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ORIGINAL PAPER

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Diseases threaten Southern Ocean albatrosses

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Abstract Infectious diseases have the potential to cause rapid declines and extinction in vertebrate populations, and are likely to be spreading with increased globalisation and climate warming. In the Southern Ocean and Antarctica, no major outbreaks of infectious diseases have been reported to date, perhaps because of isolation and cold climate, although recent evidence suggests their presence. The major threat for the Southern Ocean environment is today considered to be fishing activities, and especially controversial long-lining which is assumed to be the cause of the major decreases in albatross and large petrel populations observed recently. Here we show that the worldwide spread of avian cholera is probably the major cause of the decrease on Amsterdam Island of the large yellow-nosed albatross (*Diomedea chlororhynchos*) population, which was previously attributed to long-line fishing. Another pathogenic bacterium, Erysipelas, was also present. The diseases affect mainly young chicks, with a cyclic pattern between years, but also kill adult birds. The outbreak of the disease probably occurred in the mid-1980s when chick mortality increased, adult survival decreased and the population started to decrease. The diseases may be currently threatening the very rare Amsterdam albatross (*D. amsterdamensis*) with extinction, and are probably also affecting sooty albatrosses (*Phoebetria fusca*). The spread of diseases to the most remote areas of the world raises major concern for the conservation of the Southern Ocean environment.

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Introduction

Diseases have probably played a major role in the regulation and evolution of animal populations, including humans (May 1988; Stearns 1999). Infectious diseases have the potential to cause rapid decrease and ultimately extinction in vertebrate populations (Grenfell and Dobson 1995), and their role has only been recently fully acknowledged, especially for the potential major conservation problems they may pose. Today, they are likely to be spreading with increased globalisation and climate warming (Harvell et al. 2002). Because they spend most of their life at sea and return to land only to breed, the impact of diseases on seabirds is perhaps more difficult to detect than in terrestrial species. Although there is some evidence of mass mortalities in seabirds, they generally result from trophic problems, poisoning or pollution, rather than from diseases (e.g. Coulson 1968; Sileo et al. 1990; Burger 1993; Work and Smith 1996). In the Southern Ocean and Antarctica, there are no records of major disease outbreaks causing mass mortality reported to date, possibly because of isolation, low temperatures and reduced human interference. However, recent evidence suggests the presence of pathogens in penguins in Antarctica, but no major mortality has been noted so far (Gardner et al. 1997). Available data are, however, currently inadequate, and the recent presence of humans on scientific bases or the increasing numbers of tourists may be potential vectors for future disease outbreaks (Gardner et al. 1997). The major threat for the Southern Ocean environment is today considered to be fishing activities, and especially controversial long-lining, which is assumed to be the cause for the major decreases in albatross and petrel populations observed recently (Gales 1998), and much focus of present research has been directed logically towards research on this issue (Croxall 1998).

Amsterdam Island is one of the most isolated islands in the world, located in the middle of the southern Indian Ocean, and is the sole nesting ground of the minute population of the critically endangered Amsterdam albatross, *Diomedea amsterdamensis* (Weimerskirch et al. 1997; Inchausti and Weimerskirch 2001), but also of a large population of yellow-nosed albatrosses, *D. chlororhynchos*. The population of yellow-nosed albatrosses has halved during the past 20 years from 37,000 to 18,000 pairs (Weimerskirch and Jouventin 1998), resulting in its listing as a Vulnerable Species, and upgraded as Endangered by IUCN. The decrease was attributed to long-line fishing, which indeed causes the mortality of yellow-nosed albatrosses around Australia (Gales et al. 1998) where Amsterdam yellow-nosed albatrosses are known to winter (Weimerskirch et al. 1985). Off South Africa, Atlantic yellow-nosed albatrosses are also caught in small numbers in long-line fishing (Ryan et al. 2002). However, there has been a tendency to attribute decrease of albatross populations to long-line fishing whereas very few studies so far have tried to estimate the potential effect of long-lining on the dynamics of populations affected by this type of fishery (e.g. Weimerskirch et al. 1997; Tuck et al. 2001). For example, on Amsterdam, yellow-nosed albatrosses have suffered heavy mortalities of chicks during their first weeks of life that cannot be attributed to long-line fishing at sea, suggesting that other factors might be involved in the population decrease. Here, we have studied in detail the cause of mortality that affected the populations of yellow-nosed albatrosses on Amsterdam Island, and have looked especially whether causes other than long-lining could have induced the observed decrease of the population. Our observations in the field have suggested to us that the cause of mortality might involve diseases, and we present here the results of this research.

Materials and methods

A long-term study colony of around 200 pairs of yellow-nosed albatrosses has been monitored annually since 1979 at Pointe d'Entrecasteaux, on the western coast of Amsterdam island (37°S, 70°E). In this colony, the number of breeding pairs is counted, and all adults and chicks are banded. Banded birds are recaptured for identification in mark-recapture studies, allowing us to estimate adult and juvenile survival. During a study focusing on the foraging ecology of yellow-nosed albatrosses in December-March 1995/1996 and 1996/1997, colonies were observed continuously from dawn to dusk (Weimerskirch et al. 2001), allowing detailed study of the timing, occurrence and cause (predation, starvation or other) of chicks' deaths. From 1995/1996, long-term study colonies and neighbouring colonies were monitored for breeding success, and fresh corpses of adults and chicks were collected.

The fresh corpses of 25 individuals (21 chicks and 4 adults) collected within a few minutes to 1 h after death in the colonies were rapidly frozen, and returned frozen to France for autopsies and tissue analyses. Laboratory analyses, including necropsy, bacteriology and histopathology, were performed at the National Centre for Avian Diseases (LDA 22, Ploufragan, France). The serotype of the Erysipelas bacteria was determined by Merial Laboratories (Lyon, France). Survival of adults was estimated following Lebreton et al. (1992), using Program Mark (White and Burnham 1999).

Results

Yellow-nosed albatross

During the 1995/1996 breeding season, we investigated the causes of mortality through continuous observation of a study colony of ca. 100 pairs during 1 month from hatching. We found that during this period in the study plot, 31 healthy well-fed chicks died within a few minutes after convulsions, apparently from a disease that spread progressively between neighbouring nests, and from low to high altitude in the colonies. Laboratory analyses of 25 individuals (21 chicks and 4 adults) found dead under these circumstances during the 1995/1996 season and during the following seasons, indicate that 2 chicks were infected by the bacterium *Erysipelothrix rhusiopathidae*, during a year of lower mortality (1996). The serotype of the bacteria is 1b. Four adults and the remaining chicks collected in 1999 and 2000 (during years of very high chick mortality) were infected by the bacterium *Pasteurella multicida*, which is responsible for avian cholera.

The high mortality of healthy chicks attended by their parents within a few weeks of hatching is the major cause of the low breeding success of the colony. The typical pattern of increased mortality just after hatching is shown in Fig. 1. The population started to decrease in the mid-1980s (Fig. 2a). Breeding success decreased from 1983/1984, showing since this period a cyclical pattern, peaking with complete failure at 3- to 4-year intervals (Fig. 2b). The mortality of chicks was not distributed evenly in the colonies. Whereas it was extremely high in the lower-altitude colonies, and in some isolated colonies, it was lower in other colonies at higher altitudes (Table 1). The rate of breeding failure due to chick mortality was similar among subcolonies in two successive seasons (Table 1, $R^2 = 0.945$, $P < 0.001$)

The long-term records of demographic parameters show that adult mortality increased from the early

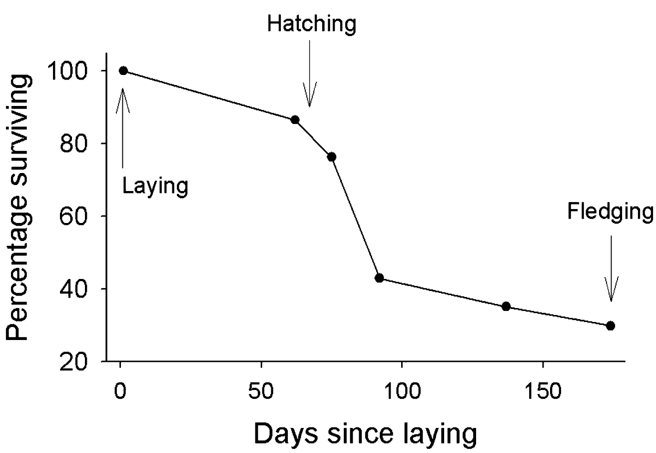

Fig. 1 Change in breeding success over the 2000–2001 breeding season from laying till fledging ($n = 1,273$ eggs laid). Hatching occurred 60 days after laying

1980s, peaked in the early 1990s, before slightly decreasing until today (Fig. 2c). The increase in adult mortality coincided with the increase in breeding failure, and was followed within 1–2 years by the crash of the population (Fig. 2). Juvenile survival varied among seasons with no particular trend (Fig. 2d).

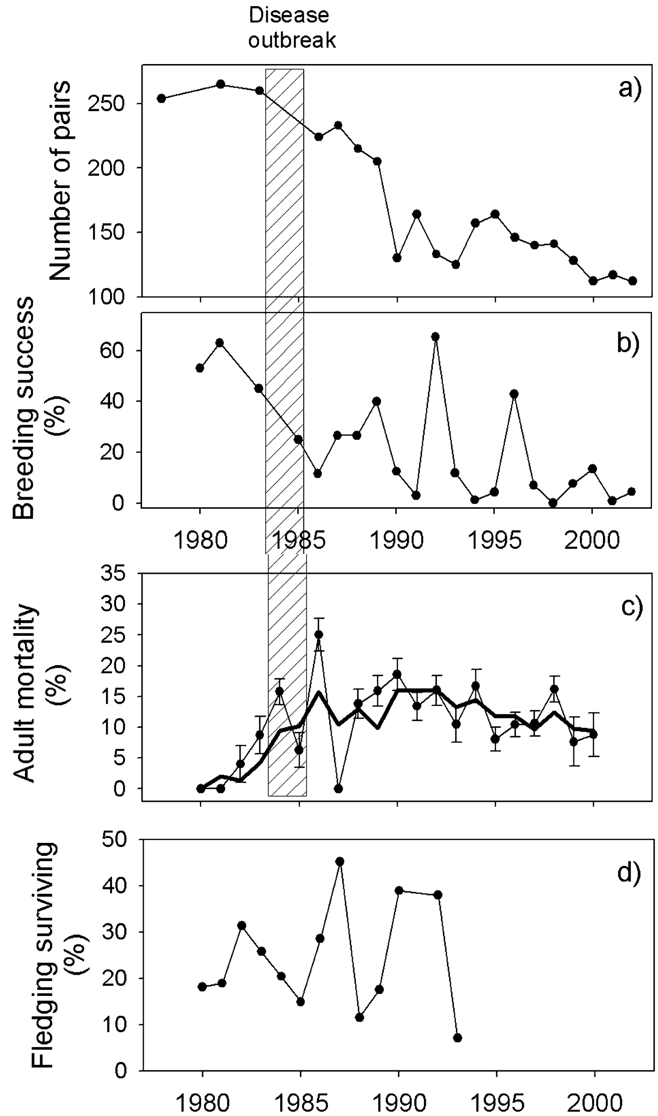

Fig. 2a–d Changes in population size, adult mortality (mean ± 1 SD, moving average over 3 years in **bold**), breeding success and recruitment rate of yellow-nosed albatrosses over the past 20 years, suggesting that the disease outbreak probably started around 1984

Amsterdam albatrosses and sooty albatrosses

The population of Amsterdam albatross has increased since its discovery in the early 1980s (Fig. 3a). Mortality of chicks, occurring during the early chick stage as in yellow-nosed albatrosses, has been recently observed in the Amsterdam albatross population, killing 66% of chicks in 2000 and 74% in 2001. This unprecedented high mortality since the discovery of the population (Fig. 3b) took place in the only zone where Amsterdam albatrosses breed in high densities. In 2002, the mortality of chicks was lower (Fig. 3). Due to the remoteness of the colony and the small size of the breeding population, no fresh corpses have been collected yet to allow autopsies. Adult survival remained high throughout the period, except for the last season of estimate (2000) when survival dropped abruptly (Fig. 3c). More recently, in 2003, high mortalities of young chicks of sooty albatrosses, *Phoebetria fusca*, have been observed.

Discussion

Since the earlier studies in the late 1980s (Weimerskirch and Jouventin 1987; Brothers 1991), it has been recognised that long-line fisheries pose a serious threat to albatross populations. However, long-line fishing is probably not the only cause of decrease of these seabirds, and a careful examination of the data available is required to identify all causative factors. Other factors that might be involved in the decrease of albatross populations include changes in the environment due to climate change (Weimerskirch et al. 2003). Our study indicates that diseases might also be a reason for population change. The symptoms observed in yellow-nosed albatrosses during die-offs of chicks are consistent with avian cholera (Friend 1999a), and most of the chicks and the few adults found dead and autopsied were infected by this bacterium. This is the first observation of the occurrence of avian cholera in albatrosses and, more generally, in procellariiforms (Friend 1999a). In yellow-

Table 1 Overall breeding success and fledging success (percentage of hatched chicks that fledged) of several yellow-nosed albatross colonies at various altitudes (size of colony in *parentheses*)

Colony	Altitude	Breeding success (%) 2000–2001	Fledging success (%) 2000–2001	Fledging success (%) 1999–2000
Demo	Low	10.7 (112)	13.0 (92)	9.4 (94)
B	Low	0 (12)	0 (6)	0 (8)
C	Low	21.0 (143)	23.8 (134)	16.2 (153)
H	Low	35.3 (47)	23.8 (42)	27.0 (46)
L	Low	0 (21)	0 (13)	0 (16)
A	Medium	37.7 (53)	44.4 (45)	42.0 (50)
D-E	Medium	37.5 (32)	23.0 (52)	32.2 (183)
Alim	Medium	41.7 (445)	53.1 (350)	48.0 (374)
M	High	52.8 (75)	50.0 (72)	52.2 (73)
N	High	60 (161)	55.6 (150)	62.0 (150)

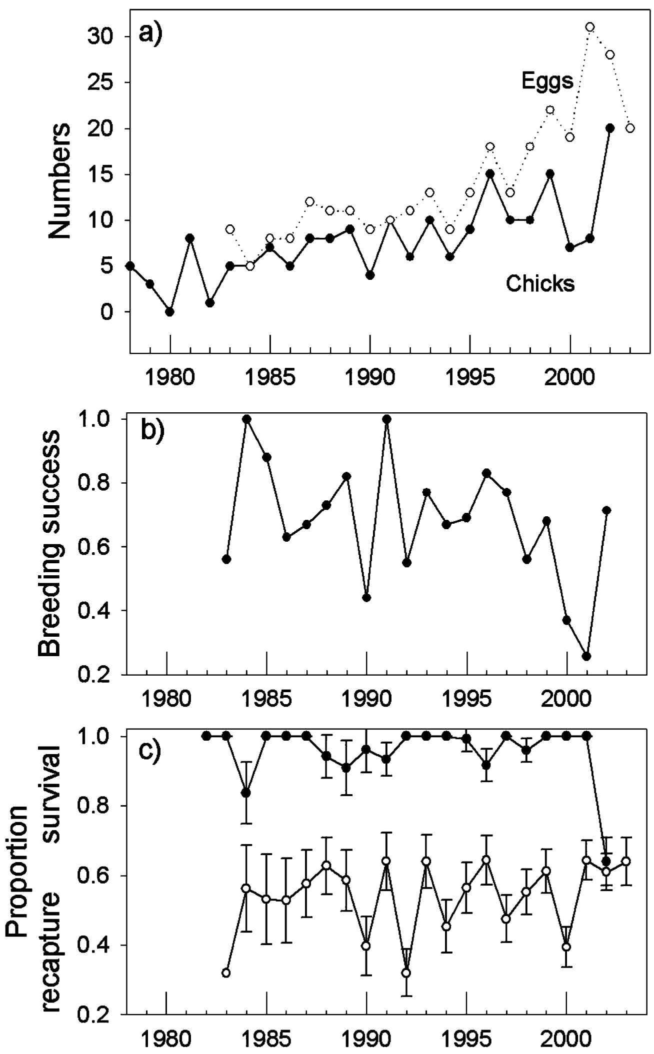

Fig. 3a–c Changes in the number of eggs and chicks produced, and in the breeding success of the Amsterdam albatross population

nosed albatrosses, the bacteria affected particularly young chicks within a few weeks of hatching. Mortality appears to vary spatially and temporally. High mortality of young chicks has been observed since the mid-1980s in the colonies. In the early 1980s, such a mortality was not present (Jouventin et al. 1983). The simultaneous increase in adult and chick mortality from the mid-1980s suggests that the outbreak probably started at this time. The mortality of adults found in colonies, and especially of healthy chicks after hatching, indicates that mortality cannot be attributed to long-line fishing. The occurrence of a second bacterium, *E. rhusiopathidae*, as the possible cause of death of chicks during one season indicates that several agents may be affecting the population, unless this bacterium is a secondary contaminant.

For the moment, we have no definitive evidence that a disease affects the Amsterdam albatrosses population, because we have not been able to find fresh corpses for autopsies and analyses, and because we are now reluctant to handle birds, to further reduce the opportunity to spread diseases. But the field signs of mortality are similar to those observed in yellow-nosed albatrosses affected by avian cholera, i.e. an anomalously high mortality during the first weeks of life of the chick. Adult survival decreased during the last year, when a reliable estimate can be obtained, i.e. just after the highest chick mortality, but additional recapture years are necessary to confirm this trend. The colony of Amsterdam albatross is located on a high plateau at an altitude of 600–700 m, only 3 km from the infected colonies of yellow-nosed albatrosses: the colonies of both species are visited regularly by sub-Antarctic skuas *Catharacta lönnbergi*, which are, as scavengers, potential vectors (Friend 1999a). Thus, even if the disease is still not affecting the population, the risk of transmission from the nearby yellow-nosed albatross colony is extremely high. The normal breeding success in 2002 could be either a better season within a cyclic pattern similar to that observed in yellow-nosed albatrosses, or a return to previous conditions where breeding success is high (Weimerskirch et al. 1997). Ongoing monitoring of the population, and especially the recovery of corpses is thus important to confirm the occurrence of disease in this population. The situation for the Amsterdam albatross is particularly dramatic, because the risk of extinction is extremely high due to its very small population (Inchausti and Weimerskirch 2001)—20 pairs in 2003, probable lack of genetic heterogeneity (only a few pairs were left in the early 1980s), and possibly the lack of natural selection by pathogens. If the occurrence of a disease such as avian cholera was confirmed, the population would face a high risk of extinction within the next 20 or 30 years. The possible occurrence of a disease in this population raises an interesting question about the reasons for the current small size of the breeding population. When it was discovered in 1981, there were only a few breeding pairs (Roux et al. 1983). However, the population was probably once much larger given the abundance of sub-fossil bones of the species (Jouventin et al. 1989). It has been hypothesised that the small size might be the result of the degradation of the island from introduced mammals such as cattle, rats or cats (Jouventin et al. 1989) or from the effects of long-lining (Weimerskirch et al. 1997). One other possibility is that the population might have suffered from a disease outbreak that could have reduced the population to only a few birds before recovering.

This study is the first to show that a major outbreak of disease is affecting Southern Ocean wildlife, and potentially threatening a species with extinction. In the Southern Ocean and Antarctica, no major outbreaks of diseases causing mass mortalities have yet been noted, although the presence of antibodies from pathogenic agents or pathogens has been noted and scattered mortality observed (Gardner et al. 1997; Anderson 1998). Like West Nile Virus, avian cholera is responsible for large-scale disease outbreaks which are continuously increasing their geographic area of occurrence (Friend 1999a). The origin of these diseases may be natural.

Avian cholera is spreading worldwide (Friend 1999a), and albatrosses and skuas from Amsterdam Island winter along the coasts of Australia and South Africa (Weimerskirch et al. 1985), potentially coming into contact with other species carrying the disease. The outbreak on Amsterdam Island may have been favoured by the marked increase in temperature that has taken place in the Indian Ocean during the 1970s (Weimerskirch et al. 2003), since host-parasite relationships are predicted to experience more frequent or severe disease impacts with global warming (Harvell et al. 2002). But infection might also be the result of a contamination by poultry, which have been present on Amsterdam Island since the early 1960s. Avian cholera is known to be widespread in poultry, and was present on Réunion Island from where poultry was introduced to Amsterdam. Today, most research stations in the subantarctic have curtailed the import of poultry products, and poultry have been removed. Now that cholera and other pathogens have reached and established on Amsterdam, the removal of poultry there would not solve the current problem, but at least would reduce the risk of novel introductions. It is recognised that human activities and domestic animals have been an agent in the spread of diseases in other parts of the world (Friend 1999a). In Antarctica, for example, crabeater seals *Lobodon carcinophagus* apparently catch canine distemper virus (CDV) from infected dogs used previously for hauling an expedition's sledges, and antibodies of poultry viruses were found only in penguin colonies located close to scientific stations (Gardner et al. 1997). Similarly, the Erysipelas bacterium could have been introduced to Amsterdam through the pigs that were reared at the base until the early 1990s, but could also have been introduced naturally, since it is widespread in marine ecosystems and present in fishes, for example (Friend 1999b).

Decreases of albatross populations are generally attributed to controversial long-line fishing (Gales 1998), with considerable research effort focused on this subject, leading to a tendency to attribute systematically decreases in albatross populations to long-line fishing. In addition to potential changes to the ecosystem due to climatic factors (e.g. Weimerskirch et al. 2003), this study indicates that a disease outbreak is, in fact, the major reason, at least for the Amsterdam yellow-nosed albatrosses. A recent survey at Prince Edward Island in the Indian Ocean (Ryan et al. 2003) shows that this population has remained stable over the last 20 years, despite known long-line fishing mortality. This indicates that great care should be taken when attributing population decreases in other species of southern seabirds, as it has now been established for the first time that at least for one species, and probably for others, disease outbreak is likely the major cause of the observed decrease. Diseases might also affect other populations of albatrosses: for example, white-capped albatrosses (*Diomedea cauta*) off Tasmania are affected by a viral disease that reduces productivity in some years (Gales 1993). On Amsterdam Island, the symptoms that have appeared in the sooty albatross population, which breed among yellow-nosed albatrosses, make us fear that this species might be also affected, but further monitoring and analyses are required.

Human-induced changes in biotic diversity and changes in the structure and function of ecosystems have been the most dramatic recent ecological trends (e.g. Vitousek et al. 1997). In Antarctica, exploitation of marine resources and associated mortality of seabirds has been the major cause for concern for the conservation status of seabirds. Effects of climate changes at various trophic levels or as catalysers of epizooties (Harvell et al. 1999), but especially infectious diseases, might be in the future a major threat for the Southern Ocean environment where ecosystems have evolved in isolation. The spread of diseases poses a major challenge for conservation because combating emerging and spreading diseases is extremely complex and especially difficult in wildlife populations (Friend et al. 2001). This is especially acute with highly pathogenic agents like avian cholera or West Nile Virus affecting highly mobile animals such as birds (Malakoff 2003).

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