Agreement on the Conservation of Albatrosses and Petrels

First meeting of the Population and Conservation Status Working Group

La Rochelle, France, 29-30 April

Recent Indian yellow-nosed and sooty albatrosses trends on Amsterdam Island, Indian Ocean

Jeremy Demay, Christophe Barbraud, Karine Delord & Henri Weimerskirch

Centre d'Etudes Biologiques de Chizé, 79360 Villiers en bois, France

ABSTRACT

Indian yellow-nosed Albatrosses from Amsterdam Island, Indian Ocean, are known to be exposed to avian cholera and this threat has been previously identified as probably the most important factor influencing the demographic parameters of the population. Using long-term counts of the colonies for the period 1983-2013, we re-evaluated the present status of all colonies and the trend in reproductive success for yellow-nosed and sooty albatrosses. Overall yellow nosed albatrosses showed an overall steep decline that is accelerating during recent years. Breeding success in several colonies, and in particular in the largest colony of the population were extremely low. Altitude of the colony has no influence on the reproductive success, but human visitation had a significant negative effect. For the sooty Albatross, overall breeding success was very low, due to high mortality of chicks after hatching, similar to yellow nosed albatrosses suggesting a common factor. These results suggest that avian cholera is today probably affecting the entire albatross populations, and constitute a serious threat for Amsterdam albatrosses. Biosecurity measures to limit the spread of the disease are necessary and presently in force on the island.

Tendencias recientes con respecto a los albatros indios de pico amarillo y albatros oscuros en la isla de Ámsterdam, Océano Índico

Se sabe que los albatros indios de pico amarillo de la isla de Ámsterdam, Océano Índico, están expuestos a la cólera aviar, y esta amenaza se ha identificado previamente como probablemente el factor más importante que afecta los parámetros demográficos de la población. Mediante recuentos a largo plazo de las colonias durante el período 1983-2013, reevaluamos el estado actual de todas las colonias y la tendencia del éxito reproductivo de los albatros de pico amarillo y albatros oscuros. En general, se observó una marcada disminución general de los albatros de pico amarillo que se acentuó en los últimos años. El éxito reproductivo en varias colonias, y en particular en la colonia más grande de la población fue muy bajo. La altitud de la colonia no incide de ninguna manera en el éxito reproductivo, aunque la visita humana tiene un efecto negativo importante. Para el albatros oscuro, el éxito reproductivo general fue muy bajo, debido a la alta mortalidad de los pichones al salir del cascarón, similar a los albatros de pico amarillo, lo que sugiere un factor común. Estos resultados sugieren que la cólera aviar en la actualidad afecta probablemente todas las poblaciones de albatros, y constituye una grave amenaza para los albatros de Ámsterdam. Son necesarias las medidas de bioseguridad para limitar la propagación de la enfermedad y actualmente se aplican en la isla.

Dernières tendances concernant les albatros à nez jaune et les albatros fuligineux de l'île Amsterdam, océan Indien

Les albatros à nez jaune de l'île Amsterdam, dans l'océan Indien, sont exposés au choléra aviaire. Cette menace est probablement le premier facteur d'influence des paramètres démographiques de cette population. Grâce aux recensements des colonies entre 1983 et 2013, nous avons pu réévaluer l'actuel statut de toutes les colonies, de même que la tendance en matière de reproduction des albatros à nez jaune et des albatros fuligineux. De manière générale, le nombre d'albatros à nez jaune a fortement diminué et ce déclin s'est accéléré au cours des dernières années. Le taux de réussite de la reproduction dans plusieurs colonies et, en particulier, dans la principale colonie, était extrêmement bas. L'altitude à laquelle est située la colonie n'influence pas le taux de réussite de la reproduction, mais la présence d'êtres humains a un effet délétère certain. S'agissant de l'albatros fuligineux, le taux de réussite de la reproduction était très bas en raison de l'importante mortalité des poussins après l'éclosion. Cette tendance est semblable à celle relevée chez l'albatros à nez jaune, ce qui suggère la présence d'un facteur commun. Ces résultats laissent à penser que le choléra aviaire affecte probablement tous les albatros et qu'il représente une sérieuse menace pour les albatros de l'île Amsterdam. Des mesures de biosécurité destinées à juguler la dissémination de la maladie sont nécessaires et actuellement mises en œuvre sur l'île.

1. INTRODUCTION

Seabird populations are known to be subject to several human-induced pressures. Considering the albatrosses, negative interactions with longliners have been well documented and identified as a major threat for these populations, by the accidental capture leading to the individuals' death (Rolland et al. 2010, Lewison et al. 2004, Tuck et al. 2001). However, a new conservation concern is arising with the emergence of infectious diseases in seabird populations (Thomas et al. 2007). On Amsterdam Island, Southern Indian Ocean, infectious diseases have been recently discovered to be potential causes of threats to albatross populations (Weimerskirch 2004). In particular, avian cholera was identified as a major cause of chick mortality. Thus both fisheries and diseases may affect albatross populations on this island.

The island shelters, among others, three species of albatrosses, one crested penguin, and one skua. With 37,000 breeding pairs in the early 1980s' (Jouventin et al. 1983), the Indian Yellow-nosed Albatross *Thalassarche carteri* population of Amsterdam represented about 70% of the worldwide population (ACAP). The Amsterdam Island population experienced a decline in numbers and a strong decrease of the breeding success during the last decades, and the major cause identified in this decrease was attributed to the a disease outbreak in the 1980s (Rolland et al. 2009), most probably avian cholera. However, so far no large scale epidemiological study has been carried out. Furthermore, the possible contamination of other Amsterdam bird species could be dramatic, especially for the very rare and endemic Amsterdam Albatross *Diomedea amsterdamensis*. The sooty Albatross *Phoebetria fusca* is also under strong conservation concern since the discovery of high mortality events of young chicks in the early 2000s' (Weimerskirch 2004). The death of chicks at this age resembles very much the symptoms that hit the Indian yellow-nosed Albatross earlier, and it is probable that it comes from the same cause.

In this context, it appears very important to update population trends and to have an epidemiological study of the different bird species on Amsterdam. The second objective is under development through large scale sampling of all seabird species on Amsterdam, the preliminary results are presented in a companion paper (Jaeger et al. ms).

Here we present updated data about demographic parameters and count surveys conducted in Amsterdam Island for Indian yellow-nosed albatrosses and sooty albatrosses. For the Indian Yellow-nosed Albatross, we use long term and short term demographic data to identify the stage of the breeding cycle that is the most critical for the reproductive success. Secondly, using long-term monitoring we evaluate trends in the number of breeding pairs, and variations between colonies. For the sooty Albatross, we use demographic data to describe the trends of different demographic parameters, in order to understand if the crash described succinctly by Weimerskirch (2004) for the population is confirmed.

2. METHODS

2.1 Study sites and species

Amsterdam Island is a remote volcanic island situated in the Indian Ocean (37°50'S 77°32'E), approximately between South Africa and Southwestern Australia. Indian yellow-nosed Albatross is an annual and colonial breeder (Jouventin et al. 1983). Nesting colonies are located on vegetated cliffs, and can include a few pairs to several thousands, depending on the cliff slope and vegetation. The sooty Albatross is a biennial breeder, and nests also on vegetated cliffs but in small grouped scattered in the cliffs, that include at most a few dozen pairs. These two species breed in cliffs situated on the west and south coasts of the island (Fig. 1).

Fig. 1: location of the study block and the different blocks on Amsterdam Island (from Rolland et al. 2009)

Monitoring was performed in three different blocks within the breeding area of both albatrosses named thereafter: ‘Fernand’, ‘Entrecasteaux’, and ‘Del Cano’, respectively block 1, 2, and 3 on fig. XX. These blocks can be considered geographically separated to each other, because of the relief configuration.

2.1 Indian yellow-nosed Albatross

Global counts. Photographic counts were carried out sporadically for the ‘Fernand’ block, hosting approximately two third of the total breeding population (Rolland et al. 2009). Data were available for the period 1982 to 2013 (here and thereafter, we name the fledging year as the breeding cycle, eg for breeding cycle 2012/2013: 2013). Entire island counts were done for only four breeding seasons between 1981 and 2006. All counts were carried out in late September or early October after the end of laying, at the beginning of egg incubation.

Demographic study. Located in the lower part of ‘Entrecasteaux’ block, three colonies named ‘Demography’ colonies were monitored every year since the breeding season 1986. Nests were counted, marked, and controlled in late September (early incubation), late November (end of incubation), late December (chick rearing period), mid-February (chick rearing period) and late March (just before fledging) each year. During each nest visit the nest content was recorded (empty, egg, chick).

Distant monitoring. During the breeding cycles 2008 to 2012, 20 different colonies were monitored in the 'Entrecasteaux' (n=15) and Del Cano (n=5) blocks for numbers of breeding pairs and breeding success. For each colony, the number of occupied nests was determined by distant photography of the colonies taken from a fixed point, and thus, the nest content could not be recorded. For each breeding season, nests were monitored in late November, late December, mid February, and late March. For the first two controls, the presence of a bird on a nest was considered as indicative of a breeding bird on egg or small chick respectively. Among these colonies, 5 have been were regularly visited since the late 1970s' for demographic and/or tracking studies (regular human visits during breeding phases). The other colonies were never visited. Study colonies were chosen for their different altitudes and proximity from the visited sites (Fig. 2).

Fig. 2: location of the study colonies. Doted lines indicate that the colony is visited for scientific studies. Two colonies of 'Entrecasteaux' and the five colonies of 'Del Cano' are not appearing on the photo frame.

Data analysis From the monitoring data we estimated five reproductive success values calculated at different stages of the breeding cycle. Table 1 shows the different names used for each reproductive success:

Hatching success	Number of chicks alive in late December / Number of eggs incubated in late November
Brooding success	Number of chicks alive in mid February / Number of chicks alive in late December
March success	Number of chicks alive in pre-fledging period / number of chicks alive in mid

	February
Fledging success	Number of chicks alive in pre-fledging period / number of chicks alive in late December
Global success	Number of chicks alive in pre-fledging period / number of eggs incubated in late November

The effects of year, colony, proximity (in meters) of each colony from the nearest visited colony, altitude of each colony (0 for 0-100m, 1 for 100-200m, 2 for more than 200m) and visiting status of each colony (0 for 'not visited', 1 for 'visited') were tested using Generalized Linear Models, Generalized Linear Mixed models and Kruskall-Wallis tests according to the distribution and nature of the data. The effects of the different variables were tested for each type of reproductive success.

Population growth rates (λ) were estimated using the relationship $\lambda = \left(\frac{N_t}{N_0}\right)^{\left(\frac{1}{t}\right)}$,where N_0 is the number of breeding pairs or occupied nests at the time when the first count of the period was made, N_t the number at the end of the same period (Caughley 1980).

To analyse the overall (31 years) population trend, we combined the time series with missing observations from the blocks 'Fernand', 'Entrecasteaux', and 'Del Cano', and made a log-linear regression model with Poisson error terms using the program Trends and Indices for Monitoring Data (TRIM) (Pannekoek and van Strien 1996). To obtain the overall estimated breeding numbers, we used the population size estimates obtained from the TRIM analysis. We took into account over-dispersion and serial correlation since they can have important effects on standard errors, although they have usually only a small effect on the estimates of parameters (Pannekoek and van Strien1996). No covariate was used.

2.1. Sooty Albatross

Data collection. Because of their cryptic plumage and their less gregarious behavior, sooty albatrosses are much more difficult to count and monitor in the field than Indian yellow-nosed albatrosses. Thus, long-term and year repeated photographic counts were not conducted for this species. Only two counts were carried out in 2003 (Weimerskirch, unpublished data) and in 2013 (Réserve Naturelle unpublished report).

As for the Indian yellow-nosed albatross, demographic colonies were monitored each year since the 1994 breeding season up to now. Seven colonies were visited each year just after egg-laying in mid-October, at the end of incubation in mid-December, and just before chick fledging in early April. During each nest visit the nest content was recorded (empty, egg, chick) and the number of nest on each colony was counted.

Data analysis. To analyze the overall (16 years) population trend we combined the time series of five of the seven monitored colonies since 1997 using TRIM. Indeed the prospected area changed between 1994 and 1997 and two colonies were only counted very recently and were not included.

In addition to the overall success (number of chicks produced from number of eggs laid), hatching success and fledging success were also estimated. Each reproductive success was calculated as for the Indian yellow-nosed Albatross (see table 1).

As the seven demographic colonies are arranged by order of altitude, we tested the influence of this parameter on the reproductive success of this population, using five different ranks of altitude. The effect of altitude of each colony (five ordinal ranks with relative values) was tested using Generalized Linear Models and Kruskall-Wallis tests.

3. RESULTS

3.1 Indian yellow-nosed Albatross

a. Population change

Number of breeding pairs:

Two of the three study blocks have decreased for the period 1983-2013. The steepest decline occurred in ‘Entrecasteaux’ block, where the annual mean population growth rate (λ_{83-07}) was 0.984 for the period 1983-2007, indicating an overall decline of 1.6% per year. For the same period, annual mean population growth rate for the ‘Fernand’ was similar (0.987), indicating a decline of 1.3% per year. For the period 1987-2013 the annual mean population growth rate was 0.984 for the ‘Fernand’ and 1.000 for the ‘Del Cano’ block. The ‘demography’ colony, which is a part of the ‘Entrecasteaux’ block, showed a mean annual population growth rate of 0.933 for the period 1987-2013, indicating an overall decline of 6.7% per year.

Thus our data suggest an overall decline of the number of breeding pairs, with slightly different patterns in each study block: a decrease in numbers at ‘Entrecasteaux’ and the ‘Fernand’, with a stronger decline in ‘Entrecasteaux’, and stable (but small) numbers of breeding pairs in the ‘Del Cano’ block (see fig. 3).

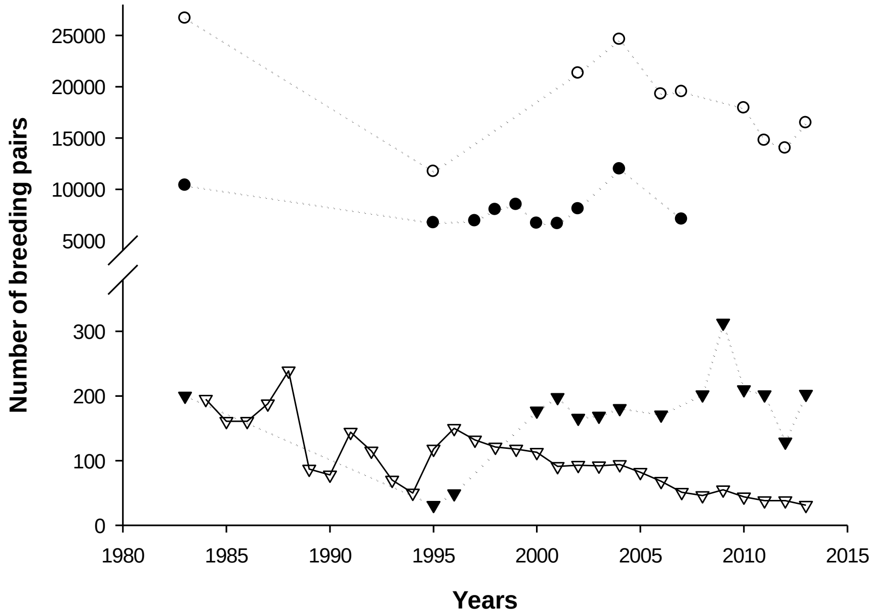

Fig. 3: annual variation of breeding pairs of Indian yellow-nosed Albatross in the three study blocks and in the 'Demography' colony. White circles: 'Fernand' block, black circles: 'Entrecasteaux' block, black triangles: 'Del Cano' block, white triangles: 'Demography colony'. Note that for the Demography colony, counts for the period 1987-1995 differ slightly from those in Rolland et al. (2009) due to the fact that a few nests outside the Demography colony were included in Rolland et al. (2009).

Using the counts data from the three different blocks and log-linear models, the average annual population growth rate was 0.989 ± 0.004 for the period 1983-2013, suggesting that the Amsterdam Island population was decreasing. This resulted in a 36.6% ± 9.5% decline between 1983 and 2013 (Fig. XX).

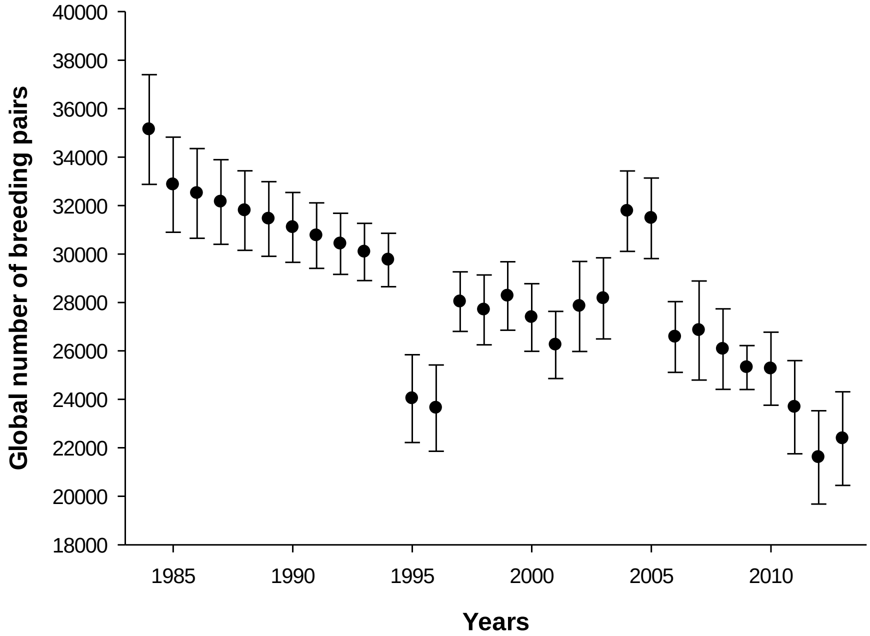

Fig. 4: Variation of the total number of breeding pairs of Indian yellow-nosed Albatross on Amsterdam Island from 1984 to 2013 estimated from counts in 'Fernand', 'Entrecasteaux', and 'Del Cano' blocks. Error bars indicate ± SE.

Reproductive success:

The mean global success calculated for the 'Demography' colony was extremely low: 0.106 ± 0.156 for the period 1987-2013. As can be seen on **fig. 5**, the global success reached zero during the breeding seasons 1999, 2004, and from 2011 to 2013, indicating that during these years, no chick reached fledging in this colony. Breeding success was low but a little higher for the 'Fernand' block with 0.221 for the 2006-2012 seasons. The 'Del Cano' block breeding success was higher again with a mean breeding success of 0.325 for the breeding seasons 2008-2012 (see table 2).

Period	Block	Mean global success	± SD
2008 to 2012	Del Cano	0,325	0,160
2008 to 2012	Fernand	0,183	0,060
2006 to 2012	Fernand	0,221	0,106

Table 2: mean global success at the 'Fernand' and 'Del Cano' blocks for different periods.

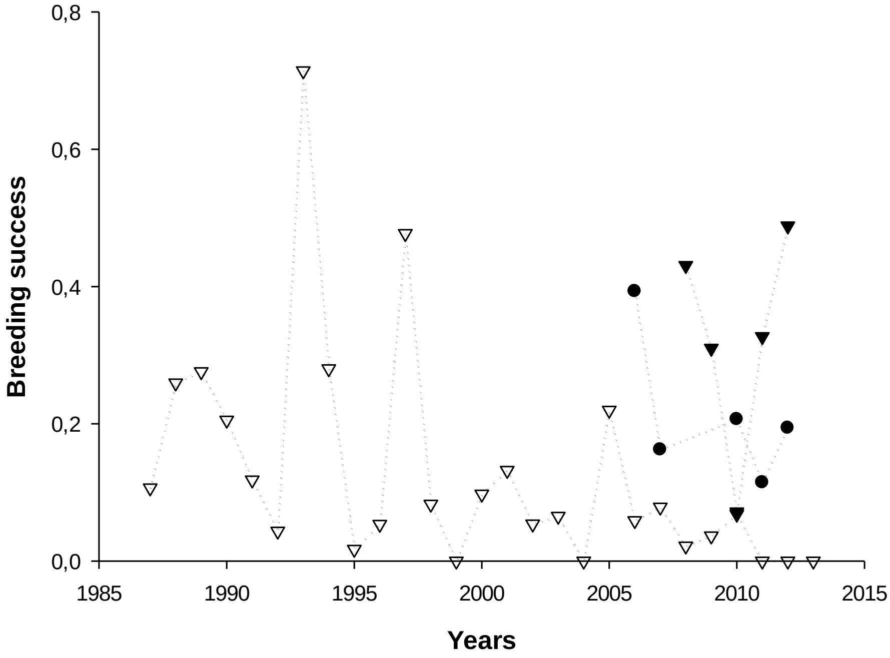

Fig. 5: variation of the global success in the 'Demography' colony (blank triangles), 'Del Cano' block (filled triangles), and the 'Fernand' block (filled circles), during the period 1987-2013.

b. Breeding stages affected

When focusing on the 'Demography' colony, where data resolution was higher for each breeding cycle, breeding failure occurred during hatching with low hatching success (see fig. 5). The major part of chick mortality occurred just after hatching.

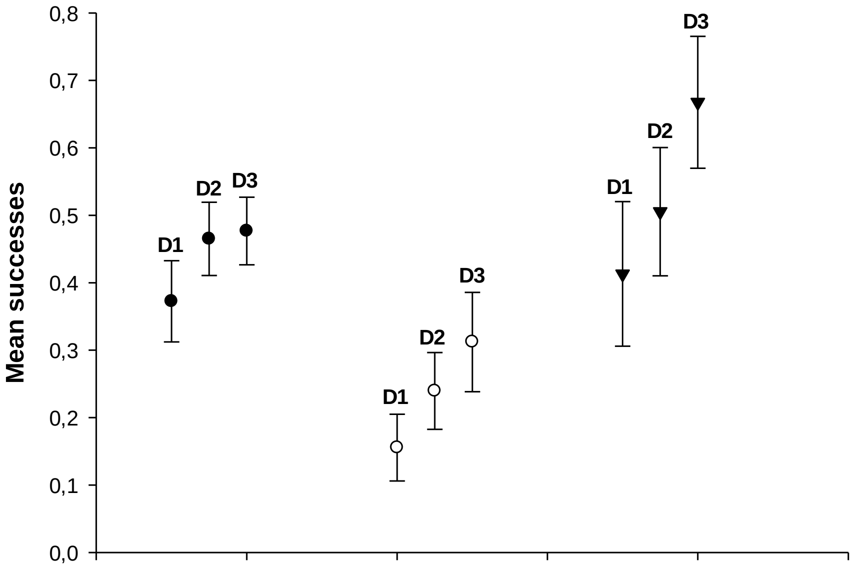

Fig. 6: mean reproductive success estimates for the breeding seasons 1987-2012 in the 'Demography' colony, divided in three sub-colonies D1, D2, and D3. Filled circles: hatching success, blank circles: chick brooding success, filled triangles: march success. Erros bars indicate ± SD.

c. Factors affecting reproductive success

Table 3: global success and tested factors for each monitored colony during the breeding seasons 2008 to 2012.

Name of the colony	Global success			Nearest visited colony (m)	Altitude ranks	Visitation status	Mean number of nests monitored each year
	Mean	± SD	Range				
Demo I	0,000	0,000	0 - 0	0	0	1	1
Demo II	0,014	0,032	0 - 0,071	0	0	1	14
Demo III	0,033	0,033	0 - 0,074	0	0	1	25
Cathédrale	0,298	0,184	0 - 0,471	250	0	0	22
E	0,333	0,577	0 - 1	47	0	0	7
F	0,043	0,075	0 - 0,130	180	1	0	43
G	0,189	0,267	0 - 0,377	103	0	0	56
B	0,333	0,577	0 - 1	130	0	0	3
H	0,115	0,163	0 - 0,231	57	1	0	26
Face cath I	0,200	0,274	0 - 0,500	110	0	0	8
Face cath II	0,410	0,354	0,024 - 0,828	110	0	0	85
Avant alim	0,048	0,067	0 - 0,095	30	1	1	19
Alim	0,145	0,175	0,021 - 0,269	20	1	1	90
Adjacente	0,097			280	1	0	355
Pignon I	0,317	0,116	0,207 - 0,477	473	2	0	69
Pignon II	0,188	0,202	0 - 0,390	442	2	0	35
Pignon III	0,206	0,152	0,052 - 0,257	437	2	0	260
Del Cano I	0,292	0,155	0,040 - 0,438	1760	1	0	112
Del Cano II	0,377	0,222	0,022 - 0,606	1760	1	0	49
Del Cano III	0,392	0,169	0,214 - 0,667	1760	1	0	33
Del Cano IV	0,449	0,395	0 - 1	1760	1	0	16
Del Cano V	0,321	0,201	0 - 0,556	1760	0	0	16
En passant	0,120	0,268	0 - 0,600	1320	0	1	4

No significant influence of altitude or distance from the nearest visited colony on the global success was detected (table 3). However, the visiting status of the colony had a significant effect on global success, the visited colonies experiencing a lower global success than colonies not visited (table 3).

We tested the influence of these three factors on mean hatching success, brooding success, March success, and fledging success. We found that altitude or distance from the nearest visited colony had no significant influence on reproductive success estimates, and only the factor visited/not visited had a significant influence on all reproductive success estimates. However, global success estimates had large variances and for colonies situated in the lower altitude class point estimates were 20 to 30% lower that those of colonies situated at higher altitudes.

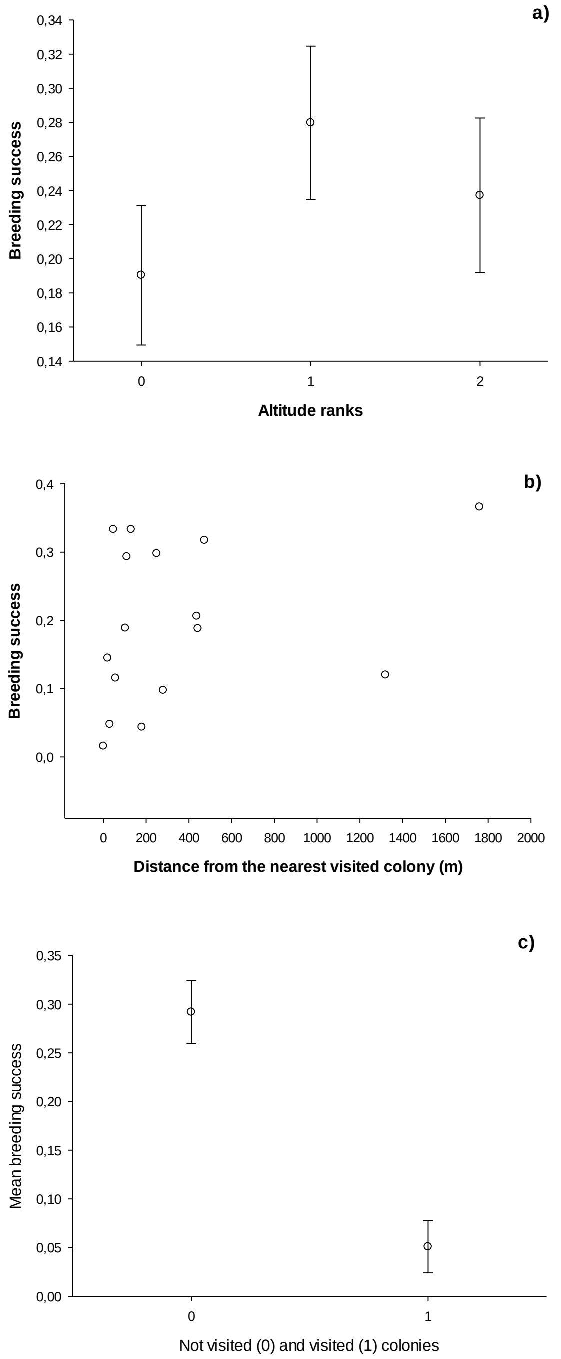

Fig. 6: global success as a function of influence of environmental parameters: a): Altitude, b): Distance from the nearest visited colony, c): Visitation status.

Variable	Effect type	df Effect	Variable Effect	p value
Altitude	Fixed	2	0,024	0,419
Proximity	Fixed	13	0,048	0,148
Visitation	**Fixed**	**1**	**1,017**	**<0,001**
Year	**Fixed**	**4**	**0,291**	**<0,001**
Colony	Ramdom	6	0,022	0,820

Table 4: ANOVA results on 5 independent variables influence on the global success. Gathering 20 colonies during the 2008-2012 breeding seasons. Significantly influent variables appear in bold.

Fig. 6 and table 4 show the result of the influence of different parameters on the global success. The analysis was performed for each breeding success separately: hatching success, chick rearing success, and chick breeding success. In each case, the only independent variables that had a significant influence on the success was the 'Visitation' variable, and the 'Year' variable. None of the three others (proximity to visited colonies, altitude, and colony), were found significantly influent in any case.

3.2. Sooty Albatross

Number of breeding pairs:

The average annual population growth rate was 0.969 ± 0.014 for the period 1997-2012, indicating that the number of breeding pairs was declining (fig. 7). The number of breeding pairs was particularly low during the period 2006-2012.

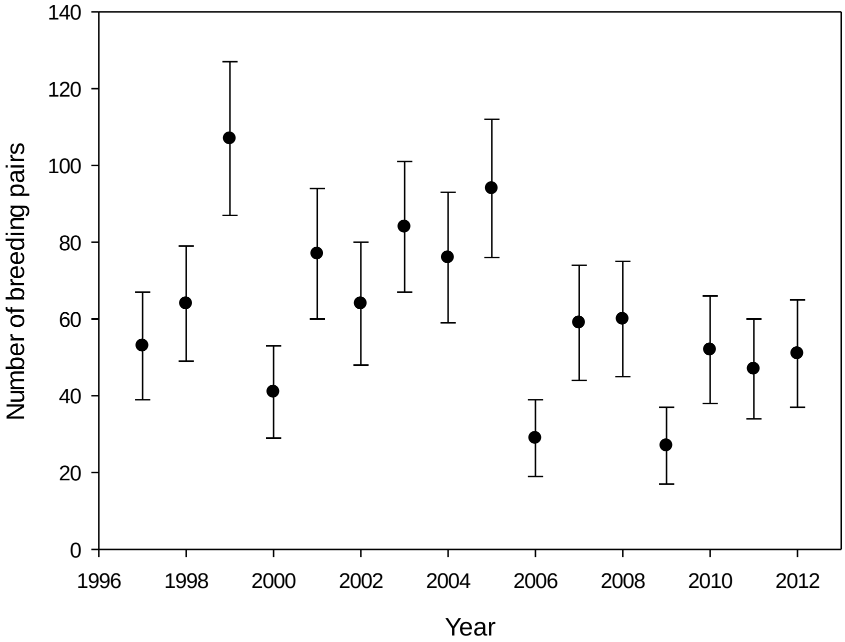

Fig. 7: variation in the total number of breeding pairs in 5 colonies of sooty Albatross for the breeding seasons 1997-2012. Error bars indicate ± SE.

Reproductive success:

The global success showed a rapid decline after the first years of monitoring, and reached zero in 2004, 2007, 2011, and 2012, indicating that no chick reached fledging in the study colony during these breeding cycles (fig.8). Mean hatching success was 0.856 for the study period, and seemed to be stable from 1995 to 2011. Therefore, and as can be noted on Fig. 8, low level and decrease in global success can be attributed to high mortality of chicks after hatching. Although data were not available between December and April, we know that most of the chick mortality occurred at young age by numerous field observations.

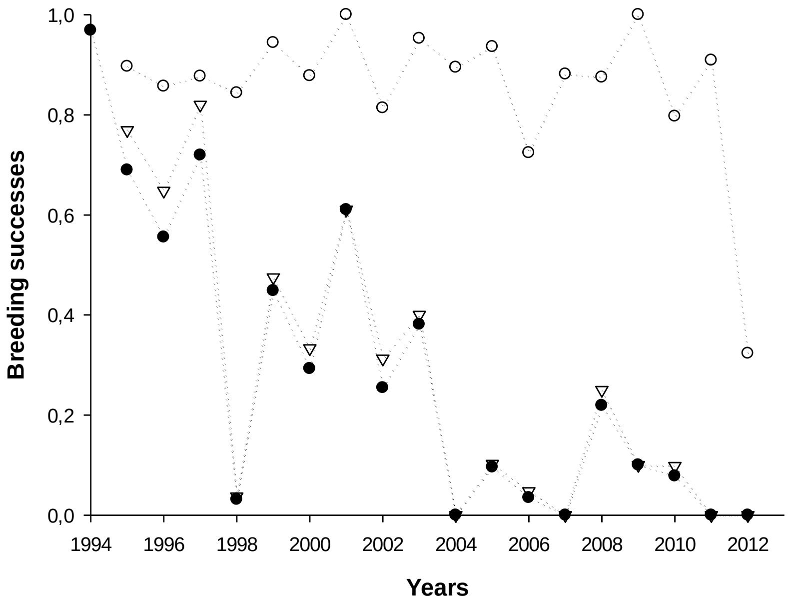

Fig 8: annual variation of the reproductive success for the sooty Albatross in the study colony. Blank circles: hatching success, blank triangles: fledging success, filled circles: global success.

Linear modeling of the trend of reproductive successes during the study period showed a significant negative trend for each success (table5).

Stage	Coefficient	±SD	p value
Hatching success	-0,013	0,004	0,002
Fledging success	-0,032	0,006	< 0,001
Global success	-0,038	0,006	<0,001

Table 5: Results of the linear regression on the breeding successes of the sooty albatross study colony during the period 1994 to 2012.

Effect of altitude:

No significant influence of altitude on the different reproductive success values was detected (table 6). However, as for yellow-nosed albatrosses, global success estimates had large variances and for colonies situated in the lower altitude class point estimates were 45% lower that those of colonies situated at higher altitudes (fig.9c). The same pattern was observed for the fledging success (fig.9b).

Stage	Chi²	df	p value
Hatching success	4,04	4	0,401
Fledging success	6,76	4	0,147
Global success	6,68	4	0,154

Table 6: results of the KW testing of the influence of altitude on reproductive successes in the sooty albatross study colonies.

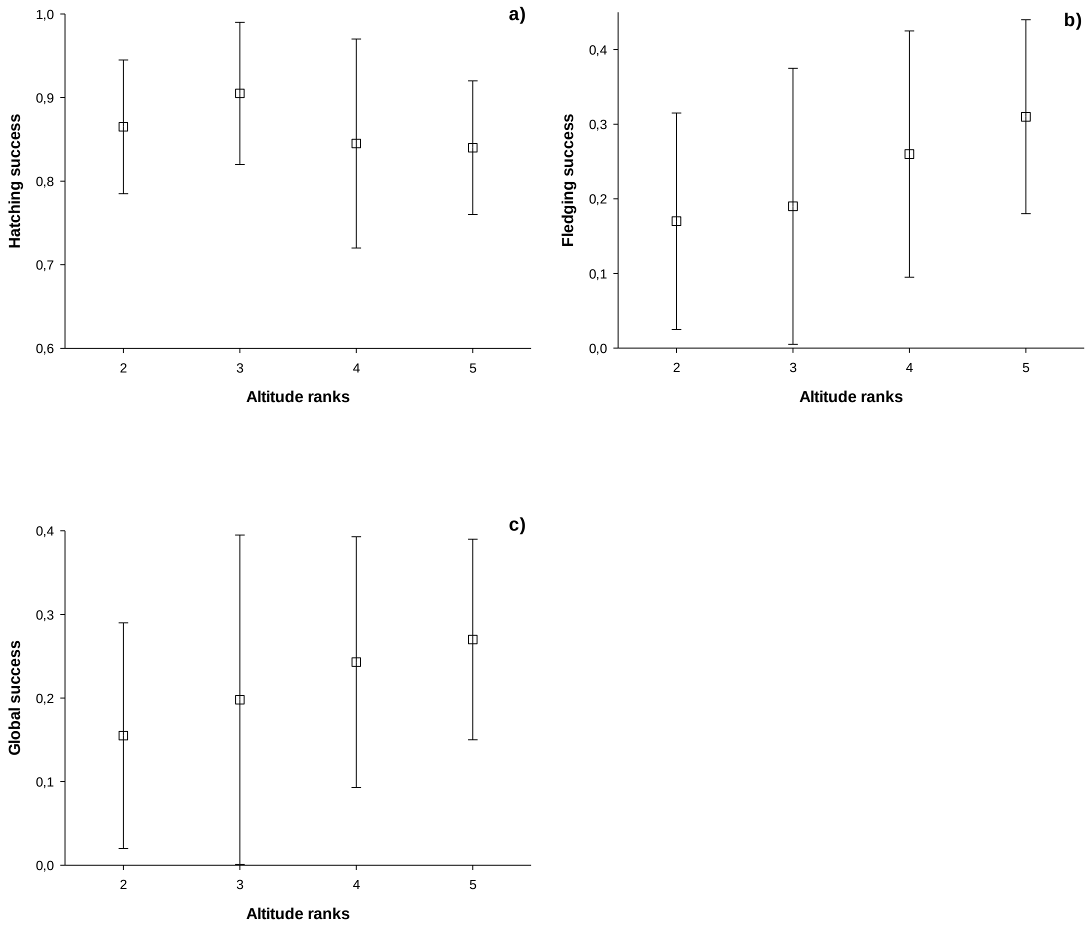

Fig. 9: variation of the a) hatching success, b) fledging success, and c) global success in response to the altitude of each colony.

4. DISCUSSION

The results of this study indicate clearly that both Indian yellow-nosed Albatross and sooty albatross populations of Amsterdam Island experienced difficult conditions over the past 30 years, and that during recent years, the situation is worsening. Indeed the largest part of the Indian yellow-nosed albatross population (Fernand) is severely declining since the mid 2000', and breeding success of both species is extremely low.

4.1. Indian yellow-nosed Albatross

If the decrease in number of breeding pairs is significant, the most worrying factor is the very low and still decreasing reproductive success observed on most parts of the island, in both species. Data were available only for the 2006-2012 period at the 'Fernand' but it is notable that the breeding success pattern is the same in this block and in the 'Demography' colony for the same period. Surprisingly, the small isolated 'Del Cano' block showed a different pattern from the two others. Low reproductive success in these two most important blocks of the island is very worrying, especially because in long-lived species with delayed maturity such as Albatrosses there is a time-lag between observed decrease in reproductive success and its repercussion on the breeding population (Nevoux et al. 2010) suggesting that the rate of decline of the population may further increase in the future with poor recruitment.

Causes of low breeding success

Since the discovery of the disease killing especially chicks (Weimerskirch 2004), observation on colonies indicated that indeed breeding failure occurred mainly and massively just after hatching. Chicks died rapidly, with symptoms corresponding to death from avian cholera, the main disease detected in earlier samples (Weimerskirch 2004). The origins of this disease are not clearly established, but it may have been introduced on the island from the poultry occurring on the island station, and secondarily introduced to the albatross colony through skuas or humans (Weimerskirch 2004).

Although the effect of altitude was not statistically significant, it does not mean that it was not biologically meaningful. Indeed point estimates of global success were much lower for colonies at low altitude compared to colonies at higher altitude, and we can not exclude that a lack of statistical power prevented us to detect a altitude effect. Therefore, the effect of altitude would need further examination with larger sample sizes.

We detected a significant negative effect of human-visitation of the global success of visited colonies. This could suggest that the disease's could be spread by human presence at these colonies. Alternatively, even if the introduction of the pathogens was not caused by human presence, the frequentation may amplify the decrease in global success. However, since most visited colonies were also at low altitude we can not exclude that the effect of the visitation status on global success was partly confounded with an altitude effect.

In addition, the successive failure of breeding attempts can lead individuals to emigrate to other colonies. Rolland et al. (2009) showed that 4% of breeders of the 'Demography' colony emigrate, while only 1.1% of the Atlantic yellow-nosed Albatross do the same in Gough Island (Cuthbert et al. 2003). As a matter of fact, infected individuals can become a vector of their own threatening pathogens.

4.2. Sooty Albatross

Data were missing to evaluate a global population trend on the entire Island. Unpublished report from the Réserve Naturelle mentioned a decrease of 17% between the 2003 and 2012 breeding seasons, but these data are two sparse (only two counts in 10 years), to propose an accurate trend for this population, especially for this biennial species. However, negative trends in both number of breeding pairs and reproductive success were evident for this species in the study colony. The very low reproductive success in recent years, reaching sometimes zero, with most of the breeders failing on very young chicks, is a evident clue that this population is facing the same threat as the Indian yellow-nosed Albatross's one.

4.2. Transmission risks between colonies and to other species

Our results suggest that visited colonies have a lower breeding success than non visited colonies, although further investigations are needed to clearly separate the effect of altitude. In view of these observations, and using a precautionary principle, strict bio security rules have been implemented since 2010 for the access to the Amsterdam albatross colony, and since 2013 for yellow-nosed and sooty albatross colonies. However, these rules may not be sufficient, since the disease is likely to occur in the large Fernand colony where human have never been able to access. One vector for the disease is likely to be subantarctic skuas *Catharacta antarctica lonnbergi*. They are foraging in all albatross colonies and make connections between infected yellow-nosed Albatross' colonies and the upland plateau of the island, where Amsterdam Albatrosses breed. Skuas are mostly scavengers and very opportunistic. At Amsterdam Island, they feed on dead fur seal pups as on fresh chicks' carcasses. Preliminary results show that skuas are carrying avian cholera (Jaeger et al. in prep). Nesting grounds of the Amsterdam skua population are situated in the upper parts of the Island, and they largely overlap the Amsterdam Albatross ones. It is then highly probable that infected skuas are frequenting the nesting grounds of the Amsterdam Albatross, and could thus become a vector of transmission of the pathogens from the Indian yellow-nosed Albatross population to the Amsterdam Albatross.

Risks for Amsterdam albatross

The rare and endemic Amsterdam Albatross *Diomedea amsterdamensis* experienced severe chick mortality in 2000 and 2001 (Rivalan et al. 2010, Weimerskirch 2004), but the chick production was again high in following years, and the responsibility of a disease in this outbreak remained uncertain. Nevertheless, physical interactions between infected birds of different species can certainly happen. The contamination of this relic population could have dramatic effects, as the death of very low number individuals per year would put the species into serious risk of extinction (Rivalan et al. 2010). So far, based on the number of breeding birds observed, the Amsterdam Albatross species growth rate was 1.049 from 1983 to 2007 (Rivalan et al. 2010), indicating an increase in the Amsterdam Albatross breeding population size during the crash observed in the Indian yellow-nosed Albatross population. Moreover, the breeding success of the species, which seems to be a good indicator of infection, is still high for the Amsterdam Albatross, with a mean annual breeding success of 0.610 (±SE = 0.026) between 1983 and 2007 (Rivalan et al. 2010). This value is not far from the breeding success reached by the wandering Albatross in Crozet (0.685 ±11.2) from 1960 to 1995 (Weimerskirch et al. 1997). However the present analyses (Jaeger et al. in prep.) indicate that the disease occurs now on this species.

Acknowledgments

We gratefully acknowledge all the wintering fieldworkers (J. Martinez, G. Jacquin, L. Daycard, B. Leroy, J.-P. Le Guillou, D. Berteaux, F. Gerard, J. Judas, P. Vallas, E. Guinard, Y. Tremblay, J.-Y. Georges, L. Zimmermann, J.-M. Salles, L. Audry, G. Beauplet, M. Ghestem, F. Le Bouard, M.-C. Martin, T. Deville, P. Thyrland, M. Authier, J.-B. Thiebot, N. Mignot, C. Alotto, C. Chauvel, L. Gaillard, B. Callard and R. Bigonneau) involved in the long-term monitoring of Indian yellow-nosed and sooty albatrosses at Amsterdam Island, and Dominique Besson and Karine Delord for their support and help in data management. This study was supported by Institut Paul Emile Victor (Program IPEV 109) and by Terres Australes et Antarctiques Françaises.

References

Cuthbert R.J., Sommer E.S., 2003. Population size and trends of four globally threatened seabirds at Gough Island, South Atlantic Ocean. Marine Ornithology 32, 97-103.

Gales, R., Brothers, N., Reid, T.A., 1998. Seabird mortality in the Japanese tuna longline fishery around Australia, 1988–1995. Biological Conservation 86, 37–56.

Guinard E., Weimerskirch H., Jouventin P., 1998. Population Changes and Demography of the Northern Rockhopper Penguin on Amsterdam and Saint Paul Islands. Colonial Waterbirds 21 (2), 222-228.

Jaeger A., Bastien M., Lebarbenchon C., Tortosa P., Thiebot J.B., Marteau C. & Weimerskirch H. in prep. Molecular detection of seven infectious agents in seabirds of Amsterdam Island.

Jouventin P., Roux J-P., Stahl J-C., Weimerskirch H., 1983. Biologie et fréquence de reproduction chez l'Albatros à bec jaune (*Diomedea chlororhynchos*). Le Gerfaut 73, 161-171

Lewison, R.L., Crowder, L.B., Read, A.J. & Freeman, S.A. 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends Ecol. Evol. 19, 598–604.

Nevoux M., Weimerskirch H., Barbraud C., 2010. Long- and short-term influence of environment on recruitment in a species with highly delayed maturity. Oecologia 162, 383–392.

Rivalan P., Barbraud C., Inchausti P., Weimerskirch H., 2010. Combined impacts of longline fisheries and climate on the persistence of the Amsterdam Albatross *Diomedia amsterdamensis*. Ibis 152, 6-18.

Rolland V., Weimerskirch H, Barbraud C., 2010. Relative influence of fisheries and climate on the demography of four albatross species. Global Change Biology 16, 1910–1922.

Rolland V., Barbraud C., Weimerskirch H., 2009. Assessing the impact of fisheries, climate and disease on the dynamics of the Indian yellow-nosed Albatross. Biological Conservation 142, 1084–1095.

Thomas N.J., Hunter D.B., Atkinson C.T., 2007. Infectious diseases of wild birds. Blackwell publishing.

Tuck, G.N., Polacheck, T., Croxall, J.P., Weimerskirch, H., 2001. Modelling the impact of fishery by-catches on albatross populations. Journal of Applied Ecology 38, 1182–1196.

Weimerskirch H., 2004. Diseases threaten Southern Ocean albatrosses. Polar Biol, 27, 374-379.

Weimerskirch H., Brothers N., Jouventin P., 1997 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. Biological conservation 79, 257-270.