POPULATION DYNAMICS OF WANDERING ALBATROSS
Diomedea exulans AND AMSTERDAM ALBATROSS
D. amsterdamensis IN THE INDIAN OCEAN AND THEIR
RELATIONSHIPS WITH LONG-LINE FISHERIES:
CONSERVATION IMPLICATIONS

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Abstract
Studies carried out over the past three decades at Crozet and Kerguelen Islands in the Indian Ocean indicate that wandering albatross Diomedea exulans populations declined markedly, but since 1986 have shown slow recovery. The population of the endangered Amsterdam albatross Diomedea amsterdamensis appears to have similarly recovered since 1985, but remains close to extinction. A demographic study of the Crozet population indicates that the earlier decline was mainly the result of increased adult mortality, and secondarily of low recruitment. Satellite tracking studies of breeding birds and band recoveries of non-breeding birds indicate that during and outside the breeding season these populations are in contact with long-line fisheries, mainly the pelagic Japanese southern blue-fin tuna Thunnus maccocyii fishery and to a lesser extent the Patagonian tooth-fish Dissostichus eleginoides fishery operating on the Kerguelen shelf. Decreased fishing effort and a concentration outside the central Indian Ocean by the Japanese fishery during recent years has probably resulted in the slow recovery of these albatross populations as a result of improved adult survival and recruitment. Long-line fisheries still represent a major threat to great albatross populations, most of which are still declining in the Southern Ocean. Possible conservation measures to reduce mortality in the fishery and to reduce contacts between fishing units and foraging albatrosses are examined. Copyright © 1996 Published by Elsevier Science Limited

Keywords: wandering albatross, Amsterdam albatross, fisheries, extinction risk.

INTRODUCTION

The past decade has seen an increasing concern over declines in the abundance of large southern Procellariformes, particularly albatrosses, and the possible relationship with fisheries, especially long-lines. In the early 1980s declines in the size of wandering albatross Diomedea exulans populations were noted at South Georgia (Croxall, 1979) and on the Crozet Islands (Jouventin et al., 1984). The decline on the Crozet Islands was shown also to result from a high adult mortality, suspected to be at least in part to long-lining off the coast of Brazil (Croxall & Prince, 1990; Croxall et al., 1990). More recently, de la Mare and Kerry (1994) also related the near extinction of the small Macquarie Island population to the Japanese long-line fishery. The closely related Amsterdam albatross Diomedea amsterdamensis, whose entire population has been reduced to 5-8 pairs breeding each year on a single island, faces a high extinction probability (Jouventin et al., 1989).

With the spread of the Asiatic long-line tuna fishery in the subtropical and sub-Antarctic Southern Ocean and the recent development of long-lining, especially for Patagonian tooth-fish Dissostichus eleginoides in Antarctic waters, these great albatross populations are more than ever at risk. However, the precise impact of fishing is a sensitive issue and needs careful analysis in relation to population demography and the foraging zones of these two species. The aim of this study is first to analyse the cause of the changes in population size and its
possible relationship with long-line fisheries. Secondly, we use the result of the analysis to model the future trends of the two species and suggest conservation measures.

**METHODS**

**Field study**

Monitoring of the wandering albatross population was carried out on Possession Island (46°S, 52°E), one of the Crozet islands in the southwestern Indian Ocean (Fig. 1), between 1960 and 1995. The entire population of Possession Island was censused seven times between 1960 and 1980, and every year since 1981. Three colonies are found on the island, at Baie du Marin, Est and Pointe Basse (Weimerskirch & Jouventin, 1987, for location). The number of nests with an egg was recorded when all laying had been completed, i.e. around 15 January every year. A total of 3312 adult birds and 4750 chicks prior to fledging were banded with monel bands between 1960 and 1994. Since 1966, recapture of banded birds has been undertaken each year between December and April. Bands of breeding birds were checked after egg-laying until April, bands of non-breeders between December and April. At Kerguelen, wandering albatrosses were censused in mid-January on the Courbet Peninsula in 1971 and between 1985 and 1993 (see Weimerskirch et al., 1989a). The small Amsterdam albatross population was censused on Amsterdam Island every year between 1983 and 1994, and breeding success was determined from monthly checks of nests from egg-laying in March until fledging the following January. Since 1983, all chicks have been banded with monel and plastic bands prior to fledging; recording of banded birds is carried out each year between March and May.

**Data analysis**

Overall breeding success was measured as the percentage chicks fledged out of eggs laid. Maximum-likelihood estimates of survival and re-sighting rates were calculated for adult birds using the program SURGE 4.2 (Pradel & Lebreton, 1993). Different models were selected by likelihood-ratio tests and fitted in order of decreasing complexity (Lebreton et al., 1992). To test whether adult survival varied significantly over time, comparison of survival in years 1966–1993 (model spt) was based on the change in deviance from fitting a model with constant survival (model sp'). The survival of adult birds was estimated from successive recaptures of breeding birds. Because wandering albatrosses breed in alternate years when they are successful in rearing a chick, a bird will not be recaptured the following season. This means that recapture rates are underestimated, but as the cohorts banded each year are pooled, the bias in the estimation of survival is most marked for the first year and last two years of the series (Rothery & Prince, 1990). Estimates for these three years were, therefore, not used in the analysis. Juvenile survival was calculated from recaptures of birds banded as chicks.

**Foraging sectors**

Foraging sectors of wandering albatrosses breeding on Possession Island were determined using satellite tracking. The movements of breeding birds were studied over the entire breeding season in 1990 and 1992 and during the incubation and brooding period in 1989 and 1994 (see Weimerskirch et al., 1992, 1993, 1994). For the other nesting sites, foraging sectors of breeding birds were assumed to be similarly distributed around each island as around Possession Island, except for South Georgia where data are available (Prince et al., 1992). The foraging areas for non-breeding adults and immature birds were derived from band recoveries (Weimerskirch et al., 1985) and observations at sea (Stahl et al., in press).

**Fisheries statistics**

Information on the southern blue-fin tuna (SBT) *Thunnus maccoyii* fishery was obtained from the Annual Reports of Effort and Catch Statistics by area on Japanese tuna long-line fishery 1952–1980 (Research Division, Fisheries Agencies of Japan), from the 1st–13th SBT Trilateral Scientific Meeting Reports (CSIRO–MAF) and from Polacheck and Tuck (1995). Two
measures of fishing intensity were used for different sectors south of 30°S in the Southern Ocean, determined for their biological significance as foraging areas: (1) the total number of hooks set each year per 5° latitude × 5° longitude square; and (2) the proportion of all the 5° squares in a particular area where hooks were set.

Population modelling

To simulate the population trends over time, we used an age-structure model, based on a Leslie matrix (Leslie, 1945, 1966) and written in Turbo Pascal by F. Franck from a modified program in Fortran described in Lebreton (1981). The model consists of 14 year classes, comprising five age categories: chicks (age 0–1), juveniles (age 1–5, when birds remain at sea before returning to the breeding colonies), immatures (6–10 or 11 years, when birds visit the colonies to form pairs, 10 or 11 being the average age at first breeding) and adults (> 10 or > 11). To run the model, we used the demographic parameters measured for the different periods: chick survival is the breeding success; juvenile survival is the survival of cohort of chicks banded at age 1–5, annual juvenile survival being (cohort survival age 1–4)0.25; immature survival is equal to adult survival (Weimerskirch, 1992). Fecundity for the different age classes was estimated as the percentage of adults breeding at different ages multiplied by the average proportion of years when an adult breeds (breeding frequency 0.589; Weimerskirch, 1992). Breeding success was considered to be similar for the different age classes (Weimerskirch, 1992).

The program was first run with the demographic parameters as measured for the different periods of population growth rate in order to test whether they would account for the observed growth rates. In a second step, age-related parameters of survival, age at first breeding and fecundity were altered to test for the sensitivity of the population to changes in these parameters, and for the importance of each age class to the stability of the population. In a third step, changes in the population size of several populations were modelled to predict possible scenarios arising from changes in mortality rates as a result of fishing.

The model was run until the rate of increase reached equilibrium, using estimated values of juvenile survival where it was not possible to use observed values.

RESULTS

Population trends of wandering albatross at Crozet

Population size and breeding success

The Possession Island population has varied extensively in numbers between 1960 and 1995 (Fig. 2). Four different periods can be recognised. Between 1960 and 1969, the population was stable or slightly increasing. It then declined steeply between 1970 and 1976 at a rate of 7.0% per year, and less rapidly between 1977 and 1985 (1.4% per year). In 1986, the population reached a minimum, having been reduced by 53.8%. From 1986 to 1995, the population increased at a rate of 4% per year. The Pointe Basse and Est colonies have followed this pattern, whereas the Baie du Marin colony was stable throughout the whole period (Fig. 2).

The overall breeding success averaged 68.5 ± 11.2% (n = 26 breeding seasons) and appears to have increased significantly over the past 28 years (Fig. 3).

Adapt adult survival

Annual adult (all breeding birds) survival varied significantly according to time between 1966 and 1993 (Fig. 3: model s'p' only accepted, s'p against s'p', deviance = 4838, d.f. = 27, rejected). Average values for the four periods where survival estimates were available indicate that survival was significantly lower during the periods 1966–1969 and 1970–1976 than during the periods 1977–1985 and 1986–1993 (Table I).
Juvenile survival and recruitment

The estimated juvenile survival to age 5 years has increased significantly after 1966, when the first cohort of chicks was banded (Figs 3 and 4). Assuming a sex ratio at fledging of 1:1, a similar proportion of males and females survived (for 4738 chicks banded, 1280 were recaptured from age 5. 49.3% of males and 50.7% of females; \( \chi^2 = 0.2955, \ d.f. = 1, \ p = 0.587 \)), indicating that their survival during their five first years was similar. There was no significant difference in the proportion of males and females surviving between the 1966 and 1984 cohorts (\( \chi^2 = 26.1, \ d.f. = 17, \ p = 0.073 \)).

The age at first breeding of males and females decreased for the first eight cohorts of chicks banded since 1966, but has remained roughly stable thereafter (Fig. 4). Partly as a result, the proportion of birds recruited into the population over the study period has increased in relation to the number of juveniles surviving to age 5 years (Fig. 4).

Immigration and emigration

Adult birds, breeding for the first time on Possession Island, tend to return to their birth place. However, the larger and denser colony on Pointe Basse appears to attract more unfaithful birds than the other colonies (Weimerskirch & Jouventin, 1987). Females appear to be less faithful to their birth place than males; 24.4% (n = 492) breed in other colonies, compared to 12.5% (n = 471) of males (\( \chi^2 = 21.6, \ d.f. = 1, \ p < 0.0001 \)). Thirteen chicks banded on Possession Island have been recaptured on Marion Island, Prince Edward Islands, 900 km to the west (Fig. 1), eight as breeders. Nine out of 10 were females.

Fourteen birds banded on Possession Island as adult non-breeders, possibly immature birds prior to breeding, have been recaptured on Marion Island; six out of the 10 sexed were females. At least seven of these birds bred on Marion Island, all three sexed birds being females. Once they have started to breed in a colony, birds tend to be faithful to their nest site. Only 5.5% of the males recorded breeding in a colony have been found breeding in another colony, whereas 10.8% of females changed (\( \chi^2 = 10.8, \ d.f. = 1, \ p < 0.001 \)). Three females banded as adult breeders on two other islands

<table>
<thead>
<tr>
<th>Period</th>
<th>Rate of increase %/year</th>
<th>Annual adult survival ± 1 SD</th>
<th>95% confidence interval</th>
<th>Mean no. of hooks set/year (millions)</th>
<th>Percentage of 5° squares with long-liners/year in the central area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960–1965</td>
<td>+0.2</td>
<td>?</td>
<td></td>
<td>2.0</td>
<td>20.0</td>
</tr>
<tr>
<td>1966–1969</td>
<td>(0)</td>
<td>89.7 ±1.2</td>
<td>87.1–91.8</td>
<td>3.9</td>
<td>50.0</td>
</tr>
<tr>
<td>1970–1976</td>
<td>−7.2</td>
<td>89.5 ±0.5</td>
<td>88.5–90.3</td>
<td>3.13</td>
<td>30.0</td>
</tr>
<tr>
<td>1977–1985</td>
<td>−1.4</td>
<td>93.7 ±0.3</td>
<td>93.0–94.3</td>
<td>8.35</td>
<td>20.8</td>
</tr>
<tr>
<td>1986–1993</td>
<td>+4.0</td>
<td>95.6 ±0.3</td>
<td>94.8–96.2</td>
<td>2.73</td>
<td>15.0</td>
</tr>
</tbody>
</table>
Population dynamics of albatrosses

of the Crozet archipelago moved to Possession Island. Although these birds were banded in the early 1970s, they immigrated to Possession Island in the late 1980s.

Kerguelen and Amsterdam populations
The Kerguelen wandering albatross population has followed a similar pattern to that of the Crozet population, with an apparent steep decline during the 1970s and a slow recovery since the mid-1980s (Fig. 2).

On Amsterdam Island, the number of Amsterdam albatross pairs breeding each year has increased slightly since the mid-1980s (Fig. 2) when monitoring studies started. For the period 1983–1994, 83 chicks were produced from 116 eggs laid, giving an average breeding success of 71.6%. For the period 1983–1993, the average adult survival was 95.7± 1.8% (c.i 90.6–98.1). Out of a total of 27 chicks banded between 1979 and 1985, 19 have been subsequently recaptured on the island, returning at an average age of 5 years (range 4–8). Birds start breeding at age 7 (one bird) with four breeding at age 8 and one at 10.

Long-line fishing distribution and effort
In the Japanese SBT fishery, the total number of hooks set in the Southern Ocean progressively increased from the late 1950s to reach a plateau in the 1980s, with a maximum of 120 million hooks in 1980 (Fig. 5). The fishing effort then declined to 50–60 million hooks in the early 1990s. In the foraging zone for the Crozet wandering albatross population, the number of hooks peaked three times over the past three decades (Fig. 5).

The number of 5° squares, where long-liners were operating, increased in parallel with the number of hooks set in the Crozet, Kerguelen and Amsterdam sectors and in subtropical waters between 30°S and 40°S (Fig. 5). A peak was reached in 1970, followed by a rapid decline that has continued more slowly throughout most sectors. This reflects the concentration of the

![Graph showing proportion of 5° squares with long-liners](image)

**Fig. 4.** Juvenile survival from fledging to age 5 and to recruitment of cohorts of chicks banded from 1966 onward in Possession Island wandering albatross.

![Graph showing changes in numbers of hooks set and proportion of 5° squares covered](image)

**Fig. 5.** Changes in the numbers of hooks set and in the proportion of 5° squares covered by the Japanese long-line fishery south of 30°S in the Southern Ocean.
fishery since 1975, mainly in the South African and the Australian sectors (Fig. 6). Whereas, since the late 1960s, the fishery operated in the Crozet sector mostly between April and July, from 1985 fishing took place mostly between January and March.

In the southern Indian Ocean, the Dissostichus fishery has only been operating since 1991 and restricted to the western Kerguelen shelf (Cherel et al., 1996).

**Foraging zones during breeding and band recoveries**

During the breeding season wandering albatrosses breeding on Crozet forage over an extensive area ranging from the coasts of Antarctica to tropical waters (Fig. 7). The foraging zone overlaps to a large extent with the Dissostichus fishery. Only males forage in the Kerguelen shelf area.

In 1990, the SBT fishery was operating in the southwestern Indian Ocean between January and July. A total of 28 breeding wandering albatrosses were tracked during this period during 61 foraging trips. Because the fishery took place mostly to the west and to the east of the central foraging area, a limited number of the tracks crossed 5° squares where long-liners were operating (Fig. 8).

A total of 37 recoveries of wandering albatrosses banded on the Crozet Islands have been obtained (not including recoveries from other breeding grounds). Twenty-two non-breeding adults and four juveniles were recovered along the coasts of South Africa and especially of Australia. Eleven were caught by long-liners (six breeding adults, one pre-breeding bird and four juvenile or immature birds), in the central Indian Ocean north of Crozet (2), in the eastern south Atlantic (2) and in the Australian sector (7).

**Relationship of fishing effort and distribution to demographic parameters**

The increased fishing effort and distribution in the Southern Ocean between 1966 and 1985 (Table 1) coincided with the steady decline of the Crozet population (Figs 2 and 5). Correlation between adult survival and number of hooks set in different sectors, or proportion of sectors with fishing boats operating, was only significant for the proportion of sectors in the central foraging zone of Crozet birds \( r = -0.418, n = 25, p = 0.037 \). Using a stepwise multiple correlation, adult survival (Sv) was best explained by the number of sectors (Sct) where fishing boats were operating in the central foraging zone of Crozet birds added to the number of hooks (H) set in the southern Australian sector \( S v = -1.155 \text{ Sct} - 0.000268 \text{ H} + 102.5, F = 4.44, r = 0.555, p = 0.025 \).

Juvenile survival between 1 and 5 years of age for the cohorts 1966–1982 was highly significantly correlated to the proportion of 5° squares where long-liners operated and also to the number of hooks set between the latitude 30 and 35°S, i.e. the foraging area of juvenile birds \( r = 0.714, p < 0.001 \).

Observed changes in the rate of increase of the Possession Island population, or in survival rates for the four periods when survival estimates are available, changed in a similar way to the cumulated number of 5° squares in which long-lining occurred (Table 1). The rate of decline of five different populations in the Southern Ocean was significantly related to the cumulative number of hooks set in the respective foraging areas and also to the proportion of 5° squares where long-liners operated within the foraging area (Fig. 9).

**Population modelling**

*Observed changes in population size on Possession Island*

The rates of population increase calculated from the model closely match the observed rates for the successive periods (Table 2). Because it was only possible to census the numbers of breeding pairs, the observed rates for the wandering albatross are those of the breeding
population, whereas the modelled rate of increase is for the whole population (Fig. 10). The comparison between the modelled change in the population structure throughout the 1960–1994 period, and the observed change in the number of breeding pairs, indicates similar numbers of adult birds derived from both methods (Fig. 10).

**Sensitivity study**

Five percent declines in adult survival, juvenile survival or chick survival (breeding success) have very different implications for the rate of decline of the population (Fig. 11). Changes in total population are dramatically affected by the decline in adult survival, moderately affected by juvenile survival and very little affected by breeding success. A decline in adult survival can be ascertained immediately because it is possible to study the breeding population. However, detecting a decline in juvenile survival relies upon a delay of at least 5 years, or 10 years for indication of a decline in breeding success (Fig. 11, lower graph). As an example, to compensate for a decline of 1% in adult survival, juvenile survival must be increased by 5.9%, breeding success by 24%, or age at first breeding decreased by 4.2 years.

![Figure 7](image1.png)

**Fig. 7.** Distribution of 10,000 satellite fixes of wandering albatrosses breeding on Possession Island. Dashed lines indicate the extent of the SBT fishery and of the Patagonian tooth-fish fishery around Kerguelen. Star indicates Crozet.

![Figure 8](image2.png)

**Fig. 8.** Foraging movements of wandering albatrosses from Possession Island in April-July 1990 in relation to the distribution and intensity of Japanese long-line fishing at the same period. Numbers in each 5° square indicate number of hooks set: 7 > 10^6 hooks, 10^5 hooks < 6 < 10^6 hooks, 10^4 hooks < 5 < 10^5 hooks, etc.

![Figure 9](image3.png)

**Fig. 9.** Relationship between rate of decline of five wandering albatross populations and the cumulated number of hooks set in the central foraging sector of each population.
Wandering albatross: global population

Seabird mortality rates caused by the long-line fishery have been studied by several authors, and in different oceanic sectors (Table 3). The figures of mortality rates are very variable according to the sector, season and time of year (Murray et al., 1993; Gales, Brothers et al., unpublished data). The New Zealand figure is thought to be more applicable to the Crozet sector as fishing at both localities is within the foraging range of large breeding populations (Auckland and Antipodes Islands), whereas Tasmania and Australia are generally just at their limits. Note, however, that the New Zealand estimates were obtained after mitigating measures were already being used to a certain extent.

Wandering albatross populations probably decreased by 41% between the early 1960s and the early 1990s, with a total loss of 72 000 birds (Table 4). If we consider that the increased mortality has affected juveniles, immatures and adult birds similarly (this study, Table 3), and using the most conservative figures for hooking rates of wandering albatrosses outside the foraging zones of breeding birds, we estimate that 50 200 birds have died. However, mortality rates are likely to be higher closer to the breeding grounds, i.e. in the centre of foraging zones where wandering albatross densities

Table 2. Observed and modelled rate of increase of the Possession Island wandering albatross population (demographic parameters in parentheses are estimated)

<table>
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<tbody>
<tr>
<td>Chick survival</td>
<td>(0.640)</td>
<td>(0.660)</td>
<td>0.680</td>
<td>0.700</td>
<td>0.720</td>
</tr>
<tr>
<td>Juvenile survival⁴</td>
<td>(0.770)</td>
<td>(0.770)</td>
<td>0.680</td>
<td>0.730</td>
<td>0.840</td>
</tr>
<tr>
<td>Immature survival</td>
<td>(0.960)</td>
<td>(0.897)</td>
<td>0.895</td>
<td>0.983</td>
<td>0.956</td>
</tr>
<tr>
<td>Adult survival</td>
<td>(0.960)</td>
<td>0.897</td>
<td>0.895</td>
<td>0.970</td>
<td>0.956</td>
</tr>
<tr>
<td>Average age at first breeding (Range)</td>
<td>12 (8–14)</td>
<td>12 (8–14)</td>
<td>11 (7–13)</td>
<td>10 (7–12)</td>
<td>10 (7–12)</td>
</tr>
<tr>
<td>Fecundity</td>
<td>0.590</td>
<td>0.590</td>
<td>0.590</td>
<td>0.590</td>
<td>0.590</td>
</tr>
<tr>
<td>Modelled rate of increase for entire population</td>
<td>1.007</td>
<td>0.953</td>
<td>0.935</td>
<td>0.986</td>
<td>1.031</td>
</tr>
<tr>
<td>Observed rate of increase for breeding population</td>
<td>1.006</td>
<td>(1.000)</td>
<td>0.930</td>
<td>0.986</td>
<td>1.040</td>
</tr>
</tbody>
</table>

⁴Respectively (0.35)⁰.²⁵, (0.35)⁰.²⁵, (0.210)⁰.²⁵, (0.283)⁰.²⁵ and (0.500)⁰.²⁵.

Fig. 10. Modelled changes in the structure of the Possession Island population between 1960 and 1994 (above), and comparison between observed and modelled numbers of breeding birds (below).

Fig. 11. Modelled changes in a total population of 1000 birds subject to a 5% decrease in (a) adult survival, (b) juvenile survival and (c) breeding success over 100 years (above), and in the breeding part of the population over 20 years (below).
Population dynamics of albatross

are highest, than outside the range of breeding birds. Applying these rates produces an estimated total of 122,000 birds killed on Japanese long-linelines. These two figures probably correspond to low and high estimates, and agree with the observed rate of population decline.

Using a similar calculation, a total of c. 10,000 wandering albatrosses have been lost from the Crozet Islands group (including Possession Island, Cochons Islands and East Island, see Weimerskirch & Jouventin, 1987, for population size). This figure corresponds to 5,500 breeding adults (i.e. 1,613 breeding pairs per year, see Table 4) plus 4,500 immature birds. Assuming that only those breeding on Crozet are foraging in the Crozet sector, a total of 4,790 breeding birds have been killed by 104 million hooks set here. The figure appears plausible as, out of 5,500 adults lost, the other 710 adults could have been killed when dispersing during their non-breeding year.

Amsterdam albatross

The breeding population of Amsterdam albatrosses was 11 pairs each year for the period 1992–1994, during which 40 breeding birds were captured. Modelling gives an annual rate of population increase of 1.040 so this population in 1994 would also include 8 chicks, 23 juvenile birds and 16 immature birds. Using this rate of increase, the model gives a population in 1984 of 60 birds including 30 breeding adults, i.e. seven pairs breeding each year (Fig. 12, 1984–1994). This is in fact the number of pairs observed breeding in 1983–1985 when fishing in this sector had ceased.

Assuming that this population has suffered a similar decline in adult and juvenile survival as at Crozet, the population in 1966 would have comprised 180 birds, including 100 breeding pairs, i.e. 30 pairs breeding each year (Fig. 12, 1966–1983), at the commencement of Japanese long-line fishing around Amsterdam. Similarly, if fishing here were to start again, and cause the same adult and juvenile mortality rates as at Crozet during the 1970–1976 period, the Amsterdam population would become extinct in 50 years (Fig. 12).

DISCUSSION

Demography of the Possession Island population of wandering albatross

The Crozet Islands have the most closely monitored breeding population of wandering albatrosses. It is the only place where changes in numbers and demographic parameters have been measured continuously over a 30-year period on a significant number of birds. Only two

Table 3. Mortality rates of wandering albatrosses in Australian and New Zealand sectors due to the Japanese long-line fishery

<table>
<thead>
<tr>
<th>Authors</th>
<th>Oceanic sector</th>
<th>Number of line settings observed</th>
<th>Total albatrosses/1000 hooks (range)</th>
<th>Percentage wandering albatrosses</th>
<th>Wandering albatrosses/1000 hooks</th>
<th>Percentage juvenile birds</th>
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<tbody>
<tr>
<td>Brothers (1991)</td>
<td>Tasmania</td>
<td>40</td>
<td>0.410</td>
<td>22.0</td>
<td>0.090</td>
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<tr>
<td>Murray et al. (1993)</td>
<td>New Zealand</td>
<td>785</td>
<td>0.240</td>
<td>19.2</td>
<td>0.046</td>
<td>38.5</td>
</tr>
<tr>
<td>Gales, Brothers et al.</td>
<td>Australia</td>
<td></td>
<td>0.140</td>
<td>13.9</td>
<td>0.019</td>
<td>76.3</td>
</tr>
</tbody>
</table>

(unpublished data)

Table 4. Number of pairs of wandering albatrosses breeding each year in the early 1960s and in the early 1990s, and estimated total population

<table>
<thead>
<tr>
<th>References</th>
<th>1960s</th>
<th>1990s</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Georgia</td>
<td>2805</td>
<td>2193</td>
<td>Croxall et al. (1990)</td>
</tr>
<tr>
<td>Gough-Inaccessible</td>
<td>(1300)</td>
<td>1000</td>
<td>Watkins (1987)</td>
</tr>
<tr>
<td>Prince Edward</td>
<td>(4085)</td>
<td>2655</td>
<td>Watkins (1987); Cooper in Gales (1993)</td>
</tr>
<tr>
<td>Crozet</td>
<td>3250</td>
<td>1637</td>
<td>This study; Weimerskirch and Jouventin (1987)</td>
</tr>
<tr>
<td>Kerguelen</td>
<td>2000</td>
<td>1094</td>
<td>This study</td>
</tr>
<tr>
<td>Macquarie</td>
<td>50</td>
<td>6</td>
<td>de la Mare and Kerry (1994)</td>
</tr>
<tr>
<td>Auckland</td>
<td>(7500)</td>
<td>4050</td>
<td>Robertson (1975); Walker et al. (1991)</td>
</tr>
<tr>
<td>Antipodes</td>
<td>(8000)</td>
<td>4500</td>
<td>Clark et al. (1995)</td>
</tr>
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Total: Annual breeding pairs 28,900 17,100
Breeding birds a 98,000 58,000
All birds b 178,000 105,450

a Successful breeding pairs only breed in alternate years. In a stable population the total number of breeding birds is 1.7 times the annual number.
b Non-breeding birds = 81.7% of breeding birds.
other demographic studies have been carried out, one on a small population at Macquarie Island (de la Mare & Kerry, 1994) and another on a larger population but over a shorter period at Bird Island, South Georgia (Croxall et al., 1990) (Table 4).

The demographic parameters measured on Possession Island appear to account accurately for the changes in breeding pairs observed over the past 30 years. The steep decline in 1970–1976 is due mostly to reduced adult survival and, to a lesser extent, reduced juvenile survival. We have no actual measurements of adult or juvenile survival for the early 1960s. Adult annual survival of wandering albatrosses at South Georgia before the start of long-line fishing was 0.960 (Tickell, 1968). This is a similar value to that used in the model which best explains the slight increase observed in the Possession Island population between 1960 and 1969. Adult survival could thus have been reduced by 6.5% per year during the 1966–1976 period. This low value suggests that we cannot exclude the possibility that the decline of the population started before 1970.

Between 1977 and 1985, annual adult survival improved by 4%, and annual juvenile survival improved by 5%, but stabilisation was not achieved and the population continued to decline though at a slower rate. From 1986 onward, annual adult survival improved further by 1.9% and annual juvenile survival by 9%, allowing a population increase. These changes in survival have been paralleled by changes in breeding success and age at first breeding. Breeding success has significantly improved since 1966, to reach very high rates in the 1990s. Between 1966 and 1985, Weimerskirch and Jouventin (1987) showed a significant relationship between adult survival and breeding success in the three different colonies of Possession Island. It was suggested that the mortality of adult birds occurred at least in part during the breeding season, the death of one of the pair causing breeding failure. Croxall et al. (1990) stated that this was an artefact because, in any season with a high breeding success, more adults will have survived until their chick has fledged and thus be available for recapture. This statement, perhaps based on the recapture experience of these authors at South Georgia, does not apply to our study because breeding birds are only captured during the incubation period, and never at the end of the breeding season (Weimerskirch & Jouventin, 1987).

During the period 1985–1990, no similar correlation between breeding success and adult survival was observed. These results suggest that the higher breeding success during recent years was the result of increased survival of breeding birds. The decline in the population has also been paralleled by a decrease in the age at first breeding which has accelerated recruitment rate. However, birds are probably physiologically unable to reproduce before 7 years (Hector et al., 1990) and the average age at first breeding stabilised at age 10. In declining populations, the decrease in the age at which birds first breed is generally assumed to be the result of density-dependent feedback. The decrease in the number of adult and immature birds has decreased intra-specific competition and thus could have improved juvenile survival. Decreased age at first breeding, together with increased juvenile survival, has produced a younger population than in 1960, but an overall decrease in breeding success as a result of lower breeding success by young birds (Weimerskirch, 1992) has not occurred.

The recent apparent decrease in philopatry of females could be the result of a destabilised population. This phenomenon occurs in other animal groups, but it is not clear why it should occur in females rather than males. Immigration and emigration rates appear limited, however, and can be excluded from the population modelling as they represent less than 0.1% of the population change.

The 1% lower annual survival rate of females compared to males during the period of decline appears small compared to previous estimates (Weimerskirch & Jouventin, 1987) and is the result of better survival estimates. However, a difference in 1% between male and female survival over a 16-year period has important repercussions for the sex-ratio and breeding structure of the population. If we consider that the population of 1600 breeding birds consisted of 800 males and 800
females in 1969, this difference would lead, in 1985, to a population having 580 males and 420 females. Thus, only 420 pairs could be formed, 250 annually. Despite a good agreement between the measured and modelled demographic parameters, the additional use of sex-specific annual survival helps to explain why the number of pairs observed in the colony (240–260 pairs) was lower than the number modelled but similar when the biased sex-ratio figures are considered. It also explains the higher number of males compared to females in the non-breeding population in the late 1980s (Weimerskirch & Jouventin, 1987; Jouventin & Lequette, in prep.).

**Interactions between the long-line fishery and the Crozet population**

Direct evidence of Crozet wandering albatross mortality comes from only 11 birds killed by long-lines. However, this low number could not be expected to reflect the real extent of mortality of Crozet birds because fishermen rarely report killed birds or band recoveries, and reports are even forbidden on board long-liners. Only since 1987 have there been observers monitoring bird mortality, originally limited to a few vessels in the Australian and New Zealand Exclusive Economic Zones, but now up to 100% in the New Zealand Economic Zone. Studies have clearly shown that Crozet birds forage where long-line fishing continues to operate in the subtropical and sub-Antarctic pelagic waters of the southwestern Indian Ocean (Weimerskirch et al., 1993; Fig. 8). As birds forage from a central point on looping routes, the probability of breeding birds encountering long-liners increases when the fishery is close to the breeding grounds. Also at some stages of the breeding season, all birds are concentrated within 200 km of the nesting grounds (Weimerskirch et al., 1993). The mortality of breeding birds is thus primarily related to the extent of the fishery and its proximity to the central foraging zone, and only secondarily to the number of hooks set in the area.

If a large number of hooks are set in this 200 km radius, during the chick-rearing period, a large proportion of the population is likely to encounter long-liners. The higher adult survival during the late 1980s compared to the late 1960s and early 1970s therefore could be due mainly to a difference in location of the fishery and its timing in relation to the chick-rearing period.

After the breeding season, adult birds leave the Crozet sector and disperse over the Southern Ocean. As birds disperse over a much wider area, their chance of encountering long-liners becomes comparatively reduced. However, a significant proportion of the population moves eastward when dispersing, with a lot of birds wintering around Australia (Weimerskirch et al., 1985). Adult mortality is, therefore, accounted for by long-liners in the Crozet sector and in the southern Australian sector as suggested by the results of this study, but probably also in fishing grounds between the two areas (Nicholls et al., 1992).

At sea, juveniles and young immature birds forage mainly in subtropical waters (Weimerskirch et al., 1989b). They are probably limited to the south by the subtropical convergence (Stahl et al., in press). The mortality of this category of birds appears to be strongly related to coverage by the Japanese fishery of the subtropical waters. As the fishery shifted from the subtropical waters to more southerly waters between the 1960s and 1980s, the probability of juvenile birds encountering long-liners decreased during the 1970s and 1980s, leading to an improvement in juvenile survival.

In the Tasmanian sector, more juveniles than adults were caught (Gales, Brothers, et al., unpublished data) compared to other sectors (Murray et al., 1993) or to those from band recoveries (Croxall & Prince, 1990; this study).

The development of the Diomedea exulans fishery at Kerguelen may also represent a threat to Crozet birds as a significant proportion of breeding adults commute from Crozet to the western part of the Kerguelen shelf. Wandering albatrosses attend long-liners in great numbers (Cherel et al., 1996) and are sometimes caught if preventative measures are not taken.

**Changes in the wandering albatross populations elsewhere**

Changes in wandering albatross populations size have occurred differently at other islands in the Southern Ocean, except for Kerguelen which is close to Crozet. Wandering albatrosses at South Georgia have declined at a constant rate of -1% per year from the early 1960s (Croxall et al., 1990), but the absence of counts or estimates of demographic parameters between 1960 and 1972 makes it impossible to know when the decline started. The decline here was much less severe than at Crozet, but continuous since 1972. Japanese fishing effort in the foraging area of breeding birds has been episodic, never covered a significant part of the foraging area, and the number of hooks set was never high. As a result, adult survival has probably been relatively high, and the supposed increased higher mortality of adults occurred outside the breeding season. Juvenile survival was low. The decline of this population therefore could be a result of juvenile mortality and dispersing adult birds encountering long-liners outside the western south Atlantic. The developing long-line fishery off the coasts of Brazil and Uruguay since the early 1980s accounts for a large part of the recaptures of wandering albatrosses banded at South Georgia (Croxall & Prince, 1990), and could account for the continuous decline of the population during the late 1980s and early 1990s.

The Macquarie Island population is at the other extreme to that of South Georgia. Decline started at the same time as at Crozet, i.e. late 1960s–early 1970s, and brought the population down to 2–4 pairs in the mid-1980s (de la Mare & Kerry, 1994). Since then, the population has appeared stable, although, with such low numbers, it is difficult to discover a clear trend.
Macquarie breeding birds probably forage in a sector where long-lining started in the early 1960s, and was most widespread in the late 1960s–early 1970s. The island is just between two major fishing grounds, Tasmania and New Zealand, and the proportion of 5° squares with hooks set in the Macquarie sector has always been high since the 1960s. The high rate of decline of the population is probably the result of the continuous contact of the breeding population with the fishery.

**Extinction risk of Amsterdam albatross**

The demographic parameters of the Amsterdam population are known accurately compared to other endangered species (Perrins et al., 1991). However, the fact that the population has been able to increase over the past 10 years suggests that, despite low numbers, it is still a viable population (Soulé, 1987). Adult survival and breeding success are very similar to those of the Possession Island population, but juvenile survival is higher at Amsterdam. The causes for the reduction of the population to its 1981 level are not known, but the island has suffered extensive degradation during the past three centuries since its discovery (Micol & Jouventin, 1995). It is possible that the population was already much reduced when long-lining started in the central Indian Ocean. However, during the late 1960s and in the 1970s, long-liners were operating in large numbers over the entire central foraging area, and would have inevitably caused mortality of Amsterdam birds especially during the early chick-rearing period.

Risks of extinction for this small population are very high. Although our model shows that it could become extinct in <50 years, in fact low numbers of breeding birds could cause breeding difficulties after 25 years. If long-liners were operating during the chick-rearing period in the vicinity of Amsterdam Island, the risk would be very high for all breeding birds and the breeding population could disappear within 2 or 3 years.

**Conservation implications**

There is no absolute proof that the decline of the Possession Island population has been caused by the Japanese long-line fishery. However, the correlation between (1) changes in fishing operation and population size, (2) fishing distribution and effort with albatross survival rates, and (3) estimated numbers of birds killed by the fishery and observed changes in the number of breeding birds, leads to the conclusion that long-line fisheries are at least partly responsible, and the largest by far is the Japanese SBT fishery. To prevent fishing operations having a serious impact upon breeding populations, there are two options: avoid fishing within the main foraging area of breeding birds, especially the central foraging area where birds with chicks concentrate; and/or use mitigating measures on fishing vessels.

The first option has already occurred in the Crozet sector, allowing recovery of the population despite the ongoing non-breeding adult, immature and juvenile mortality elsewhere. The proposed reduction in the total number of hooks set in the Southern Ocean to a maximum of 41.6 million hooks as a measure to stabilise wandering albatross populations (de la Mare & Kerry, 1994) appears too simplistic: the Crozet population was recovering when most hooks were being set there. If, for example, only 41.6 million hooks were set within the foraging zones of the three most numerous populations, Auckland, Antipodes and South Georgia, these populations might still decline. Complete restriction of fishing in these areas is unrealistic as it would virtually exclude any profitable activity in a large part of the Southern Ocean. However, at least some key sectors, such as the New Zealand area, should be considered as sanctuary to safeguard the large and diversified populations breeding there.

Measures to limit mortality by long-lines exist. Wandering albatrosses are mostly diurnal feeders (Weimerskirch & Wilson, 1992; Weimerskirch et al., 1994), so setting lines at night when birds do not attend ships will assist greatly in reducing mortality, not only for this species but also for many others that are caught (Cherel et al., 1996). The use of a bird line and pole to scare the birds away, a bait-throwing machine and methods for increasing the sinking rate of baits will also significantly reduce catch rates during day setting (Brothers, unpublished data). However, it is important in the future to quantify the effect of these mitigating measures. Because the large albatross species require a complete year to breed, changes in the timing of the fishery would not necessarily reduce the mortality.

Albatross populations probably can remain stable or even increase while sustaining a certain level of mortality due to fisheries. The Possession Island population is presently increasing despite birds still being killed. Fishery managers may therefore ask what mortality rate wandering albatross can sustain. However, conservationists would prefer that no mortality should occur and, even if a certain level of mortality is accepted, should it permit stabilisation of populations at present levels, or recovery to previous levels? Maintaining the present dangerously low Amsterdam albatross population level is unacceptable. The immediate protection of some populations is important because fishing mainly takes place outside the EEZ, and, consequently, changes in the fishing routine are generally difficult to enforce and would take several years to be fully implemented.

**CONCLUSIONS**

This study demonstrates that the conservation of wide-ranging long-lived seabirds is a complex task. Long-term monitoring programmes are essential to gather and analyse population data, but also data are needed on foraging ecology, in order to be able to define reasons for the population changes and propose conservation measures.
With regard to fisheries that operate in international pelagic subtropical waters, which currently constitute the major threat for large Procellariiformes, the future of these long-lived seabirds depends not on authorities that administer breeding grounds, but primarily on commercial considerations. Although SBT stocks have probably been depleted, the long-line fishery is likely to expand in the future as nations other than Japan have started to target SBT. Also, fisheries targeting other tuna species such as albacore Thunnus alalunga or yellow-fin tuna T. albacares range as far as 40°S in the south Indian and Pacific Oceans, and overlap with albatrosses. With ships formerly used for the now banned drift-net fishery being converted into long-liners, enforcement of conservation measures will be difficult to apply. The development of a new long-line fishery for Dissostichus in the CCAMLR zone constitutes the second major threat for these populations and should be closely controlled. This fishery is small compared to the tuna fishery, and the impact of the local population can be limited if recent measures to reduce mortality (CCAMLR, 1994) are enforced.

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