Evaluating threats to New Zealand seabirds

Report for the Department of Conservation

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Cover Notes

To be cited as:

Abraham, Edward; Yvan Richard; Katherine Clements (2016). Evaluating threats to New Zealand seabirds, 19 pages. Report for the Department of Conservation.

Cover image:

https://www.flickr.com/photos/4nitsirk/16121373851

EXECUTIVE SUMMARY

The New Zealand Department of Conservation is developing a seabird threat framework, "to better understand, and manage, at-sea threats to our seabirds". This framework will allow the impact of threats on seabird populations to be qualitatively assessed, and will be used to prioritise a programme of seabird population monitoring.

As a first stage in developing the framework, a database of demographic parameters and threats was prepared. In this project, a process was established for reviewing and synthesising this information. The demographic parameters were then used to develop an online tool, which allowed for the impact of changes in parameters on population growth rates to be assessed. In the future, this tool will allow the impact of current and potential threats on seabird populations to be promptly explored.

The process was trialled on the 12 albatross taxa recognised by the New Zealand Threat Classification System: Gibson's wandering albatross (*Diomedea antipodensis gibsoni*); antipodean wandering albatross (*Diomedea antipodensis antipodensis*); southern royal albatross (*Diomedea epomophora*); northern royal albatross (*Diomedea sanfordi*); Campbell Island mollymawk (*Thalassarche impavida*); New Zealand white-capped mollymawk (*Thalassarche cauta steadi)*; Salvin's mollymawk (*Thalassarche salvini)*; Chatham Island mollymawk (*Thalassarche eremita*); grey-headed mollymawk (*Thalassarche chrysostoma*); southern Buller's mollymawk (*Thalassarche bulleri platei*); northern Buller's mollymawk (*Thalassarche bulleri bulleri*); and light-mantled sooty albatross (*Phoebetria palpebrata*).

An online survey was conducted, with 16 seabird researchers invited to review the albatross demographic data. Of these researchers, seven participated in the survey. A statistical model was then used to estimate the demographic parameters, and the population growth rate was estimated through a matrix population model. A web application was built that provides these demographic estimates as a base case, allowing the user to explore how changes to the parameters affect the population growth rate.

For most albatross species, there was a wide uncertainty, both in the demographic parameters and in the population growth rate. The growth rate of Gibson's wandering albatross was negative (a mean annual population growth of -4.7%, 95% c.i.: -9.5 to -1.0), aligning with results from more detailed modelling. The uncertainty of the growth rates of all other taxa included zero, and so this analysis could not differentiate whether or not their populations were stable. The parameters will continue to be updated as more information becomes available.

1. INTRODUCTION

New Zealand has over 90 breeding seabird taxa, with a higher number of single-country endemic seabirds than any other country (Croxall et al. 2012). A number of these taxa are critically endangered, with several species in decline (Robertson et al. 2013). Most seabirds are protected species, and the Department of Conservation (DOC) has statutory responsibilities for their management. As a signatory to international conventions such as the Agreement for the Conservation of Albatrosses and Petrels (ACAP) and the Convention on Migratory Species (CMS), New Zealand also has international obligations to conserve seabirds.

DOC is developing a seabird threat framework, "to better understand, and manage, at-sea threats to our seabirds"[1]. This framework will allow the impact of threats on seabird populations to be qualitatively assessed, and will be used to prioritise a programme of seabird population monitoring.

The first phase of the seabird threat framework has been a review of literature containing information on the demographics of New Zealand seabirds, and of threats to them. A database of demographic parameters and threats was prepared. In this report, we summarise a project that was carried out to synthesise this information, making it available through a demographic modelling website. An expert survey was used to review the demographic data. Participants were provided with the available information, and were invited to independently provide their assessment of the demographic parameters. Structured reviews, where experts are elicited for quantitative information, have been used in assessing the threat status of Australian birds (McBride et al. 2012). We asked the experts to contribute the information independently, avoiding the dynamics of meetings, where individuals can dominate, and asked that they evaluate the uncertainty in the parameters (Burgman et al. 2011, Martin et al. 2012).

We developed an online application to allow users to assess how changes in demographic parameters affect changes in seabird populations. This application allowed the experts to evaluate how the demographic parameters influenced population trajectories. The application will be used to assess how changes in demographic parameters, representing the action of threats to seabirds, influence the populations.

In this project, the process was trialled on the 12 albatross taxa recognised by the New Zealand Threat Classification System (Robertson et al. 2013): Gibson's wandering albatross (*Diomedea antipodensis gibsoni*); antipodean wandering albatross (*Diomedea antipodensis antipodensis*); southern royal albatross (*Diomedea epomophora*); northern royal albatross (*Diomedea sanfordi*); Campbell Island mollymawk (*Thalassarche impavida*); New Zealand white-capped mollymawk (*Thalassarche cauta steadi)*; Salvin's mollymawk (*Thalassarche salvini)*; Chatham Island mollymawk (*Thalassarche eremita*); grey-headed mollymawk (*Thalassarche chrysostoma*); southern Buller's mollymawk (*Thalassarche bulleri platei*); northern Buller's mollymawk (*Thalassarche bulleri bulleri*); and light-mantled sooty albatross (*Phoebetria palpeb-*

[1]http://www.doc.govt.nz/our-work/seabird-prioritisation-framework/

rata).

2. METHODS

2.1 Estimating population growth rate

The seabird population growth rate was estimated using a simple matrix model (Caswell 2001), chosen so that the parameters can be estimated for a wide range of taxa. Birds are either in immature age-classes, I, or are adult, A, with the transition from immature to adult happening deterministically at the age at first breeding, AFR. The matrix model has $AFR - 1$ immature states, and a single adult state, with the demographic parameters specifying the annual transitions between them (Figure 1). The annual adult survival rate is S_A and the annual survival rate of immature birds is S_I. The proportion of fledglings that recruit into the breeding population is S_I^{AFR-1}. For each adult, the annual number of fledglings is half of the product of the proportion of adults breeding, P_B; the clutch size (CS, eggs laid by a breeding pair in a breeding season); and the breeding success (BS, the proportion of eggs laid that survive to fledging). For the albatross considered here the clutch size is one ($CS = 1$), but other seabirds may have larger clutches.

The parameter values were assumed to represent population average values. Variation between individuals, or between years, was not represented. For a given set of parameter values, the annual population growth rate was estimated from the largest eigenvalue of the associated population matrix (Caswell 2001). Uncertainty in the growth rate was estimated by drawing samples from the distribution of demographic parameters, and calculating the growth rate independently for each sample.

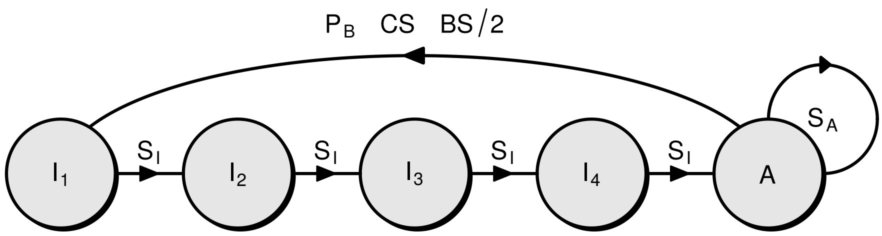

Figure 1: State transitions in a model of seabird demographics, with an age at first breeding (AFR) of five years. The model has four immature year classes (I_1, I_2, I_3, I_4) and an adult state, A. Each year, a proportion S_I of immature birds survive and a proportion S_A of adult birds survive. For each adult in the population, $P_B \times CS \times BS/2$ fledglings are produced each year, where P_B is the proportion of adults that breed; CS is the clutch size; and BS is the breeding success.

2.2 Estimating input parameters

A literature review was carried out to search for field data and analyses that could be used to help specify the demographic parameters. A wide range of published and unpublished literature (including scientific papers, government reports, and academic theses) was collated. The relevant parameters were extracted from the reports and saved into a Microsoft Access database, developed by DOC. The database includes information on seabird literature, threats, and demographic parameters.

A two-step Delphi survey (Martin et al. 2005) was then used to ask seabird researchers to interpret these parameters. A total of 16 researchers were asked to participate in the review. A website was established which contained parameters from the literature review and database, as well as background text by Taylor (2000a) and Taylor (2000b). The survey was restricted to the twelve albatross recognised by the New Zealand Threat Classification System (Robertson et al. 2013). Interpretation of the data is required, as direct estimates of population parameters from field data may be biased. For example, in a study of Gibson's wandering albatross, Dillingham et al. (2012) noted that estimates of the age at first breeding may be biased low if birds are not followed for a sufficient period of time, and that this bias can result in an over-estimate of the population growth rate.

For each taxon, participants were asked to estimate the adult survival; juvenile survival; average age of first breeding; current population size (number of breeding pairs); annual probability of breeding of adults; and breeding success (defined as the percentage of eggs laid that result in a fledged chick). For each of these questions, participants were asked to enter an upper and a lower bound, representing a 95% confidence interval. For albatross, the clutch size is one, and so the answers to these questions are sufficient to parameterise the demographic model (Figure 1).

In addition, participants were presented with distribution maps used by Richard & Abraham (2015), and asked (through a "yes" or "no" question) whether the distribution was adequate for assessing threats to the taxon. A process to evaluate spatial distributions in more detail is being developed by DOC, using its seabird SeaSketch project[2].

The present survey also included a list of threats, and participants were asked to select the threats "that, if not actively managed, would result in a change of the species' conservation status over the next 20 years". This information will be used to prioritise evaluation of the threats. Finally, participants were asked whether they had any additional information.

We used a Bayesian hierarchical framework to estimating consensus from multiple expert opinions (i.e., a supra-Bayesian approach, Jacobs 1995). This method is similar to the method developed by Lipscomb et al. (1998), who applied a Bayesian hierarchical model for expert opinion to improve physician staffing in care centers. We assumed that individual expert answers were a sample from an underlying consensus distribution of

[2]http://seabirds.seasketch.org/

Table 1: Description of survey questions about seabird demography and threats to seabirds, as presented to participants in the second round of the Delphi survey.

Adult survival Please estimate the annual survival of adults, expressed as the percentage of all adults that survive each year. Where survival has been changing, consider the period 2010 to 2015. Please specify the 95% confidence interval of your estimate. The answer is intended to represent typical adult survival of the whole New Zealand population.

Juvenile survival Please estimate the survival of juveniles, expressed as the percentage of all juveniles (birds between fledging and first breeding) that survive from fledging to mean age at first breeding. For example, if a species has a mean age at first breeding of six years, and 10% of the juveniles die each year, then the juvenile survival will be 59% (as 59% survive the 5-year period between fledging and the mean age at first breeding). Note that this estimate may be different from how you answered in the first round.

Average age of first breeding Please estimate the average age (in years) of first breeding. If this age has changed, consider the period 2010 to 2015. Specify the 95% confidence interval of your estimate. This interval is intended to represent uncertainty in knowledge of the average age at first breeding of the population, rather than variation in age at first breeding between individuals. Where this estimate has been changing, consider the period 2010 to 2015.

Current population Please estimate the current population, expressed as the number of annual breeding pairs in the New Zealand region, at all breeding sites. Please specify the 95% confidence interval of your estimate.

Annual probability of breeding Please specify the annual breeding probability, interpreted as the average percentage of adults that breed in each season (over the period 2010 to 2015). Please specify the 95% confidence interval of your estimate.

Breeding success Please estimate the breeding success, defined as the percentage of eggs laid that result in a fledged chick. Consider the period 2010 to 2015, or most recent. Please specify the 95% confidence interval of your estimate.

Distribution The maps shown are from the seabird risk assessment (Richard & Abraham 2015), and indicate the New Zealand distribution in the breeding and non-breeding season (where applicable). They are derived from a combination of NABIS, satellite tracking data (where that is available), and heuristic rules that increase the number of birds near breeding colonies. Please indicate whether these maps are an adequate description of current knowledge of the New Zealand distribution.

Threats Please select all threats that, if not actively managed, would result in a change of the species' conservation status over the next 20 years.

expert opinions. This assumption allowed us to employ a hierarchical model structure for the questions, and use Bayesian methods to estimate the parameters of the consensus distribution. This approach is akin to conducting a formal meta-analysis of separate studies, each of which lead to an estimate about some quantity (the expert opinion), along with a measure of uncertainty (the expert's uncertainty). To make predictions based on the expert consensus, we drew samples from the posterior predictive distribution, which can be interpreted as predictions from the expert consensus for each question. This prediction integrates over uncertainty in the consensus distribution parameters. All analyses were performed in the R language for statistical computing (R Development Core Team 2008), with Bayesian models run using the rjags package for the Bayesian estimation software JAGS (Just Another Gibbs Sampler) (Plummer 2005).

Having derived consensus answers, they were then used to derive population growth estimates. Participants were invited to a workshop to discuss the results. This workshop allowed participants to discuss any discrepancies in the interpretation of the questions, and to discuss how the demographic parameters influenced the population growth rates. Immature survival was initially requested as annual survival, however there was confusion among the participants over the interpretation of this parameter. Following discussion, it was decided to specify this parameter as cohort survival (the percentage of fledglings that survive until breeding). To specify the matrix model, this parameter was transformed into an annual immature survival assuming that the cohort survival represented survival of immature birds to the age at first breeding.

2.3 Online seabird demographic application

A web application was built to allow exploration of the impacts of changes in demographic parameters on the population growth rate, using the software Shiny (Chang et al. 2015). The web application allowed users to specify the demographic parameters that are needed for the matrix population model (Figure 1), corresponding with the questions asked in the expert survey (Table 1). The application was initialised with the results from the expert survey, so that a visitor to the web application can select these parameters for each of the twelve albatross. (Source code for the application is available at GitHub[3]. The code can be downloaded and run on computers that have R installed. The source code is openly licensed so that anyone is able to download, modify, and adapt the code, provided only that credit is given.)

The demographic parameters were specified through 95% quantiles, and distributions of population parameters (including population growth rate) were then derived by drawing samples from these distributions and using them to parameterise the matrix model (Figure 1). Distributions were derived for the number of immature birds, the number of adults, the total number of individual, the population growth rate, the annual fatalities of adults, and the annual fatalities of immature birds. These last values give a

[3]https://github.com/dragonfly-science/seabird-threats-shiny

context to fatalities that are estimated to occur from sources such as fisheries bycatch.

Specifying the demographic parameters sets up a base-case population, users of the web application are then able to explore the impact of removing existing threats, or adding potential future threats, on the population. The threats are represented as changes to the demographic parameters, specified either as a change in the parameter or the annual addition or removal of a number of individuals. For example, fisheries bycatch may impact adult survival and a reduction in fisheries bycatch can be represented as an increase in adult survival.

3. RESULTS

3.1 Survey

Of the 16 people invited to participate in the expert review, there were seven experts who took part in the survey. Response rates varied from respondents who answered 12 individual questions (primarily relating to a single taxon), to one respondent who answered 96 questions across the all the albatross. Overall, not considering the questions inviting other information, there was a total of 96 questions on albatross demographic parameters and threats. In the first round, each of these questions was answered by at least one person: 18 questions were answered by one person, 36 questions were answered by two people, 31 questions were answered by three people, ten questions were answered by four people, and one question was answered by five people.

A workshop was held after the completion of the first round. The online tool was presented, showing what the assessed parameters implied for albatross growth rate. Discussion during the workshop showed that there had been a misunderstanding about the interpretation of immature survival. Some participants had interpreted the parameter as annual survival (which was the intended meaning of the parameter), while others had interpreted it as survival from fledging to first return or first breeding. Following discussion, it was decided to ask for information on juvenile survival as cohort survival, from fledging to first breeding. Cohort survival can be more directly assessed from field data, whereas estimating annual immature survival requires statistical analysis.

Following the workshop, participants were invited to update their responses, through a second round to the Delphi survey. There was low participation in the second round of the Delphi survey, with only two participants updating their responses.

Following the second round, consensus estimates were prepared. Because of the limited response to the second round, estimates of immature cohort survival were modified outside of the survey process. The 95% confidence interval of immature cohort survival was set to 24–34% for antipodean and Gibson's wandering albatross (Francis et al. 2015); 0.32–0.39% for southern royal albatross (Moore et al. 2013); 0.5–0.8% for northern royal albatross

(Richard et al. 2015); and 0.15–0.4% for all other mollymawk taxa (Francis & Sagar 2012, Waugh et al. 1999). Some upper bounds of adult survival had been set at 100%. These bounds were adjusted to 99%, as an adult survival of 100% is not biologically plausible.

A summary of the estimated demographic parameters, and of quantities derived from the matrix model, are given in the appendix (Table A-1).

3.2 Population growth rates

Included among the quantities derived from the estimated demographic parameters are the population growth rates (Table A-1, Figure 2). These growth rates had broad uncertainty, and for all albatross other than Gibson's wandering albatross their range overlapped with zero (indicating a stable population). The value for Gibson's wandering albatross was consistent with recent modelling, which estimated that Gibson's wandering albatross are declining by 5.7% per year (Francis et al. 2015).

Chatham Island mollymawk were estimated to have a low mean population growth rate of -4.5% per year (Table A-1). This estimate contrasts with the perception based on population census data that the population is stable (Agreement on the Conservation of Albatrosses and Petrels 2010) or increasing (Birdlife International 2016). The low population growth rate is influenced by a low estimated adult survival of 88.7% (95% c.i.: 80.6–94.0%). This value was the lowest estimated adult survival of any of the albatross, and was influenced by the estimate of adult survival of 86.8% (95% c.i.: 84.0–89.2%), based on data from 1974 to 2001 (Robertson et al. 2003). As these data

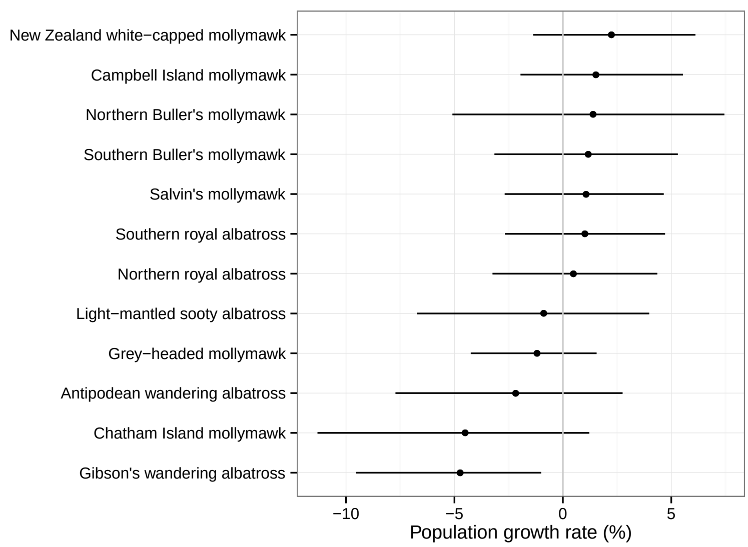

Figure 2: Population growth rates of albatross, derived from estimated demographic parameters. For each taxa, the dot indicates the mean of the annual population growth rate, λ, and the line shows the 95% credible interval.

were collected via mark-recapture, the survival estimates may be biased low if there was tag-loss, or if animals moved away from the study site.

Surveys of antipodean wandering albatross have documented declines in the population in study colonies, with declines in both adult survival and breeding success (Elliott & Walker 2014). The rate of decline in the number of breeding birds in the study area, between 2004 and 2014, was estimated as -7% per annum. This value was at the lower end of the credible interval of population growth rates estimated from the demographic parameters (Table A-1).

For all other albatross, the annual population growth rate was within the range -1.5 to 2.2%. Surveys of southern Buller's mollymawk at Snares Islands indicate that the number of breeding pairs was stable (varying by less than 2% between 2002 and 2014, Sagar 2014). Photographic surveys of New Zealand white-capped mollymawk at Auckland Islands show large inter-annual variability in the number of breeding pairs. Between 2006 and 2015, a linear regression found a population decline of -1.73% per year (Baker et al. 2015); however because of the inter-annual variability the authors concluded that there was "insufficient evidence to reject the null hypothesis of no trend in the total population".

3.3 Threats

Participants were presented with a list of threats and asked to "select all threats that, if not actively managed, would result in a change of the species' conservation status over the next 20 years" (a summary of the responses is given in the appendix, Table A-2). The five threats that were selected by the most respondents, across all 12 albatross, were all fishing related. In decreasing order of the total number of respondents, these threats included international fishing, New Zealand commercial surface longline, indirect effects of fishing, New Zealand commercial trawl, and New Zealand commercial bottom longline. Respondents were not asked to rank threats, or to quantify the potential impact of the threats.

4. DISCUSSION

For this project, we developed a database of demographic estimates, a process for synthesising those estimates, and a method for inferring a population growth rate from the demographic parameters. The results were used to provide a base case for an online application. This application calculated the population growth rate as the distributions of the demographic parameters are changed, allowing prompt exploration of the relationships between demographic parameters and populations. Given a plausible base case for the population, the impact of current and potential threats can be explored. The online application allows, for example, an exploration of the relative impacts of threats that affect adult survival (such as fisheries bycatch) and threats that affect breeding success (such as ecosystem effects).

The Delphi process allowed experts to contribute their information independently. In addition, the experts were able to participate in the survey remotely. Although there was adequate participation in the first round, participation in the second round was low. The project was intended as a trial, and so less effort was put into coordinating the second round. Reading the information and answering eight questions about twelve taxa was time-consuming, and respondents generally did not complete the survey a second time. In the future, the online survey will allow subsequent rounds to be carried out, so that the demographic parameters can be updated as new information becomes available, or if participants believe their responses should be modified. Before further use of the survey, we recommend that a process is established to improve the response rate of participants.

We used a simple matrix model to estimate population sizes and growth rates for the albatross from the demographic parameters. From a population modelling point of view, this approach is simplistic. For example, an important assumption of the matrix modelling is that the population age-structure is at a steady state. For long-lived species, such as albatross, changes in demographic parameters will cause changes in the population that take a long time to stabilise, and this timeframe is not reflected in the analysis presented here. The matrix modelling was suitable for prompt exploration of the consequences of changing demographic parameters. For other applications, however, more sophisticated approaches may be appropriate (e.g., Francis 2012, Richard et al. 2015, Francis et al. 2015).

5. ACKNOWLEDGMENTS

We are grateful to the expert participants in the review (Barry Baker, Mike Bell, Lorna Deppe, Graeme Elliott, Lyndon Perriman, Paul Sagar, and David Thompson) for contributing their time and expertise. Thanks are also due to Katrin Berkenbusch for proof-reading the draft report.

This project ("Seabird Framework 2014–15") was funded by the Department of Conservation. Particular thanks to Igor Debski of the Department of Conservation for managing this project.

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A. APPENDIX

Table A-1: Summary of the distribution of population parameters from the expert survey, and derived through the matrix model for the 12 albatross taxa included in the present study. For each parameter, the table gives the mean and 95% credible interval. Population parameters include the age at first breeding (years), immature cohort survival (%), immature annual survival (%, derived), adult annual survival (%), breeding success (%), breeding probability (%), number of breeding pairs, number of immatures (derived), number of adults (derived); total number of individual birds (derived), annual population growth rate (%, derived), annual adult fatalities (derived), and annual immature fatalities (derived).

Taxon	Parameter	Mean	95% c.i.
Northern Buller's mollymawk	First breeding age	10.0	4.0 – 20.0
Northern Buller's mollymawk	Immature cohort survival (%)	26.2	15.2 – 39.9
Northern Buller's mollymawk	Immature annual survival (%)	86.5	81.8 – 90.7
Northern Buller's mollymawk	Adult annual survival (%)	95.8	89.6 – 98.9
Northern Buller's mollymawk	Breeding success (%)	47.3	27.9 – 67.2
Northern Buller's mollymawk	Breeding probability (%)	86.9	70.8 – 96.0
Northern Buller's mollymawk	Breeding pairs	17 991	10 569 – 26 658
Northern Buller's mollymawk	No. immatures	43 542	16 476 – 87 775
Northern Buller's mollymawk	No. adults	41 616	24 251 – 63 867
Northern Buller's mollymawk	Total individuals	85 158	45 288 – 143 953
Northern Buller's mollymawk	Growth rate (%)	1.4	-5.1 – 7.4
Northern Buller's mollymawk	Adult fatalities	1 718	371 – 4 590
Northern Buller's mollymawk	Immature fatalities	5 833	2 063 – 11 566
Antipodean wandering albatross	First breeding age	12.0	6.0 – 21.0
Antipodean wandering albatross	Immature cohort survival (%)	29.0	24.3 – 34.1
Antipodean wandering albatross	Immature annual survival (%)	89.4	88.0 – 90.8
Antipodean wandering albatross	Adult annual survival (%)	91.8	82.2 – 97.1
Antipodean wandering albatross	Breeding success (%)	62.7	47.1 – 76.2
Antipodean wandering albatross	Breeding probability (%)	48.9	25.7 – 72.2
Antipodean wandering albatross	Breeding pairs	4 270	2 522 – 6 793
Antipodean wandering albatross	No. immatures	20 226	8 835 – 40 066
Antipodean wandering albatross	No. adults	18 836	8 725 – 39 296
Antipodean wandering albatross	Total individuals	39 063	19 074 – 73 425
Antipodean wandering albatross	Growth rate (%)	-2.2	-7.7 – 2.8
Antipodean wandering albatross	Adult fatalities	1 544	402 – 3 932
Antipodean wandering albatross	Immature fatalities	2 133	913 – 4 226
Campbell Island mollymawk	First breeding age	10.0	6.0 – 15.0
Campbell Island mollymawk	Immature cohort survival (%)	26.1	15.2 – 39.6
Campbell Island mollymawk	Immature annual survival (%)	86.2	81.5 – 90.4
Campbell Island mollymawk	Adult annual survival (%)	95.3	93.0 – 97.0
Campbell Island mollymawk	Breeding success (%)	59.3	42.5 – 74.2
Campbell Island mollymawk	Breeding probability (%)	88.6	81.3 – 93.7
Campbell Island mollymawk	Breeding pairs	23 680	15 620 – 36 087
Campbell Island mollymawk	No. immatures	71 052	36 673 – 121 577
Campbell Island mollymawk	No. adults	53 481	34 929 – 80 478
Campbell Island mollymawk	Total individuals	124 533	74 857 – 193 542
Campbell Island mollymawk	Growth rate (%)	1.5	-2.0 – 5.5
Campbell Island mollymawk	Adult fatalities	2 497	1 350 – 4 320
Campbell Island mollymawk	Immature fatalities	9 759	4 814 – 17 392
Chatham Island mollymawk	First breeding age	8.0	5.0 – 13.0
Chatham Island mollymawk	Immature cohort survival (%)	26.0	15.1 – 39.5

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Table A-1 – Continued from previous page

Taxon	Parameter	Mean	95% c.i.
Chatham Island mollymawk	Immature annual survival (%)	82.8	77.1 – 88.0
Chatham Island mollymawk	Adult annual survival (%)	88.7	80.6 – 94.0
Chatham Island mollymawk	Breeding success (%)	46.3	30.8 – 62.7
Chatham Island mollymawk	Breeding probability (%)	77.3	61.8 – 88.9
Chatham Island mollymawk	Breeding pairs	4 885	3 400 – 6 524
Chatham Island mollymawk	No. immatures	11 426	5 545 – 20 636
Chatham Island mollymawk	No. adults	12 770	8 570 – 18 307
Chatham Island mollymawk	Total individuals	24 196	15 324 – 37 042
Chatham Island mollymawk	Growth rate (%)	-4.5	-11.3 – 1.2
Chatham Island mollymawk	Adult fatalities	1 444	661 – 2 743
Chatham Island mollymawk	Immature fatalities	1 953	882 – 3 759
Southern royal albatross	First breeding age	13.0	8.0 – 21.0
Southern royal albatross	Immature cohort survival (%)	35.4	32.1 – 38.9
Southern royal albatross	Immature annual survival (%)	91.8	91.1 – 92.5
Southern royal albatross	Adult annual survival (%)	95.6	91.9 – 98.0
Southern royal albatross	Breeding success (%)	55.6	27.0 – 81.7
Southern royal albatross	Breeding probability (%)	59.6	42.6 – 74.5
Southern royal albatross	Breeding pairs	5 325	3 703 – 7 620
Southern royal albatross	No. immatures	21 908	9 685 – 41 780
Southern royal albatross	No. adults	18 264	11 519 – 29 931
Southern royal albatross	Total individuals	40 172	22 587 – 65 218
Southern royal albatross	Growth rate (%)	1.0	-2.7 – 4.7
Southern royal albatross	Adult fatalities	796	312 – 1 675
Southern royal albatross	Immature fatalities	1 793	768 – 3 443
Gibson’s wandering albatross	First breeding age	12.0	7.0 – 20.0
Gibson’s wandering albatross	Immature cohort survival (%)	28.8	24.1 – 34.0
Gibson’s wandering albatross	Immature annual survival (%)	89.7	88.4 – 91.0
Gibson’s wandering albatross	Adult annual survival (%)	89.7	81.9 – 94.7
Gibson’s wandering albatross	Breeding success (%)	39.5	27.0 – 53.7
Gibson’s wandering albatross	Breeding probability (%)	53.6	40.5 – 66.9
Gibson’s wandering albatross	Breeding pairs	4 351	2 714 – 6 666
Gibson’s wandering albatross	No. immatures	15 485	7 084 – 29 275
Gibson’s wandering albatross	No. adults	16 510	9 510 – 26 557
Gibson’s wandering albatross	Total individuals	31 995	17 937 – 52 982
Gibson’s wandering albatross	Growth rate (%)	-4.7	-9.5 – -1.0
Gibson’s wandering albatross	Adult fatalities	1 695	684 – 3 554
Gibson’s wandering albatross	Immature fatalities	1 590	701 – 3 039
Northern royal albatross	First breeding age	9.0	5.0 – 16.0
Northern royal albatross	Immature cohort survival (%)	35.1	25.7 – 45.4
Northern royal albatross	Immature annual survival (%)	87.6	84.3 – 90.6
Northern royal albatross	Adult annual survival (%)	96.0	93.1 – 98.0
Northern royal albatross	Breeding success (%)	42.7	22.0 – 65.0
Northern royal albatross	Breeding probability (%)	58.1	45.8 – 69.6
Northern royal albatross	Breeding pairs	5 632	3 959 – 7 793
Northern royal albatross	No. immatures	12 075	4 882 – 23 646
Northern royal albatross	No. adults	19 609	13 110 – 28 665
Northern royal albatross	Total individuals	31 684	19 712 – 49 351
Northern royal albatross	Growth rate (%)	0.5	-3.2 – 4.4
Northern royal albatross	Adult fatalities	775	344 – 1 463
Northern royal albatross	Immature fatalities	1 493	594 – 2 991

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Table A-1 – Continued from previous page

Taxon	Parameter	Mean	95% c.i.
Grey-headed mollymawk	First breeding age	12.0	8.0 – 18.0
Grey-headed mollymawk	Immature cohort survival (%)	25.9	14.9 – 39.7
Grey-headed mollymawk	Immature annual survival (%)	88.3	84.2 – 92.0
Grey-headed mollymawk	Adult annual survival (%)	94.9	92.0 – 97.1
Grey-headed mollymawk	Breeding success (%)	42.7	30.1 – 56.9
Grey-headed mollymawk	Breeding probability (%)	60.1	42.6 – 75.5
Grey-headed mollymawk	Breeding pairs	7 793	5 062 – 11 367
Grey-headed mollymawk	No. immatures	22 431	11 253 – 38 321
Grey-headed mollymawk	No. adults	26 490	15 866 – 42 616
Grey-headed mollymawk	Total individuals	48 921	28 436 – 75 944
Grey-headed mollymawk	Growth rate (%)	-1.2	-4.2 – 1.6
Grey-headed mollymawk	Adult fatalities	1 346	602 – 2 636
Grey-headed mollymawk	Immature fatalities	2 602	1 300 – 4 553
Light-mantled sooty albatross	First breeding age	11.0	6.0 – 20.0
Light-mantled sooty albatross	Immature cohort survival (%)	26.3	15.0 – 39.9
Light-mantled sooty albatross	Immature annual survival (%)	87.6	83.2 – 91.5
Light-mantled sooty albatross	Adult annual survival (%)	95.9	88.8 – 98.9
Light-mantled sooty albatross	Breeding success (%)	35.2	9.1 – 72.6
Light-mantled sooty albatross	Breeding probability (%)	59.7	43.9 – 75.0
Light-mantled sooty albatross	Breeding pairs	1 273	661 – 2 272
Light-mantled sooty albatross	No. immatures	2 736	594 – 7 286
Light-mantled sooty albatross	No. adults	4 359	2 142 – 8 242
Light-mantled sooty albatross	Total individuals	7 095	3 194 – 14 100
Light-mantled sooty albatross	Growth rate (%)	-0.9	-6.7 – 4.0
Light-mantled sooty albatross	Adult fatalities	179	36.0 – 592
Light-mantled sooty albatross	Immature fatalities	335	68.0 – 870
Southern Buller's mollymawk	First breeding age	12.0	7.0 – 18.0
Southern Buller's mollymawk	Immature cohort survival (%)	26.2	15.9 – 39.4
Southern Buller's mollymawk	Immature annual survival (%)	88.2	84.4 – 91.8
Southern Buller's mollymawk	Adult annual survival (%)	93.9	88.7 – 96.9
Southern Buller's mollymawk	Breeding success (%)	71.1	55.3 – 83.9
Southern Buller's mollymawk	Breeding probability (%)	85.3	78.3 – 91.0
Southern Buller's mollymawk	Breeding pairs	13 794	9 821 – 18 621
Southern Buller's mollymawk	No. immatures	58 755	32 379 – 93 762
Southern Buller's mollymawk	No. adults	32 386	22 636 – 43 906
Southern Buller's mollymawk	Total individuals	91 141	59 474 – 136 130
Southern Buller's mollymawk	Growth rate (%)	1.2	-3.2 – 5.3
Southern Buller's mollymawk	Adult fatalities	1 986	927 – 3 746
Southern Buller's mollymawk	Immature fatalities	6 883	3 654 – 11 369
New Zealand white-capped mollymawk	First breeding age	9.0	5.0 – 13.0
New Zealand white-capped mollymawk	Immature cohort survival (%)	26.2	15.4 – 39.5
New Zealand white-capped mollymawk	Immature annual survival (%)	83.4	78.0 – 88.4
New Zealand white-capped mollymawk	Adult annual survival (%)	97.3	94.0 – 99.0
New Zealand white-capped mollymawk	Breeding success (%)	61.2	48.2 – 73.0
New Zealand white-capped mollymawk	Breeding probability (%)	69.1	57.7 – 78.5
New Zealand white-capped mollymawk	Breeding pairs	94 682	65 306 – 130 666
New Zealand white-capped mollymawk	No. immatures	239 016	142 791 – 376 535
New Zealand white-capped mollymawk	No. adults	276 104	182 763 – 406 526
New Zealand white-capped mollymawk	Total individuals	515 120	343 354 – 754 244
New Zealand white-capped mollymawk	Growth rate (%)	2.2	-1.4 – 6.1
New Zealand white-capped mollymawk	Adult fatalities	7 411	2 316 – 16 889

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Table A-1 – Continued from previous page

Taxon	Parameter	Mean	95% c.i.
New Zealand white-capped mollymawk	Immature fatalities	39 284	21 787 – 62 485
Salvin's mollymawk	First breeding age	9.0	6.0 – 13.0
Salvin's mollymawk	Immature cohort survival (%)	26.3	15.1 – 40.7
Salvin's mollymawk	Immature annual survival (%)	83.7	78.1 – 88.9
Salvin's mollymawk	Adult annual survival (%)	96.0	93.1 – 98.0
Salvin's mollymawk	Breeding success (%)	46.7	34.8 – 58.0
Salvin's mollymawk	Breeding probability (%)	85.9	79.2 – 91.0
Salvin's mollymawk	Breeding pairs	37 333	26 470 – 50 638
Salvin's mollymawk	No. immatures	76 178	44 421 – 123 113
Salvin's mollymawk	No. adults	87 077	61 419 – 118 593
Salvin's mollymawk	Total individuals	163 255	110 488 – 233 737
Salvin's mollymawk	Growth rate (%)	1.1	-2.7 – 4.7
Salvin's mollymawk	Adult fatalities	3 453	1 581 – 6 489
Salvin's mollymawk	Immature fatalities	12 314	6 645 – 20 524

Table A-2: Summary of threats selected during the survey to be relevant to the 12 albatross included in the present study. Participants were presented with a list of threats and asked to "select all threats that, if not actively managed, would result in a change of the species' conservation status over the next 20 years". For each threat, the table gives the number of albatross taxa for which the threat was selected, and the total number of responses for which that threat was selected (where one response is one respondent selecting the threat for one albatross taxon).

Threat group	Threat	Taxa	Responses
Fishing direct	International	12	30
Fishing direct	NZ commercial surface longline	12	25
Fishing indirect		12	24
Fishing direct	NZ commercial trawl	12	23
Fishing direct	NZ commercial bottom longline	12	20
Natural disasters	Storms	12	17
Climate change	Other	12	16
Climate change	Temperature	12	15
Mining and oil activities	Pollution	12	14
Mining and oil activities	Habitat degradation	12	14
Climate change	Prey availability	12	13
Pollution	Marine debris	12	13
Climate change	Sea level rise	12	12
Pollution	Plastics	12	12
Fishing direct	NZ commercial gillnet	11	11
Natural animal threats	Mammal	10	13
Fishing direct	NZ recreational line	10	11
Disease	Avian cholera	10	10
Disease	Avian pox virus	10	10
Natural disasters	Tsunami	5	6
Human impacts at nest site	Research	5	5
Introduced animals	Introduced pests	4	5
Cultural harvesting		3	5
Human impacts at nest site	Other	3	3
Introduced animals	Destruction of habitat	3	3
Natural disasters	Earthquake	3	3
Fishing direct	NZ commercial setnet	2	2
Human impacts at nest site	Noise disturbance	2	2
Human impacts at nest site	Deliberate harassment	2	2
Introduced animals	Predation	2	2
Natural disasters	Fire	2	2
Fishing direct	NZ recreational setnet	1	1
Human impacts at nest site	Vehicle	1	1
Human impacts at nest site	Costal development	1	1
Human impacts at nest site	Farming stock	1	1
Pollution	Untreated sewage	1	1
Introduced animals	Domestic animals	1	1
Natural animal threats	Avian	1	1
Natural disasters	Marine biotoxins	1	1