that the use of a brush with seawater to wash boots was insufficient to prevent transmission of bacterial pathogens from occurring and that, 'the potential for transmission of microorganisms between colonies, and perhaps from Antarctica to other destinations' exists (Curry and others 2002). Subsequent studies showed that the disinfectant Virkon S was acceptable for use in a footbath when used in a prescribed manner (Curry and others 2005; Amass and others 2005). Guidelines for boot, clothing and equipment decontamination for tourists on IAATO member vessels that resulted from these studies, state as follows.

> While there is at present no conclusive evidence that tourists have introduced or transmitted diseases within Antarctica, there is indirect and circumstantial evidence that raises concern. There is the potential for visitors to be vectors of disease, both into and within the Antarctic ecosystem (IAATO 2008).

It is relatively difficult to find any information about national programmes' policies toward the introduction of diseases, much less their biosecurity measures. The only published biosecurity guidelines for Antarctic researchers are those written by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR 1997) and these are for personnel investigating mass mortality events. Kerry and others (1999) eventually incorporated the CCAMLR guidelines into a report for SCAR and COMNAP. However, no guidelines exist for researchers conducting studies on seal or seabird populations that have not experienced diseases, that is, a proactive approach to prevent the introduction or spread of infectious agents. The CCAMLR guidelines are for mass mortality events after they have been identified or suspected.

A number of inherent problems associated with the study of wildlife, are compounded in the Antarctic due to the extreme conditions and remoteness of the region (Jones and Shellam 1999). At any location, one of these problems is the risk of spreading disease, not only to the animals involved, but also to the researchers (Corn and Nettles 1995). Even though the number of scientific personnel is very low compared to the number of commercial tourists, crew and staff, (one estimate is of 50 compared to more than 70,000: Jabour 2009), the activities of the biologists bring them into closer contact with the wildlife. Although not all tourists, staff and crew land, those that do actually land multiple times in multiple locations, although they generally only look at wildlife from a distance. Researchers on the other hand, are not only handling birds or seals (for example weighing, measuring, banding or placing external tracking devices), they might also undertake a range of invasive procedures including inserting microchips, collecting oropharyngeal and/or rectal/cloacal swabs, collecting blood and tissue samples, and performing stomach lavages. It should be noted that these procedures are similar to those used in wildlife studies elsewhere and require prior approval from an approved animal ethics committee. Some of these approvals might include requirements for procedures to protect the scientists from catching anything from the wildlife.

Some of the invasive procedures carry a risk of transmitting disease causing agents among animals or causing infections in individuals through procedures that break the skin or affect other tissues. Handling animals for such purposes increases stress levels and therefore could increase susceptibility to infection. If other stress factors are coincidentally present, such as decreased food availability, then the probability of precipitating a disease outbreak may be increased (Williams and Ward 2002).

In 2006, Gateway Antarctica in New Zealand hosted a workshop on non native species in the Antarctic and conducted a short survey of the participants. Responses were received from only six representatives of national Antarctic scientific research programmes in attendance. Six questions were asked, one of which was, '[d]o you have standard practices in place to guard against the unintentional introduction of non-native species (e.g. guidelines, code of conduct, etc)?' (CEP 2006). The responses varied from no practices (one programme) to biosecurity policies focused primarily on poultry products (echoing the Madrid Protocol), to procedures to deal with rats and other organisms found in ballast water, to laws that enforced IAATO's guidelines on decontamination and its policy on the introduction and detection of diseases.

Disinfection guidelines for minimising disease spread have been established for practitioners who handle animals elsewhere in the world, such as veterinarians. These guidelines set very high standards for institutions in which control of infectious agents could be attempted relatively easily. Two such examples are *Developing infection control guidelines, a guide for veterinary hospitals and animal shelters* (The Rocky Mountain Regional Center for Excellence for Biodefense and Emerging Infectious Diseases 2006) and *Compendium of veterinary standard precautions: zoonotic disease prevention in veterinary personnel* (Elchos and others 2006). Examples of guidelines that apply more to field settings are *Disinfection 101* (Dvorak 2008) and *Infection control* *guidelines for animal control* (Queensland Government 2008). However, almost all of these practices are, if not entirely impossible, then impractical to implement in the field in the Antarctic.

Conclusions and recommendations

As has been noted, increasing temperatures observed globally, with a particularly pronounced and rapid rise in the Antarctic Peninsula, introduce significant regional concerns. With this global rise in temperature, there are predictions of an increase in emerging infectious diseases worldwide, though this is a complex association as a suite of factors come into play (Brown 2010; Lafferty 2010; Slenning 2010). Infectious diseases might become more prevalent in the sub-Antarctic and the Peninsula if conditions allow pathogens to gain entry and the environment becomes suitably matched.

The natural behaviour of Antarctic wildlife contributes further risk to them. The Madrid Protocol, in this case, cannot address preventing the spread of disease causing organisms by natural pathways arising from migration or other biological mechanisms. The protocol can and does, however, establish the legal obligation for regulation of human activities in order to prevent the introduction of disease causing organisms through article 4 of annex II (Madrid Protocol 1991).

Tourism will probably continue to bring more people to the Antarctic. Unless decontamination procedures of boots and equipment are strictly adhered to and improved, the additional numbers of tourists will increase the opportunity to introduce or spread pathogens that may be dormant in the Antarctic landscape. Similar practices must also be in effect for the members of national science programmes conducting studies where there are concentrations of seabirds and seals. This could include considering the practice that boots are worn in one area are not worn into different areas without first cleaning them with appropriate agents and/or at least scrubbing them to remove any visible organic matter (Amass and others 2000).

To decrease further the risk of human activity causing an outbreak of an infectious disease or causing infections in individuals, other standardised biosecurity measures should be considered where feasible. The following list of organisms has been reported from Antarctic wildlife as either isolated or antibodies detected to them and are capable of causing serious disease in humans such as *Salmonella* spp. (Oelke and Steiniger 1973; Olsen and others 1996; Palmgren and others 2000), *Campylobacter* spp. (Broman and others 2000; Bonnedahl and others 2005), *E. coli 0157* (Hernandez and others 2007), *B. burgdorferi* (Gauthier-Clerc and others 1999), *Brucella* spp. (Retamal and others 2000), and the virus responsible for avian influenza (Morgan and Westbury 1981; Austin and Webster 1993; Baumeister and others 2004; Wallenstein and others 2006; Miller and others 2008).

Tuberculosis is a disease that can pass from humans and be transferred to wildlife and *vice versa*. One such case, caused by a member of the *Mycobacterium tuberculosis* complex, has been reported as being passed from captive seals to trainers (Thompson and others 1993). This isolate and isolates recovered from other seal species worldwide, both wild and captive, were later considered a new species within this complex and named *M. pinnipedii* sp. nov. (Cousins and others 2003). Another case of cross species transmission was detailed in a report from the United Kingdom and describes tuberculosis diagnosed in a veterinary nurse, her daughter, and their dog caused by *M. bovis*, (ProMED-mail 2008). Tuberculosis has been reported in a wild Australian fur seal *A. pusillus doriferus* (Woods and others 1995) and a sub-Antarctic fur seal *A. tropicalis* (Bastida and others 1999). Since, 'the risk of acquiring disease by scientists . . . handling marine mammals is not well understood' (Hunt and others 2008), biosecurity measures should be exercised to reduce the potential transmission of such agents to researchers.

Travel to the Antarctic is occurring by aircraft, moving people more rapidly from other regions of the world. However small the risk is, these people (tourists and scientific staff), who are travelling to a region with naïve populations of animals, could unknowingly be accompanied by disease causing organisms. It seems prudent to continue with basic biosecurity steps similar to those already being practiced by wildlife researchers elsewhere in order to safeguard animals from being unintentionally infected with a pathogen, whether it already exists in the environment or is brought in from elsewhere. Because understanding of the population scale of microbial and parasitic infections in aquatic birds is poor (Newman and others 2007) and the pathogenicity of many bacteria is similarly poor (Steele and others 2005), adequate biosecurity precautions with the Antarctic wildlife must be exercised.

Whatever the degree of interaction is with wildlife, whether it is passive observations from a given distance or more invasive procedures, steps need to be taken to minimise the potential for introducing or spreading pathogens to the Antarctic landscape and Antarctic wildlife. There is an apparent low prevalence of disease in the Antarctic and as yet there are no known outbreaks of infectious diseases directly attributable to the human activities in the region. This should not, however, allow any room for complacency and because of the results of Gateway Antarctica's survey, a recommendation would be to have the CEP work on standardised biosecurity guidelines for all national programmes. In light of the documented regional warming and the continued increasing influx of people to the Antarctic, instituting effective biosecurity procedures should be made a priority. This precautionary approach would not only serve to more fully protect the wildlife, but uphold the purpose of the Madrid Protocol, the comprehensive protection of the Antarctic environment and its dependent and associated ecosystem.

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