Extended abstract

Demographic responses of white-chinned petrels *Procellaria aequinoctialis* and grey petrels *P. cinerea* to climate and longline fishery bycatch

by

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White-chinned petrels *Procellaria aequinoctialis* Linnaeus, 1758 and grey petrels *P. cinerea* Gmelin, 1789 are among the seabird species most frequently killed by accidental bycatch (Barnes *et al.*, 1997; Weimerskirch *et al.*, 2000; Nel *et al.*, 2002; Favero *et al.*, 2003; Delord *et al.*, 2005; Robertson *et al.*, 2006). An estimated 94% of white-chinned petrels are killed in the Kerguelen and Crozet archipelagos due to toothfish longline fisheries since 1997 (Weimerskirch *et al.*, 2000; Delord *et al.* 2005); even so, both species have received a high level of scrutiny by conservation groups (Birdlife International, 2000). Therefore, data on population sizes and dynamics are required to evaluate the impact of bycatch and to establish management plans. Several studies worldwide have documented the impact of climate on populations through local weather and large-scale climatic phenomena (Stenseth *et al.,* 2002; Dulvy *et al.,* 2008). Both climate and fisheries can affect the dynamics of marine predators; effective management actions rely on the understanding of the respective magnitude of the population-level effect of these threats and their respective effects on specific life history stages. However, very few studies have disentangled the effects of fisheries and climate on vital rates of species affected by bycatch (Nel *et al.*, 2003; Frederiksen *et al*,. 2004; Rolland *et al.*, 2008), and the direct link between fisheries and observed population declines has been hard to establish (Guenette *et al.*, 2006). Climate change may act simultaneously with fisheries on population dynamics, and for many species available demographic information is incomplete.

We used population survey data, capture-mark-recapture methods, population modelling, and the demographic invariant method to investigate the effects of climate and fisheries on the demography of white-chinned and grey petrels breeding at Crozet and Kerguelen islands (Barbraud *et al.*, 2008; Barbraud *et al.*, 2009). Specifically, our objectives were: 1) to estimate the demographic parameters and to determine the relative impact of climate and fisheries on the vital rates using a 20-year dataset of life history data of white-chinned petrels at Crozet; 2) to develop a matrix population model for this species, allowing us to explore the impact of climate and fisheries on the population rate of increase (λ); 3) to validate this model using population survey data; 4) to assess whether the additional mortality due to fisheries is sustainable or not for this population; 5) to conduct population projections with different levels of fishing effort and climate change; 6) to estimate densities and numbers of active burrows of white-chinned and grey petrels at Kerguelen islands, a major breeding locality for both species; and 7) to use these estimates, basic demographic information and the numbers caught in fisheries, to estimate the potential impact of fisheries bycatch on these populations. Methods were described in Barbraud *et al.* (2008) and Barbraud *et al.* (2009) and we only present the main results.

At Crozet, the number of breeding pairs of white-chinned petrels declined by 37.1% between 1983 and 2004, corresponding to a λ of 0.983 ± 0.001 (i.e., an average rate of decline of 1.76% per year), lower than 1 ($z = 12.16$, $P < 0.001$). Breeding success during the period 1986-2004 was 38.2% ($\pm$ 4.2), and increased nonlinearly, varying around an average of 51.4% since 1995. No climate covariate was found to affect breeding success, but fishing effort for toothfish *Dissostichus eleginoides* Smitt, 1898 had a positive effect on breeding success. Only 16 (4%) of the 401 chicks ringed since 1986 were observed as breeding recruits in the colony. Excluding the last seven years of the study for which the recruitment process was not terminated, the average return rate was 9%, and the average annual juvenile survival was low and estimated at 39.3% with a low precision (SE = 29.2%). Modelling the recapture probability indicated that it was constant across years, and high (0.826 ± 0.057, CI_{95}: 0.686 – 0.911). Local survival of adults was estimated at 0.895 ± 0.019 (CI_{95}: 0.851 – 0.928). Adult survival decreased three years after El Niño events. Fisheries covariates negatively affected recruitment probability in year t, but also in year t+1 and t+2. Most important was the effect of the toothfish fishery on the number of birds killed, with a lag of one year, which remained significant using a Bonferoni corrected P value, and which explained 53.2% of the variability in recruitment. The number of individuals killed also negatively affected the recruitment probability in year t+1 and t+2, and this effect remained nearly significant after using the Bonferoni method. Incorporating the improvement in breeding success observed since 1995 in the population model and keeping other parameter values and their variance constant, achieved $\lambda \approx 1$. Using the mean values of Southern Oscillation Index (SOI), toothfish and hake *Merluccius* spp. fishing efforts in the Benguela during the last three years of the study achieved $\lambda = 0.99$, indicating that the population is still declining at a slow rate of 1% per year. The stochastic model indicated that the projected mean λ was strongly dependent both on variations in the mean and variability of SOI with a three year lag (SOI_{-3}) and fisheries activities (Fig. 1). When fisheries are operating, λ is more sensitive to a decrease of the mean or to an increase of the variance of SOI_{-3}. It is likely that if the fisheries continue to operate at current levels the population will probably not recover unless SOI_{-3} increases significantly. If the

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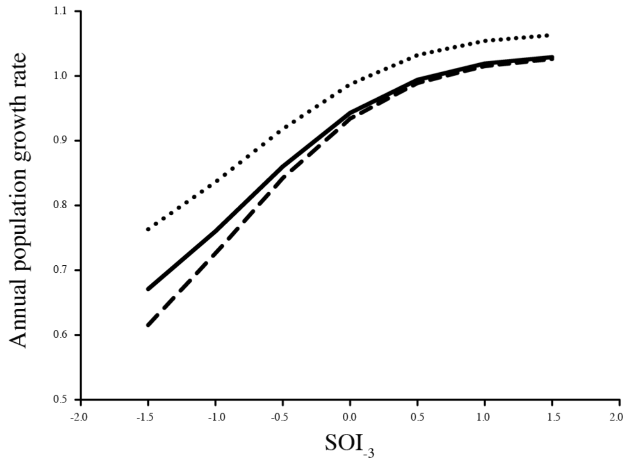

Figure 1. - Mean projected growth rate of the white-chinned petrel population in Possession Island (Crozet) from a stochastic matrix model as a function of a change in mean SOI_{-3}. Plain line indicates the current effect of fisheries, dashed line a doubling of fishing effort of both toothfish and hake fisheries, and dotted line no effect of fisheries.

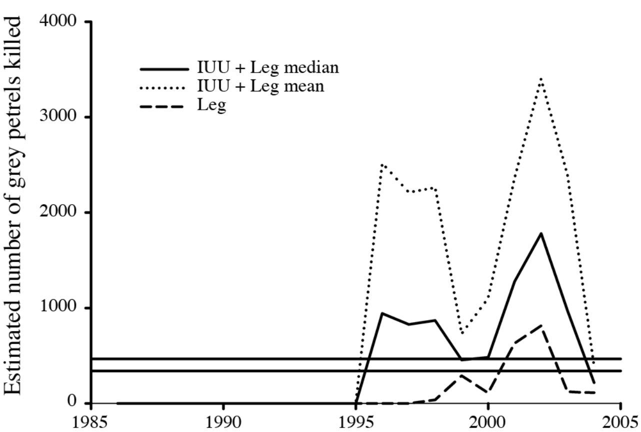

Figure 2. - Numbers of grey petrels killed by the longline toothfish fishery in the CCAMLR area 58.5. Dotted (plain) lines indicate the estimated mean (median) numbers killed by both the Illegal, Unregulated and Unreported (IUU) and legal fisheries, dashed line indicates the mean numbers killed by the legal fishery only. Horizontal plain lines indicate the potential excess growth.

fisheries continue to operate and SOI_{-3} decreases it is likely that the population will decrease dramatically. A doubling of fishing efforts would strongly impact λ for decreasing, but not increasing, values of SOI_{-3}.

At Kerguelen, estimated population sizes were 234 000 (95% confidence intervals: 186 000-297 000) active burrows for white-chinned petrels and 3 400 (1 900-5 600) for grey petrels. For white-chinned and grey petrels, maximum population growth rates were estimated 9.4% per year and 6.8% per year, respectively. Based on the estimated number of breeding pairs and on Leslie matrix models, the population sizes of grey petrels and white-chinned petrels at Kerguelen were respectively close to 19 000 (95% CI: 10 600-31 300) and 1 336 000 individuals (95% CI: 1 062 000-1 696 000). Then, any additional source of mortality that respectively approaches 300 individuals (180-530 individuals) and 31 000 individuals (25 000-40 000 individuals) for both petrels would likely result in a decline of the populations.

Bycatch data strongly suggest that the additional mortality of white-chinned petrels and grey petrels caused by the fisheries operating around Kerguelen can be considered a serious threat to both species at least at the regional scale of the Southern Indian Ocean, especially for grey petrels (Fig. 2). Numbers killed by the toothfish fishery alone during the late 1990s and early 2000s were not sustainable, but have declined since 2003. Complementary approaches suggest that longline fishery bycatch and climate had a significant impact on white-chinned petrel and grey petrel populations.

Our results suggest that both climate fluctuations and fisheries affected the population dynamics of white-chinned and grey petrels. Because of the diversity and plasticity of the foraging strategies of marine top predators at the species and population levels (Weimerskirch, 2007), more studies disentangling the effects of climate and fisheries on their dynamics are needed to understand the underlying processes. Better knowledge of the status (e.g., sex, age) and at sea distribution of individuals caught in longlines is needed to facilitate our understanding of the demographic processes involved. This additional information could be modelled together with demographic and bycatch data using Bayesian integrated population modelling that would allow efficient use of information in the data and description of uncertainty (Punt *et al*., 2001; Maunder, 2004). For both species, ours and previous studies suggest that several actions (eradication of introduced predators, reducing bycatch) may help the populations to recover in the long term, depending on the future impact of climate change.

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