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Report of the Final Global Seabird Bycatch Assessment Workshop

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Birdlife International

Report of the Final Global Seabird Bycatch Assessment Workshop

Seabird Bycatch Component

for Output 3.2.1 of the

Sustainable Management of Tuna Fisheries and Biodiversity Conservation in the ABNJ

25 February – 1 March 2019
Skukuza Conference center, Kruger National Park, South Africa

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Workshop Report

Project: FAO-GEF Project *Sustainable Management of Tuna Fisheries and Biodiversity Conservation in the ABNJ* (GCP/GLO/365/GFF)
Reporting organisation: BirdLife South Africa
Report prepared by: BirdLife South Africa

Report of the Final Seabird Bycatch Assessment Workshop
25 February – 1 March 2019

The Final Global Seabird Bycatch Assessment Workshop was held from 25 February to 1 March 2019. Participants at the workshop are listed in Annex 1; the workshop agenda is shown in Annex 2. The workshop comprised presentations, data analysis and discussion. Workshop participants agreed to a report format that was focused on Background/Methods/Results/Discussion, in order to present the results of the analyses in the clearest way.

The report adoption procedure was discussed and explained to participants. The report adopted at the workshop, with track changes and agreed additional amendments annoted as 'comments', was circulated to all participants as the meeting closed. The project team them completed the amendments as agreed by participants, and the technical annexes were added. This cleaned version was then circulated to all participants and then shared with FAO, and finalised. No further diagnostics can be undertaken as the dataset no longer exists.

Background

The Food and Agriculture Organization of the United Nations (FAO) is the implementing agency of the project "Sustainable Management of Tuna Fisheries and Biodiversity Conservation in the Areas Beyond National Jurisdiction (ABNJ)" (also known as the "Common Oceans ABNJ Tuna Project"), which aims to: (i) support the use of sustainable and efficient fisheries management and fishing practices by the stakeholders of the tuna resources; (ii) reduce illegal, unreported and unregulated [IUU] fishing; and (iii) mitigate adverse impacts of bycatch on biodiversity. BirdLife International, through its local partner, BirdLife South Africa (BLSA), has implemented the seabird bycatch component of the Common Oceans Tuna Project (Output 3.2.1).

The seabird bycatch component of the project responds to the recognition within tuna Regional Fisheries Management Organisations (t-RFMOs) that reduction of the current impacts of pelagic longline fisheries on albatross and petrel populations requires two actions. One is the implementation of seabird bycatch conservation and management measures across fleets overlapping with albatross distribution. More broadly, enhanced capacity within member states is desirable, to monitor and assess bycatch impacts (IOTC-2015-WPEB11; ICCAT 2015 SC ECO). In addition, all t-RFMOs have made commitments to review the effectiveness of their seabird conservation and management measures (ICCAT Rec 11-09, IOTC Res 12/06, IATTC C-1102, CCSBT ERS Recommendation 2011 and WCPFC CMM 2012-07). Approaches that might be used to support achieving such assessments were elaborated at a workshop hosted by CCSBT in November 2014 (CCSBT SMMTG 2014), and recommended undertaking of a collaborative global impact assessment in addition to regular monitoring of seabird bycatch within t-RFMOs.

The seabird bycatch component of the Common Oceans Project held a series of workshops to facilitate a collaborative assessment of seabird bycatch, and to address the urge to strengthen national scientist capacity to analyse bycatch data. Three preparatory workshops were held in 2017/18 to bring together experts, national scientists and institutions working with seabird bycatch data from vessels operating south of 25°S.

Twenty-seven workshop participants and Project Team members attended the meeting. The list of participants is provided in Annex 1. Ross Wanless from BirdLife South Africa chaired the meeting.

Workshop Objectives

The expected outcomes of the workshop were identified and agreed as follows:

1. A global estimate of seabird bycatch in pelagic longline fishing in the Southern Hemisphere, with associated measures of uncertainty, and sensitivity analysis where possible
2. Assessment of the population level impact of this level of bycatch for key species
3. A toolbox of methods to estimate bycatch, with guidelines on the most appropriate approaches given various data-quality circumstances
4. A roadmap for the future, including:
    a. Discussion on data limitations and suggestions on how they may be overcome
    b. Suggestions for future monitoring and assessment in relation to seabird bycatch in global pelagic longline fisheries

In addition, this workshop contributed to the overall project goal of building national scientist capacity to analyse seabird bycatch data.

Methods

Metadata and descriptive statistics

A request for data (including aggregated data), to be shared under specific conditions for the purposes of this workshop only, was circulated to all data holders in advance of the workshop (Annex 3). At the workshop, data owners who were satisfied with the conditions shared 5x5 degree aggregated observer data for a joint analysis. Nine datasets were contributed. Participants spent several hours compiling this joint dataset (JDS). Attributes of this JDS are shown in Table 1.

Table 1. Summary of data attributes of the JDS that was assembled for the purposes of the workshop, reflecting total and observed surface longline fishing effort (in millions of hooks) south of 20°S

Year	Total reported effort	Hooks observed	5x5 cells with reported effort	5x5 cells observed	5x5 cells with observed seabird captures
2012	258.7	6.8	260	80	37
2013	239.2	9.8	249	77	32
2014	235.3	10.2	237	81	47
2015	206.1	9.8	260	92	53
2016	218.6	10.2	241	85	48

The JDS assembled for the purposes of this workshop represents, to our knowledge, the largest and most comprehensive dataset ever compiled in relation to analysis of seabird bycatch in pelagic longline fisheries. Nevertheless, a comparison between the observed fishing effort, defined as hooks fished with an observer onboard, (Figure 1) identifies that observer data is not proportionally sampled. Overall, only 12% of 5x5 grid cells have observed coverage ≥5% of total effort (Figure 2), and coverage is particularly non-representative in the Eastern Pacific Ocean (Figure 1). The temporal coverage has improved over time, and recent coverage is fairly similar across year-quarters (Figure 3). Cells where coverage was ≤5% are displayed in Figure 4. It was noted that zero observed effort would have the most impact when occurring in cells in which there was high fishing effort.

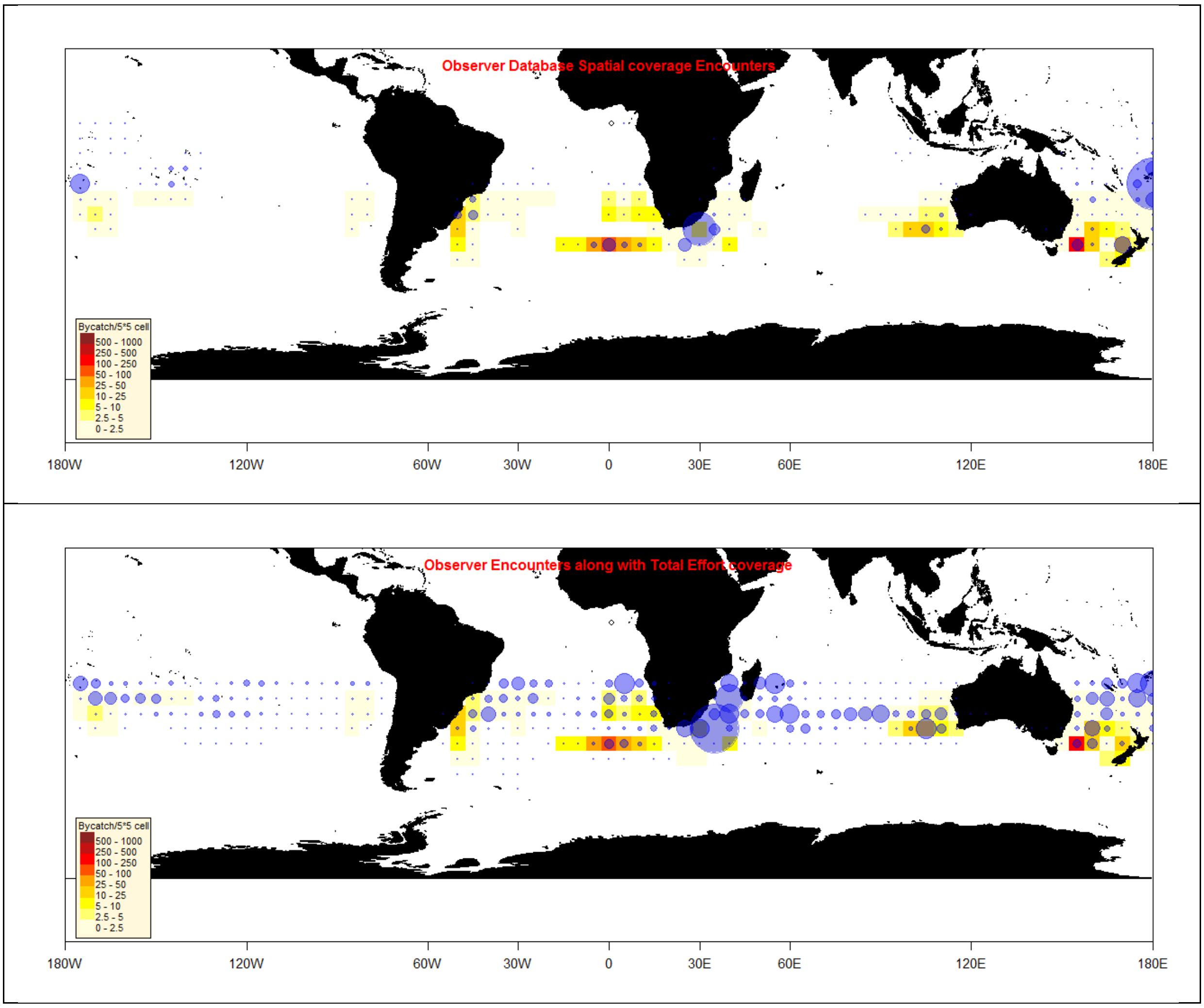

Figure 1: Upper panel shows spatial distribution of total number of observed birds caught (indicated by colour) compared to distribution of observed effort (indicated by size of the blue circle, scaled by 800K hooks), per 5x5 grid cell, for the period between 2012-2016. The lower panel indicates total pelagic longline fishing effort distribution reported by t-RFMOs in the period 2012-2016 (scaled by 5 million hooks), compared to total number of birds caught 2012-2016. Both figures are scaled to the largest circle scaled by circle area.

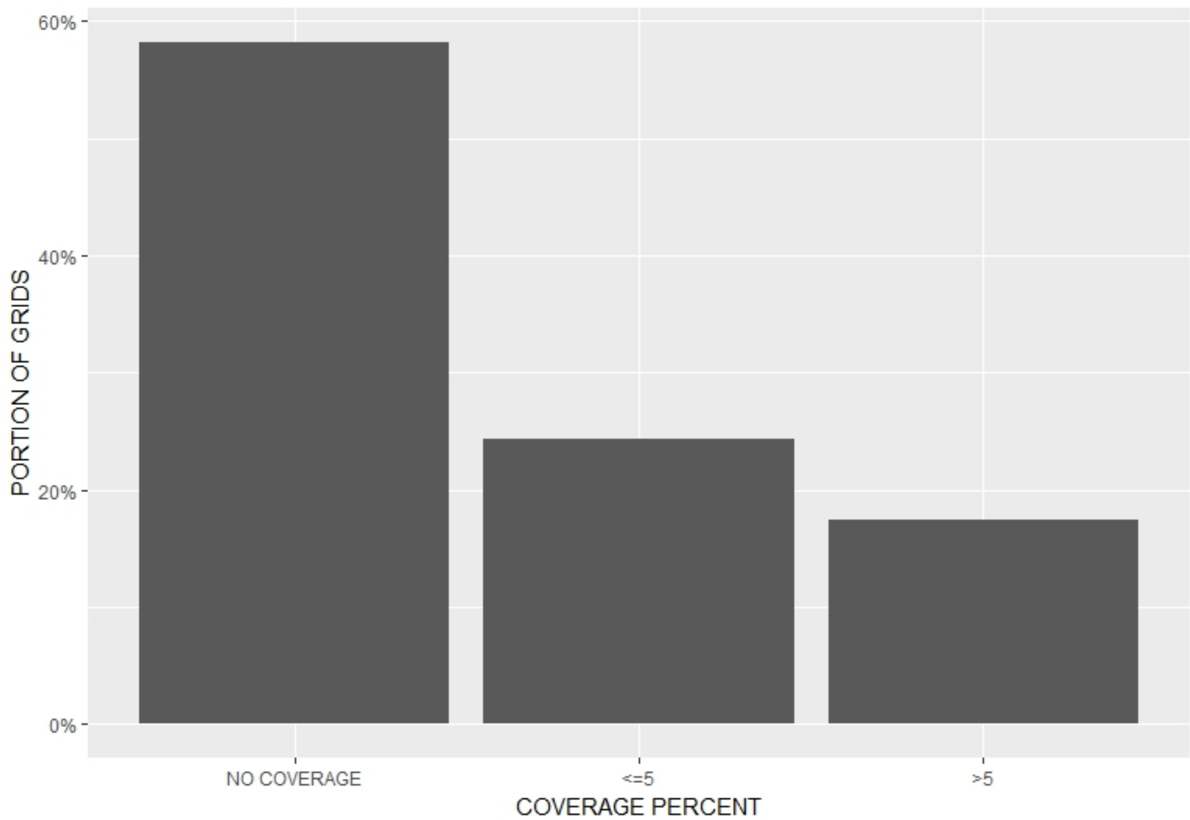

Figure 2: Observer Effort coverage over all oceans (number of cells meeting % observer coverage)

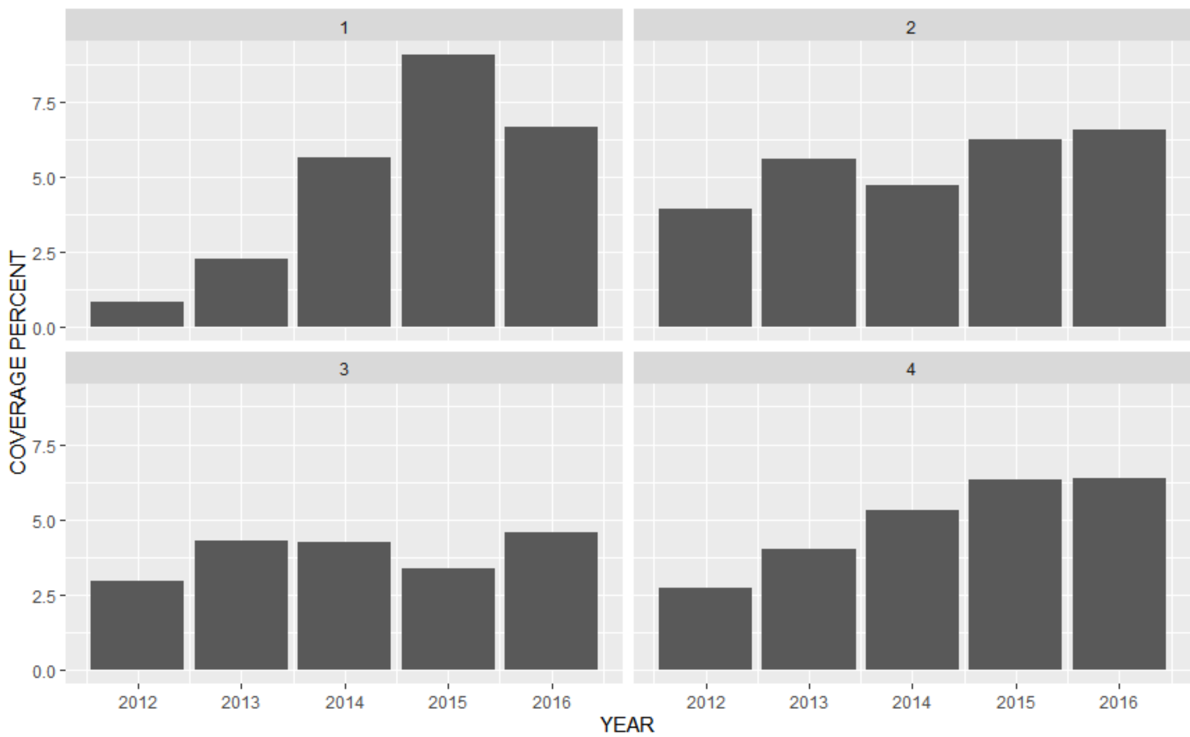

Figure 3: Annual observed coverage of pelagic longline fishing effort, by year-quarter, south of 20°S

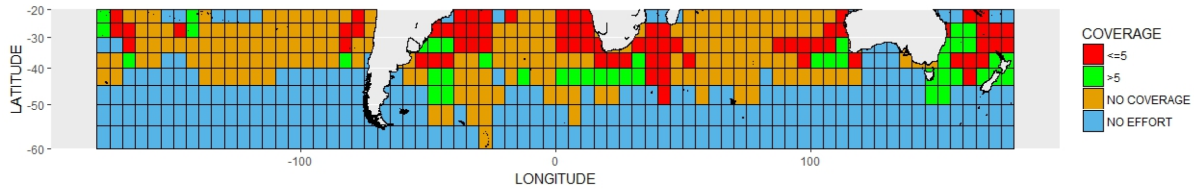

Figure 4: Distribution of coverage globally by area indicating where we have observer coverage greater (or less than) 5% and where no observer coverage exists on a 5*5 area.

Seabird density surfaces

The Global Seabird Tracking Database (www.seabirdtracking.org) is a repository of seabird tracking datasets. Access to data can be requested, and data owners can decline or accept the request. BirdLife International requested access to relevant datasets for the purposes of developing seabird density surfaces to be used in this bycatch assessment. A full description of the data, methods of calculation and sources is in preparation (A. Carneiro *in litt*). In brief, the process checked that tracked datasets approved for use were sufficiently representative of the tracked population/life history stage (juvenile, non-breeding adult, etc.) to generate kernel densities. The monthly distribution grids for each life-history stage was multiplied by the number of individuals, calculated from stable age distribution demographic models of known numbers of breeding pairs. Those stage/class values were summed to create monthly distribution grids for the whole population and provided in Raster file format to the workshop participants under a confidentiality agreement. A summary of tracking data compiled for this workshop, together with data gaps, is given in Annex 4. Figure 5 compares the seabird density surface to observed seabird captures and total fishing effort for the most recent year (2016).

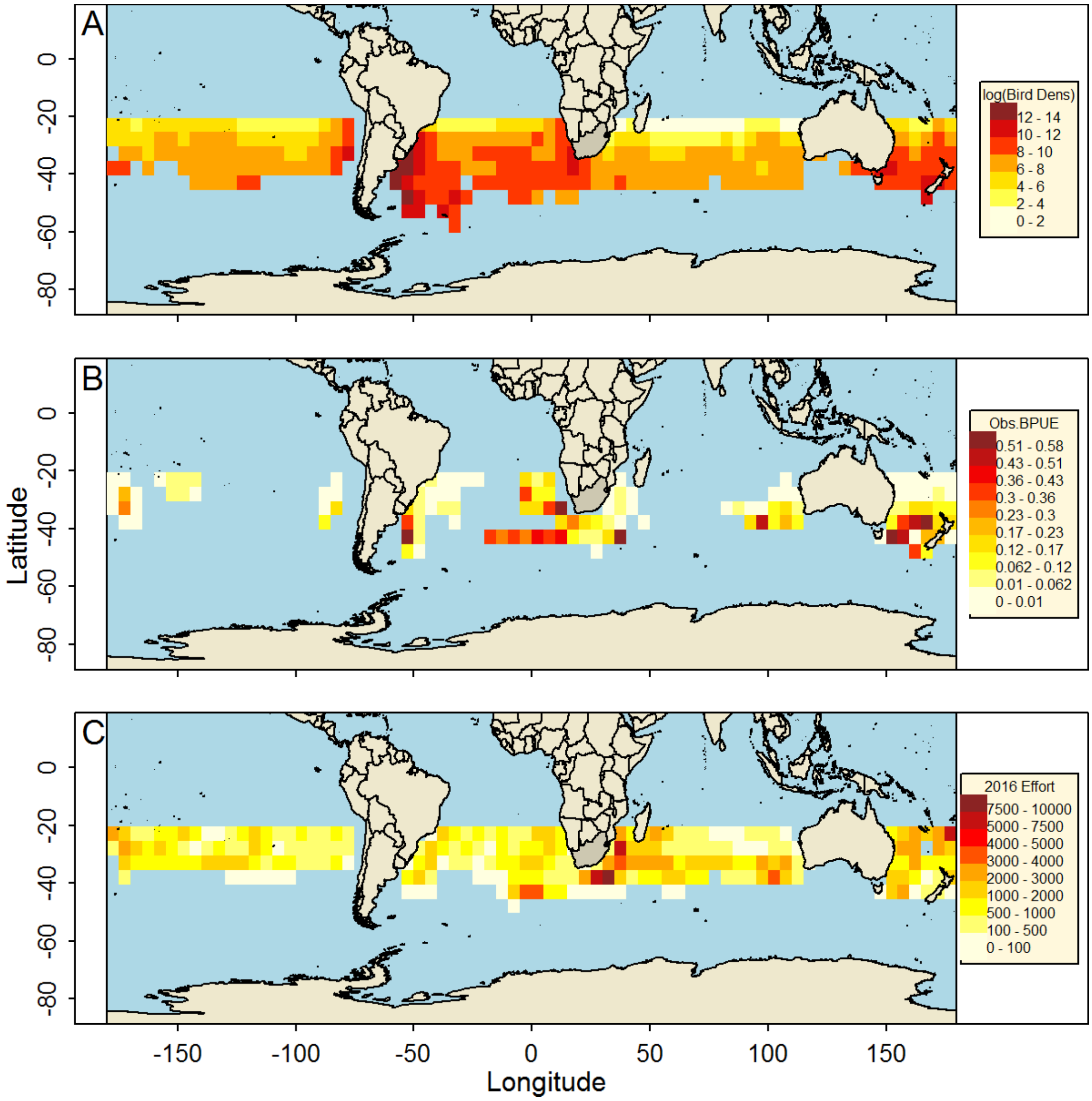

Figure 5. Comparison of seabird density distribution with total fishing effort and observed seabird bycatch in 2016. Panels indicate seabird density surface from tracking data (A), observed seabird bycatch per 1000 hooks (BPUE) for 2016 (B) and total fishing effort by 1000 hooks for 2016 (C).

Fine-scale observer datasets

Observers record a diversity of data for each set (set by set data). The expectation leading up to this workshop was that all participating experts would analyse their national observer data and develop national bycatch estimates using some or all of the methods proposed in the Data Preparation Workshop (Anon 2018). Additionally, datasets from the Republic of Korea, South Africa and Brazil were combined (Winker et al. 2018). This combined, finescale dataset was used to explore various model options, as well as to compare the impact of aggregating observer data to 5x5 degree granularity (the JDS).

Data Analysis

The overall assessment approach comprised a number of stages (Figure 6). Firstly, a range of different methods were used to attempt to generate an estimate of bird bycatch rates (BPUE). This included the use of a simple Stratified Ratio Based Estimate (SRBE), Generalised Additive Models (GAMs), Integrated Nested Laplace Approximations (INLA) and a Spatially Explicit Fisheries Risk Assessment (SEFRA). For each method, the best model was selected (x2 for the GAMs).

These estimates of bycatch rates were then scaled to the total effort using effort data reported by the various tRFMOs, to generate total estimates of the numbers of seabirds caught globally (a 'Global C'. A range of different methods were used to scale the estimates: for SRBE the bycatch of unobserved fleets was estimated from proxy fleets; for the GAMs, INLA and SEFRA this was estimated using the Japanese fleet effect (selected based on expert opinion amongst workshop participants, see Annex 6); and for the INLA and SEFRA methods a random fleet effect was also used to generate estimates.

To assess the population level impacts of these seabird captures, a Population Viability Analysis (PVA) was used. Species-specific estimates, derived from the SEFRA models, were used as inputs to PVA models for five key species for which good demographic data were available. The SEFRA approach uses Population Susceptibility Threshold (PST) values, which estimates risk of negative population growth.

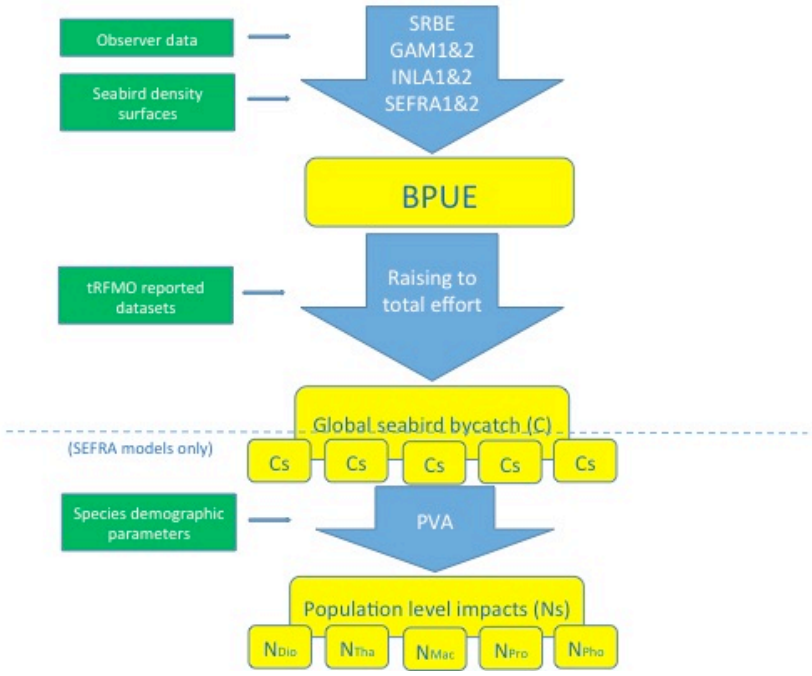

Figure 6: A flow chart showing the overall assessment approach and various stages followed. SRBE = Stratified Ratio-based Estimate, GAM = Generalized Additive Model, INLA = Integrated Nested Laplace Algorithm, SEFRA = Spatially Explicit Fisheries Risk Analysis, PVA = Population Viability Analysis. Subscripts denote potential taxon-specific estimates. In the case of SEFRA, the model does not estimate a BPUE, but a species-specific vulnerability to being caught.

Two assumptions were made across all analytical approaches. Firstly, the analyses did not explicitly account for cryptic mortalities due, for example, to birds being caught during the set but falling off the hook before being retrieved on board the vessel (Brothers 2010). Secondly, no account was made of live captures. All captures were assumed to be mortalities. For more detailed descriptions of model parameterizations and related aspects, refer to [Annexes 5-8]

Stratified Ratio-based Estimate (SRBE)

A ratio-based estimate was calculated by fleet and year. Data were taken from the JDS and literature-based estimates. Where there were no available information, proxy fleets were used (Annex 5). Japan's Birds Per Unit of Effort (BPUE, with effort equal to 1000 hooks) was applied to unobserved distant water fleets. For other unobserved fleets a global mean BPUE, derived from the JDS, was used (0.19 BPUE). The BPUE rates from all sources (published and from the joint data set) were combined into a full BPUE dataset. The workshop noted that for some distant water fleets, bycatch rates may be lower than the Japanese bycatch rates, in which case the ratio estimate may be an over-estimate.

Generalized Additive Models (GAM)

Generalized Additive Models (GAMs) provide a flexible tool to model fisheries catch and effort data for estimating catch per unit of effort in space and time, and are an extension of generalised linear models (GLMs). Often the objective of the modelling is to identify whether there is evidence for a space-time interaction in abundance, which may suggest local aggregation or strong seasonal variability. The JDS was modelled via GAM to produce estimates of the BPUE south of 20°S. Multiple models and various error distributions were explored. In the end, two characteristic models using a Tweedie distribution were chosen. For more details, see Annex 6.

Integrated Nested Laplace Approximation (INLA)

Like many fisheries datasets, seabird bycatch data are characterised by complicated statistical features, such as excess of zeros, nonlinearity, nonconstant variance structure and spatiotemporal correlation. Integrated Nested Laplace Approximation (INLA) are based on some of the same fundamentals as GLMs and GAMs, but instead of representing space as a set of fixed or continuous variables, INLA constructs flexible fields using hierarchical Bayesian spatiotemporal models which are better able to handle datasets with complex spatial structure and allow for the identification of temporal strata and areas of higher bycatch risk. They further identify environmental and fisheries drivers which affect bycatch rates. For more details, see Annex 7.

Spatially Explicit Fisheries Risk Assessment (SEFRA)

The seabird risk assessment followed the methods developed for estimating seabird captures in New Zealand fisheries (Spatially Explicit Fisheries Risk Assessment, SEFRA; Sharp 2016, Abraham et al. 2017a, b), and subsequently applied to the capture of *Diomedea* albatrosses in southern hemisphere longline fisheries (Ochi et al 2018).

The goal of the risk assessment is to estimate the capture of each species in fisheries, and to relate those captures to a measure of seabird population productivity. The core assumption of the method is that the capture of seabirds is proportional to the overlap between seabird distributions and fishing effort—seabird captures do not occur where there is no fishing, nor do they occur where seabirds are not present. The constant of proportionality is given by the product of a susceptability, and a catchability. The susceptability expresses how likely different groups of seabirds are to be caught in fisheries.

The overlap between seabirds and fisheries was calculated using seabird distributions derived from tracking data, where they were available (A. Carneiro *in litt*). Estimates were made of the annual average captures during 2016 for each seabird species, using either the flag-specific or the fleet-averaged method for extrapolating to unobserved fleets. For more detasils, see Annex 8.

In addition to the estimation of captures and risk, the analysis by Ochi (2018) was repeated, estimating the captures of *Diomedea* albatrosses, using the JDS.

Modelling impacts of bycatch on key albatross species/populations

Bycatch impacts were modelled on certain albatross populations using the Population Viability Analysis (PVA) software Vortex v10 (Lacy & Pollack 2014) for which good demographic parameters are available from the literature. The species included were Wandering *D. exulans* (Atlantic and Indian ocean populations), Tristan *D. dabbenena*, Antipodean *D. antipodensis* (Antipodes and Gibson's populations) Information on the most recent annual growth rate for each species/population was taken from the literature (see Annex 9). For all demographic models there were five scenarios. The Baseline Scenario used best estimates of adult survival with no anthropogenic impacts, i.e. no bycatch already accounted for. The remaining scenarios then included the removal of individuals. Scenarios 1 and 3 used the relevant bycatch estimates for the species/population as derived from SEFRA Models 1 and 2, respectively. Scenarios 2 and 4 were the same as 1 and 3, respectively, but with a multiplier to explore the impact of cryptic mortality, under-reporting and other biases that deflate bycatch estimates. The multiplier used was to double the estimated bycatch, based on Brothers et al 2010.

Results

Comparisons of estimates of total seabird bycatch from the best performing models of the various modelling approaches for the most recent year (2016) yielded broadly similar results (Table 2). Comparisons of the spatial distribution of seabirds with estimated bycatch are shown in Figure 7. Seabird density surface information was an important explanatory variable/predictor of bycatch, and all models selected included this parameter.

Table 2. Mean estimated seabird bycatch for 2016, with 95% confidence/credible intervals (*). JPN = Japanese bycatch rates

Model	Mean	LCI 95%	UCI 95%	Unobserved Fleet Treatment
SRBE	39,147	1,030	110,395	Estimated using proxy fleets
GAM1	38,632	29,962	50,504	Estimated using JPN fleet effect
GAM2	32,108	12,460	53,035	Estimated using JPN fleet effect
INLA1	52,487	24,785*	78,918*	Estimated using JPN fleet effect
INLA2	33,239	22,119*	45,242*	Estimated as a random effect
SEFRA1	21,456	12,372*	41,476*	Estimated as a random effect
SEFRA2	35,396	34,244*	36,567*	Estimated using JPN fleet effect

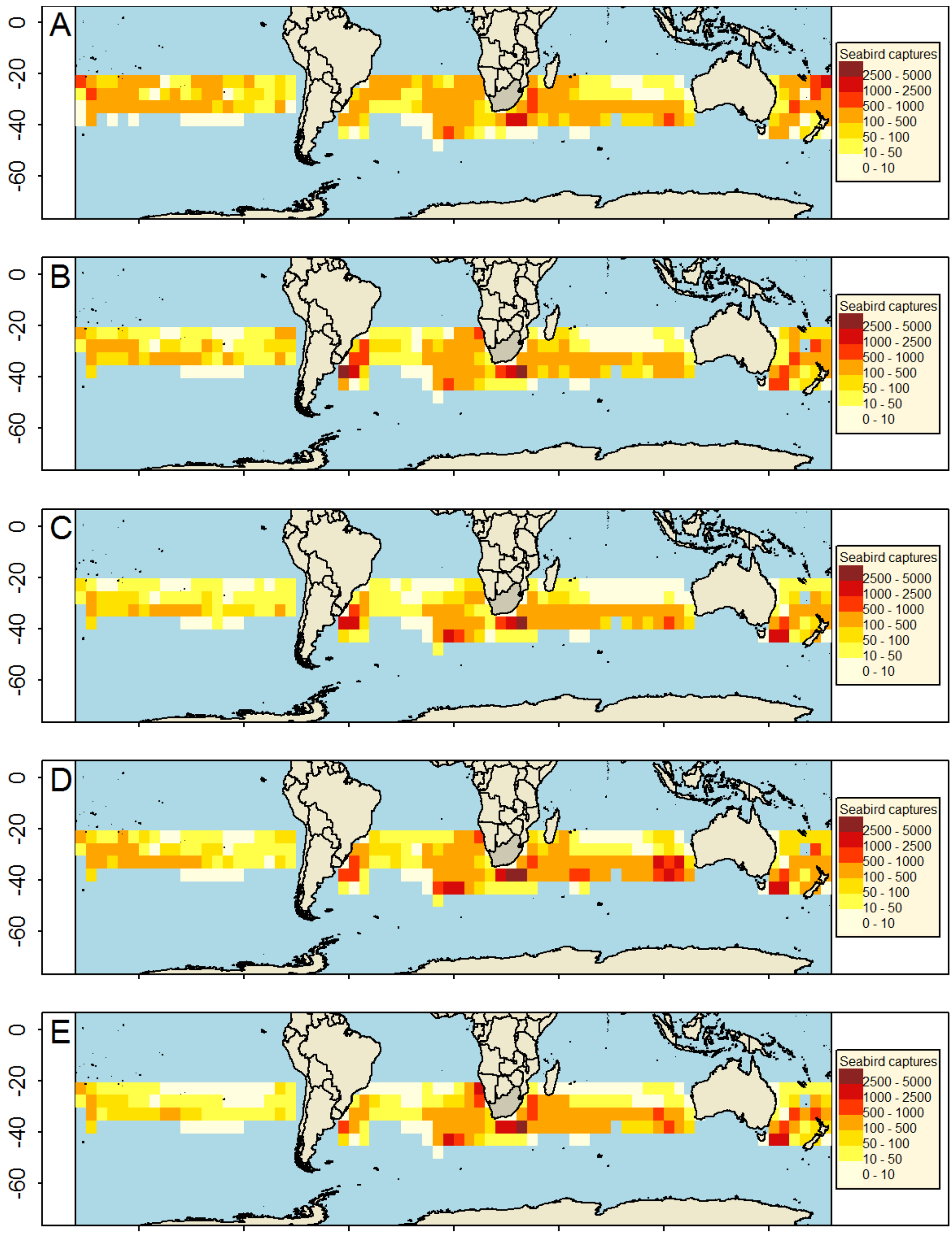

Figure 7. Plots of estimated seabird bycatch in 2016. Panels indicate results from the ratio estimate (A), GAM1 (B), GAM2 (C), INLA1 (D), SEFRA2 (E). Note that 5x5 degree squares frequently straddle international borders. Therefore cells that appear to fall within a particular EEZ may reflect effort and predicted bycatch from the portion of the cell that falls in another jurisdiction or in the high seas.

SRBE

The total estimated bycatch per year for 2016 was 39,147 birds (CI 1,030 to 110,395) (Table 2). The temporal variation (Figure 8) is a function of annual effort changes.

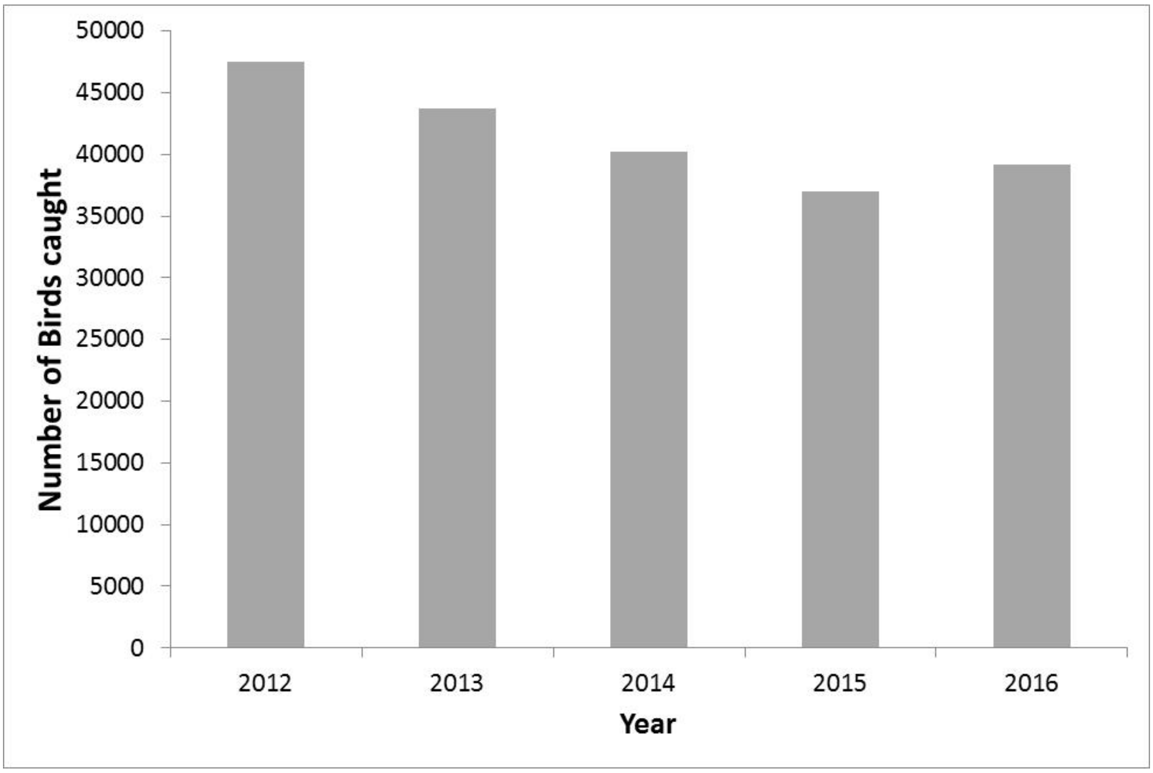

Figure 8: Total seabird bycatch from surface longline fisheries south of 20°S, estimated using a stratified ratio-based approach

The workshop noted there is large uncertainty in the estimates associated with this approach. High variation is an inherent component of BPUE estimates based on rare events, in addition to other factors that can inflate uncertainty (e.g. low or unbalanced observer data coverage).

The group recognised that the ratio approach is most appropriately used as a 'back of the envelope' check. Uncertainty can be reduced by using spatial and temporal stratification within the ratio approach, but this was not possible in this analysis due to data limitations. For example, BPUE estimates could be stratified by year, but in the available data set stratification by year would primarily be driven by a minority of fleets in few oceans, and hence stratification was considered unlikely to add value to this analysis.

GAMs

Several GAMs were used to estimate BPUE distribution from the JDS. Ultimately, two models with alternative fixed effects were considered. GAM1 estimated seabird bycatch as a function of seabird density distribution, year quarter and flag, and GAM2 estimated seabird bycatch as a function of seabird density distribution, flag and season.

Estimated BPUE surfaces were multiplied by fishing effort data (number of reported hooks aggregated by 5x5 grid, fleet, quarter and year) to generate estimates of total bird bycatch numbers. In GAM1, a parametric bootstrap approach was used to propagate the uncertainty of the BPUE estimates to the global estimate. It was noted that this generates fairly narrow confidence bounds, which are likely to be an underestimate. In GAM2 a normal approximation to the confidence interval was used.

Total bycatch estimates for 2016 were 38,632 birds (CI 29,962, 50,504) for GAM1, and 32,108 birds (CI 12,460, 53,035) for GAM2 (Table 2). There was notable inter-annual variation in total bycatch numbers, which is attributable to changes in absolute fishing effort and its relative distribution.

Total bycatch estimates from the GAM models by ocean are associated with high levels of uncertainty. The East Pacific estimate is potentially compromised due to the very low observer coverage for this area. The workshop also noted that missing seabird density surfaces within the Indian Ocean is likely to result in an under-estimate of seabird bycatch due to incomplete white-chinned petrel distribution data, which represents a high proportion of observed bycatch species in the Indian Ocean.

INLA

Of eight INLA models under consideration, the model with the best fit was based on seabird distribution density, a spatial-temporal structure with replicated spatial effects between the years and a cyclic spatial correlation between quarters. The workshop noted that the residual plots indicate a good model fit.

Based on this model, two approaches were used to predict seabird bycatch in fleets for which there were no available observer data. The first approach used Japan as a proxy fleet for all unobserved fleets. This resulted in a global estimate of birds caught south of 20°S of 52,487 birds per year (CI 24,785, 78,918). The second method was an adaptation of the best model that used random effects in fleets to assign bycatch rates to unobserved fleets, with a global estimate of 33,239 birds per year (CI 22,119, 45,242). This approach likely underestimated total bycatch because the majority of the observed datasets used in the estimation of the random effect are concentrated in relatively small geographical areas. In contrast, the Japanese data set is representative of a large geographical area.

The workshop noted the strong predictive relationship identified in the model between seabird density and bycatch. Relating to this, it was noted that the seabird distribution data based on tracking data have no correction for missing colonies or missing species, emphasising the importance of work to try to fill or account for these data gaps.

SEFRA

The SEFRA 1 risk assessment model estimated 21,456 seabird captures (CI 12,372-41,476) in 2016 (Table 2). The majority of these captures (14,461, CI 8,278-32,194) were of *Thalassarche* albatross species, followed by *Procellaria* petrels, and *Diomedea* albatrosses (Table 3, Figure 9). Under SEFRA 2, the estimated captures were higher, at 35,396 (CI 34,244-36,527) (Table 2), and the estimated captures of each genus also increased (Table 3, Figure 9).

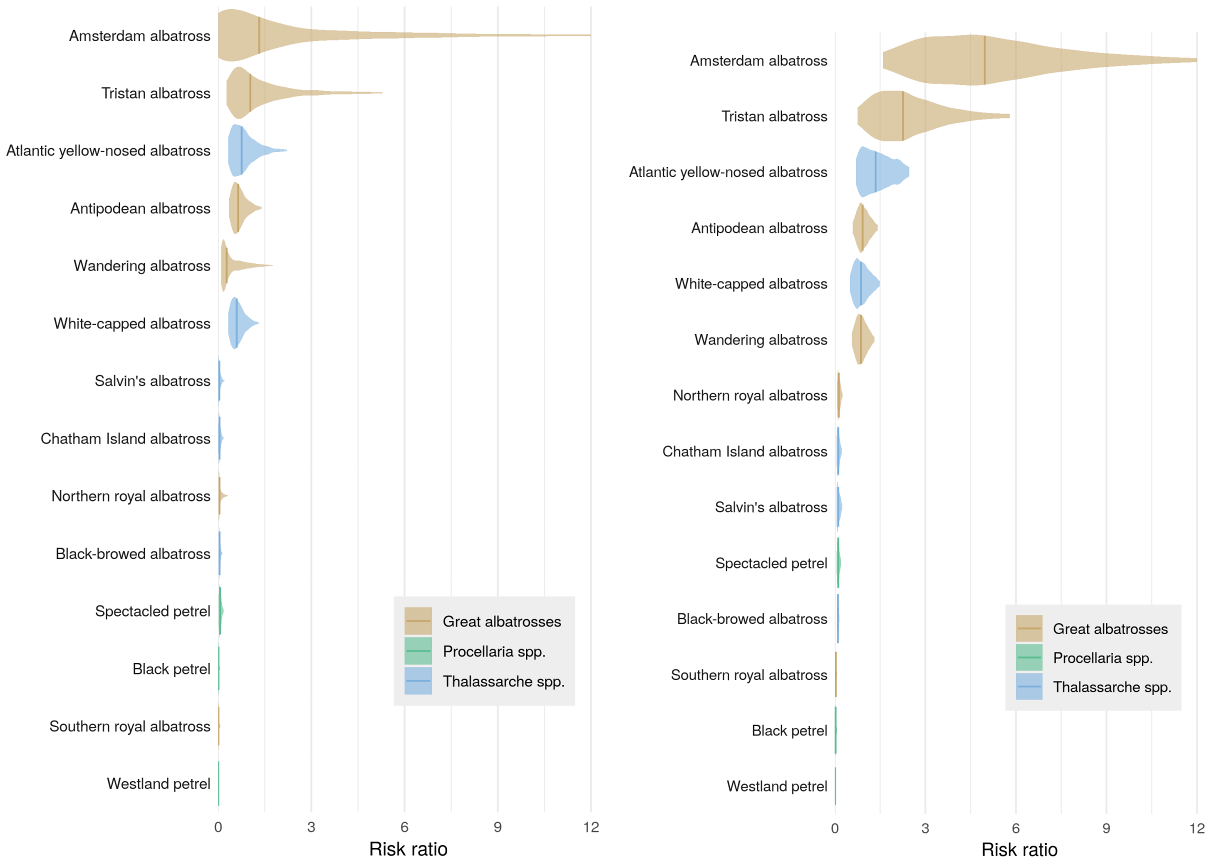

Figure 9. The ratio of the estimated captures to the Population Sustainability Threshold (PST) for each species from the risk assessment models, (a) SEFRA1, (b) SEFRA2. For each species, the figure shows the distribution of the risk ratio. The line indicates the median risk ratio and the distributions are truncated at the 95% credible interval. The species are sorted in decreasing risk. The risk is only shown for species with distributions derived from tracking data.

Table 3: Estimated captures, by seabird genus, in surface longline fishing south of 20°S, during 2016, derived from risk assessment models (SEFRA1, SEFRA2). Lower (2.5%) and upper (97.5%) credible intervals were calculated from the posterior distributions.

	SEFRA1			SEFRA2		
Genus	Mean	Lower CI	Upper CI	Mean	Lower CI	Upper CI
Diomedea	1063	501	2676	1653	1367	1972
Thalassarche	14,661	8278	32,194	23,468	22,552	24,362
Macronectes	628	362	1556	1636	1344	1950
Procellaria	4226	2116	6892	6461	5828	7126
Phoebetria	874	483	2044	2175	1780	2594

The risk assessment model provided estimates of the captures of each species. The species with the highest estimated captures was white-chinned petrel (SEFRA1: 3939, CI 1980-6414; SEFRA2: 6019, CI 5414-6652). The capture estimates can be compared to an index of population productivity, such as the Population Sustainability Threshold (PST) . The species with the highest median ratio of captures to the PST were shy, Amsterdam and Tristan albatrosses (SEFRA1; Figure 9a). When the proxy method was used for estimating captures on unobserved fleets, sooty albatross had the highest median ratio (SEFRA2; Figure 9b). Estimated captures of sooty albatross and shy albatross relied on range maps, and the high apparent ratio of captures to PST for these species may be an artefact of the use of range maps.

When the model reported by Ochi et al. (2018) was updated with the JDS and seabird density surfaces, the estimated total number of *Diomedea* captures reduced to 963 (684-1317), compared with 1070 (834-1345) estimated previously. These estimates were very similar to the results from SEFRA1 (Table 3). Note, however, that there were key differences between these estimates, such as the method for extrapolating to unobserved fleets, and the treatment of unobserved captures.

Modelling impacts of bycatch on key albatross species/populations

The species selected for modelling were those where there was reliable demographic information based on long-term monitoring and analysis. Species that were more numerous in the bycatch, e.g. white-chinned petrel, were not modelled because there was low confidence in demographic parameters. This highlights the importance of having good demographic information for quantitative analyses of impacts on populations at risk from bycatch. The proportion of the total bycatch estimate from SEFRA 1 and 2 that was included in the PVA models was 4.7% and 4.4% respectively.

The PVA model for wandering albatross in South Georgia using no bycatch resulted in population growth of ~0.4% per year. However, under each of the bycatch scenarios the population was predicted to decline (Annex 9, Figure A9-1). The worst-case scenario resulted in annual change of 1.9% per year with a 91% probability that the population would decrease to 50% of the initial population size within 50 years.

The model for wandering albatross breeding in the Indian Ocean, and that of Antipodean albatross (both Antipodes and Gibson's) had more mixed results: under at least one bycatch scenario the population was estimated to still have a slight growth.

The Tristan albatross was the only species included in this analysis that started with a negative growth rate in the scenario with no bycatch. This is because of the very high mortality of chicks due to mouse predation (Wanless et al. 2009). Any additional mortality causes a steeper decline, and Scenarios 2-4 indicated that the species could become extinct within 50 years (See Annex 9, Figure A9-3).

For both Antipodean albatross populations and wandering albatross breeding at South Georgia, the actual growth rate is more negative than the modelled scenarios (e.g. for the South Georgia wandering albatross the current observed growth rate is -1.8% per year, while even under the worst case scenario the maximum decline predicted is -0.78% per year, Table 4), suggesting either that the SEFRA models are underestimating bycatch, or there are other sources of at-sea mortality besides bycatch in tuna longline fisheries. For the Indian Ocean wandering albatross population, only the Scenario 1 rate of decrease was within the boundaries of the current estimated population trajectory (Table 4). The Tristan albatross population model scenarios with bycatch rates included resulted in decreases that are greater than the actual (current) decrease, i.e. any of the bycatch estimates is higher than the current rate. This suggests bycatch for this species is overestimated in the SEFRA models.

The modeling exercise undertaken demonstrated that bycatch from pelagic longlines could be having a population-level impact for specific populations. However, it was noted that this workshop was the first time that the population-specific bycatch estimates coming out of the SEFRA model were then run in population models. Further calibration and testing between approaches could be useful.

Table 4. Trends in annual change in growth rates for selected populations from the literature and modelled scenarios. Of the models represented, Actual is the current estimated population growth rate, which includes any actual bycatch impacts, Baseline removes any bycatch impacts, Scenario 1 is bycatch numbers as estimated from the SEFRA model using a “fleet average” bycatch rate, Scenario 2 models the addition of cryptic mortality to values used in Scenario 1, Scenario 3 is bycatch numbers as estimated from the SEFRA model using flag-specific bycatch rates, and Scenario models the addition of cryptic mortality to values used in Scenario 3.

Species/pop	Trend	Actual	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Antipodean albatross (Antipodes)	Decline	-6 to -7%[a]	1.47%	0.43%	-0.62%	0.10%	-1.63%
Antipodean albatross (Gibson’s)	Decline	-6.6 to -1.6%[b]	0.25%	0.09%	-0.01%	0.05%	-0.27%
Tristan albatross	Decline	-2.8% [c]	-1.32%	-3.81%	-6.48%	-5.59%	-9.40%
Wandering albatross South Georgia	Decline	-1.8% [d]	0.44%	0.16%	-0.09%	-0.10%	-0.78%
Wandering albatross Indian Ocean	Stable/slight decline	-0.56 to 0.52%[e]	0.45%	-0.11%	-0.78%	-0.67%	-1.97%

a. Elliot & Walker 2018
b. Francis et al 2015
c. Wanless et al 2009
d. Poncet et al 2017
e. Weimerskirch et al 2018

Discussion

Characteristics of various seabird mortality estimation procedures (general characteristics, data requirements, robustness, impacts of partial data, extrapolation)

Workshop participants expressed their appreciation of the progress that had been achieved at the workshop, including the compilation of the JDS, the achievement of having successfully undertaken a range of modelling approaches to achieve estimation of C, and that the estimates of C are broadly similar across models (Table 2, Figure 7).

The distribution of predicted seabird bycatch shows congruity between the various methods (Figure 7). This is likely due to three factors: the influence of the use of a global effort layer, the broad representation of input (observer) data, and the seabird density surfaces in all the models.

Overall, the results indicate several areas of higher bird bycatch, which arise as a result of high BPUE and/or high fishing effort. The SW Indian Ocean and an area NE of New Zealand are two examples of relatively low predicted BPUE but very high fishing effort.

The impact of analyses on aggregated (5x5) versus finescale, set-by-set data was considered via an analysis using the set by set observer data set assembled from the Atlantic and SW Indian Ocean. This observer data set was aggregated in the same manner as the JDS, and used with two GAM models, implementing the same functional form to estimate BPUE. The estimations and resultant calculations of seabird bycatch were very similar. However, trade-offs in the explanatory power of the models exist with respect to the aggregation of data. The aggregated dataset had reduced detail and lower variance , resulting in an artificially high proportion of deviance explained. However the aggregated data set was thought to less accurately reflect the nature of seabird bycatch (e.g. lacking rare event large captures). It would be useful to undertake similar comparisons in the future.

Workshop participants discussed the fact that seabird density distribution has emerged as a significant predictor of bycatch in all the model-based estimates presented here. By being a powerful explanatory variable, this has the advantage of simplifying models. However, it also emphasises the importance of ensuring that these data layers will be available for future analysis, as well as the importance of these seabird density surfaces being reliable. It was noted that the forthcoming meetings of the ACAP Advisory Committee in May 2019 offer an opportunity to express this need to relevant tracking data owners.

Workshop participants discussed the potential to present the results of the analyses by ocean, but concluded that this might be misleading as differences may be arising as a function of gaps in seabird distribution data.

More broadly, there are multiple sources of bias and uncertainty that can have a significant impact on estimates of C. These biases can cause inflation or deflation of estimates (Table 5). The best available information has been used in these estimates and the model results are considered sufficiently precise. Nonetheless, the results may lack some accuracy as a result of limitations indicated in Table 5, and there remain areas for improvement to reduce these sources of uncertainty.

Table 5. Sources of bias that could influence seabird bycatch estimates (not exhaustive). This excludes the description of challenges with observer datasets.

Sources of bias and uncertainty	Expected impact if not accounted for
Use of rangemaps instead of seabird density surfaces	Unknown, possible overestimate
Not using seabird densities	Increases uncertainty
Incomplete seabird distribution information (stages, colonies, species, etc.)	Overestimations in data-rich areas and underestimation in data-poor areas
Incomplete seabird demographic information	Unknown
Incomplete fishing effort data	Underestimate
Fleets without observer data	Unknown
Cryptic mortality	Underestimate
Post-release survival	Underestimate

Data limitations

Based on the results and experience drawn from undertaking this analysis, the workshop discussed data limitations and suggestions for how they may be overcome. To set the context for this discussion, information was presented on current reporting requirements within the three t-RFMOs who were present at the workshop.

Current reporting requirements within t-RFMOs

Representatives from IOTC and ICCAT Secretariats presented summaries of the reporting requirements of their organizations. Reporting requirements for WCPFC were summarised by a representative from SPC.

Data collection and reporting requirements relevant to seabirds vary over time within each t-RMFO, and among t-RMFOs. For ICCAT, observer program requirements changed slightly between 2015-2017, but generally some detailed fishing operation level data were collected; but in 2018 the format of data submissions to the Secretariat was changed to be highly aggregated so that much information about fishing operations was lost. On account of the current state of the data (and other reasons), ICCAT could not conduct a seabird bycatch assessment or contribute data on behalf of CPCs to a regional assessment.

For IOTC, seabird data reporting requirements are defined in CMM 12/06. Data currently held by the IOTC are fairly divergent in content as well as aggregated in nature and have been submitted in a wide range of formats. As a consequence, incorporating these into the regional database is ongoing. Observer data reporting requirements have recently been reviewed and revised and the Scientific Committee has recommended these are to be adopted by the Commission in 2019. The new observer data requirements involve the submission of detailed, set-level information, including information on the use of bycatch mitigation measures, in approved electronic format which can be used for regional-level analyses.

For WCPFC, reporting requirements are defined in CMM 2018-03 and its predecessors. Commission Members, Cooperating Non-members and participating Territories (CCMs) are required to report mitigation options used by their fleets and their technical specifications in Part II of their annual reports. CCMs are also required to provide in Part I of their annual reports information on observed seabird bycatches to enable estimation of seabird mortalities, disaggregated by region (south of

30°S, 30°S to 25°S, 25°S to 23°N and north of 23°N). This includes: the proportion of observed effort with specific mitigation measures; observed bycatch by species; total and observed effort; and, observed bycatch rates. Reporting template guidelines are provided to ensure that information is provided in a consistent format by all CCMs. This information, if reported consistently by relevant parties, could be used annually to perform a stratified ratio estimate of seabird bycatch.

The group discussed some of the advantages of harmonizing data requirements across the t-RMFOs and the difficulties in achieving this. They noted that while harmonization of reporting was highly desireable, and annual reporting in the way required by WCPFC would be very useful, the workshop did not make suggestions as to how such harmonizations might be achieved.

Challenges with fishing effort data

The workshop noted that the gaps in the current tuna RFMO pelagic longline effort datasets pose significant problems for producing an accurate estimate global seabird bycatch, and is likely to mean that the estimated generated at this workshop is an underestimate, of unknown but possibly substantial scale. The improvement in some t-RFMO fishing effort datasets was identified as a high priority. Investigations into the scale of current underestimation in total longline effort would also be valuable.

Challenges with observer datasets

The workshop noted that for the purpose of a seabird bycatch estimate, a lot of confidence was put in observer data. However, it was acknowledged that observer programmes are typically designed for monitoring tuna operations and not monitoring seabird interactions. The workshop discussed the possible shortcomings and biases of observer data for estimating seabird bycatch. It was noted that the purpose of this exercise was not to make recommendations, but rather to investigate how these shortcomings might affect the accuracy of the bycatch estimation calculations.

1. *Reporting observer coverage:* Some programs require dedicated bycatch observations of hauling operations, whereas others record the proportion of the set observed (bycatch and other duties combined), and others consider coverage to be all effort when an observer is onboard. These approaches introduce potential biases, and standardisation is required.

2. *Observation time bias:* If the entire line hauling is not observed, and setting and hauling observations occur on a regular daily cycle, there is significant risk that a certain portion of the line (e.g. those during night setting) will be missed systematically from observation. While the group acknowledged that this is a serious concern and will have an affect on the outcome of the estimate calculations, it was not possible to correct for this bias in the analyses at this workshop. It was suggested that this is a concern that should be addressed in future.

3. *Data not representative at trip and fleet levels:* The group acknowledged that coverage is frequently biased (in space and time), particularly for seabird bycatch events. Further, coverage of the fleet may be incomplete and there may be some systematic biases in which vessels carry observers. The group agreed that systematic underobserving certain fleet segments/vessels was likey to lead to underestimation (vessels with nothing to hide are less likely to avoid carrying observers) and the group agreed that this concern should be noted in the report.

4. *Behaviours change when observer is/isn't on board:* There is evidence from a diversity of sources that fleet behaviour (e.g. use of mitigation measures, areas fished, etc.) changes when observers are/are not onboard. The workshop agreed that this could lead to a strong bias and underestimation of seabird bycatch when extrapolating. It was also noted that there may be incentives (such as social pressure) on the observer to under-report seabird captures. The

workshop acknowledged that there was uncertainty around how this problem could be resolved, particularly as those influences may not be overt. Research into strategies for how to detect under-reporting should be explored.

5. *Deliberate actions to conceal seabird captures from the observer:* The workshop discussed and agreed that it has been noted at multiple fora that there are ways in which crew can reduce the numbers of seabirds for an observer to record (including line cutting, shaking seabirds off the line, positioning the observer at a point where the hauling operation cannot be observed easily, etc). The workshop acknowledged that total seabird bycatch recorded by observers was therefore a minimum estimate of actual bycatch.

6. *Total interactions versus mortality, and post-release survival:* Certain observer programmes discriminate between live releases and mortalities, others only report total captures. The group agreed that this will not affect the seabird bycatch estimate, as this has been based on total captures. In addition, in most cases the proportions of live releases is small. However, standardising how this information is recorded and reported would remove potential biases. In relation to post-release survival, the group agreed that this will not have an effect on the seabird estimation being undertaken at this workshop, but that it remains unknown and studies to evaluate post-release survival would be very valuable.

7. *Species identification:* The group agreed that while this is a concern, it will not have an effect on estimating total seabird bycatch in this report. It would cause problems for disaggregation of bycatch to species or population level.

8. *Degree of training received by observers:* Observers that have not received specific training on particular aspects, such as seabirds, may not appreciate the importance of collecting bycatch events and may thus inadvertently under-report these.

9. *Recording use of seabird bycatch mitigation measures.* The group agreed that this was an exceptionally important but difficult challenge. The lack of available data on proper use of seabird bycatch mitigation measures means that these data are not included as factors in the current models. However, careful consideration should be given to identify key factors that determine the effectiveness of a particular mitigation measure, to improve current reporting requirements. RFMOs may be unable to evaluate the effectiveness of Conservation and Management Measures if this is not addressed.

Suggestions for future monitoring and assessment in relation to seabird bycatch in global pelagic longline fisheries.

Cryptic mortality is a concern when estimating seabird bycatch and assessing impacts on populations. Published research (Brothers et al. 2010) has shown that up to 50% of seabirds hooked during setting are not returned to the vessel at hauling – i.e. they are not observed as captures. The group agreed that this is a very important factor to consider when calculating the impact of bycatch on species, but was accounted for in this report using a correction factor in the population-level impact models. It would be inappapriate to try to account for this within the models themselves.

Based on the analyses undertaken in this workshop, participants identified that there is significant value that is gained from undertaking a global collaborative approach to estimating the level and impact of seabird bycatch in pelagic longline fisheries, such as that undertaken at this workshop. Participants unanimously recommended that this process be repeated in the future in order to monitor impacts. Participants also recognised the continuing value in RFMOs undertaking ongoing monitoring of seabird bycatch on a regional basis.

Toolbox

Scripts for models that were used in this process have been reposited and are publicly available at https://github.com/seabird-risk-assessment/abnj-seabird-bycatch-analysis. It is planned that seabird distribution data, as derived from the analysis of seabird tracking data, will be made publicly available at the Global Seabird Tracking Database website (http://www.seabirdtracking.org). An expected outcome of the workshop was to generate guidance on which analytical approach was most suited under different scenarios of data availability (a toolbox). Participants discussed the outcomes from the analyses and agreed that in fact, the different analyses undertaken had produced largely comparable results. This was a welcome result, however, as a consequence, the analyses have not provided information to distinguish when a particular approach is suited over another. As such, participants agreed that it was not possible to use the results from these analyses to generate a toolbox for different data scenarios.

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Annex 1. List of participants

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Sebastián Jimenéz*^	Direccion Nacional de Recursos Aquaticos
Tom Peatman^	Pacific Community
Sarah Martin^	Indian Ocean Tuna Commission
Nathan Taylor^	International Commission for the Conservation of Atlantic Tunas
Nicolas Gutierrez Emelie Martensson	Food and Agricultural Organisation
Igor Debski^	Agreement on the Conservation of Albatross and Petrels
Cleo Small Ross Wanless Nini van der Merwe	Royal Society for the Protection of Birds/BirdLife International BirdLife South Africa/BirdLife International BirdLife South Africa
Joel Rice^	Rice Marine Consulting
Rishi Sharma^	National Oceanic and Atmospheric Administration
Stephanie Good^	University of Exeter
Edward Abraham^	Dragonfly Data Consulting
Gary Alport*	Observer (BirdLife International, 25-26 Feb)

* Participation funded from other sources

^ Participants who presented during the workshop

~ Partipant also part of project team

Annex 2. Annotated agenda

1. **Welcome:** Introductions and explanation of anticipated process and expected outcomes

2. **Review of existing information**: National estimates (data owners), Density surfaces (R Wanless), GAM method, (J Rice), INLA method (R Sant'Ana) and SEFRA work (E Abraham), Species Demographic Model (S Good)

3. **Discussion on estimates presented**: data availability, pros and cons of individual methodologies, what is required to achieve global seabird mortality estimates, how to compare estimates from different approaches, reducing CVs, etc

4. **Approaches for joint analyses:** Discuss and agree on type of analysis to be conducted during the workshop

5. **Data preparation and analyses**

6. **Break-out session:** RFMOs present on reporting requirements and discussion on improving reporting

7. **Discussion 1:** Identifying shortcomings within observer programmes

8. **Report on initial findings**, followed by brief discussion

9. **Presentation of final results**

10. **Discussion 2:** Characteristics of various seabird mortality estimation procedures (general characteristics, data requirement, robustness, impacts of partial data, extrapolation)

11. **Discussion 3:** Estimates of seabird LL bycatch mortality in the Southern Hemisphere

12. **Discussion 4:** How to facilitate future improvements

13. **Final discussion:** Contents to be included in the report, Vortex outcomes, Next steps (RFMO reporting, etc.)

14. **Report adoption**

Annex 3. Data request

Communication Regarding Analysis and Data for the Seabird Bycatch Assessment Meeting, 25 February – 1 March 2019

This communication is to inform the workshop participants regarding the expected outcomes, intended activities for achieving the goals, and a request for data preparation prior to the meeting. We would like to stress that the workshop itself (i.e the participants) is fully responsible to determine what analyses to do at the workshop, and how to report its outcomes to the outside audience, including the RFMOs.

OBJECTIVE

The main objective of the Kruger workshop is to agree on a range of estimates of seabird bycatch mortality caused by tuna longline fishing in the southern hemisphere, through careful review and comparison of various estimation methodologies at the meeting. To date, estimates of seabird bycatch are derived from standardizing observed seabird bycatch rates (generally collected by onboard observers) extrapolated to total effort. Confidentiality concerns mean that observed seabird bycatch data have not been shared broadly. As a consequence, never before have analyses been conducted with a comprehensive, combined dataset. In other words, analysis and estimation results currently available are all based on partially available information. This workshop seeks to explore options for making more reliable and comparable estimates, without compromising data ownership and confidentiality.

There are two options for analysis: one is to compare the results of analyses conducted on individual datasets, and the other is 'joint' analyses with temporarily assembled, comprehensive datasets. The first option allows for comparison of obtained results and exploration of divergent patterns, undertaking sensitivity analyses, and possibly additional model runs with certain data. Ultimately, this approach will allow individual results to be summed to estimate total bycatch. If appropriate, our expert consultants will be on hand to assist with running additional analyses during the workshop according to the decision taken at the meeting, but this should ideally be done on standardised data tables indicated below. The second option (which may be undertaken in addition to the first option) intends to run a range of models with data assembled at the meeting, in particular to clarify pros and cons of a range of models and to evaluate sensitivities of models to a temporal and spatial coverage of input data. Should a combined dataset be constructed at the workshop, it will exist only during the meeting (February 25 - March 1 2019). Any intermediate files produced within a process of 'joint' analyses and combined dataset will be destroyed at the end of the meeting.

REQUEST

All data owners participating in the meeting are kindly requested to consider whether it is possible to join the collaborative activity indicated above. In the interest of saving time, we would like to request all data owners that are interested in undertaking standardised analyses with their own data, and/or joining the combined analyses, to bring their observer data in the format described below. This represents the broadly accepted level of granularity of data sharing as much as possible, while reflecting the need of species-level bycatch information for some methods. Please be informed

that the seabird distribution data will be available to the meeting subject to similar caveats.

Data formatting guidelines for estimating seabird Bycatch in surface longline fisheries using a species-specific model

The assessment of seabird bycatch at the species level requires data on observed fishing effort, and observed captures of seabirds. This information is needed in 5-degree spatial resolution, at quarterly (three-monthly) time resolution, for all surface-longline fishing south of the equator. I n order to easily include your data in the analysis, we will need the following information:

- For each 5-degree by 5-degree latitude-longitude cell (with the borders at latitudes and longitudes evenly divisible by 5);
- For each year (up to 2016, and covering the period when seabird captures, across all species, are considered to be reliably recorded);
- For each quarter (where Quarter 1 is January to March, Quarter 2 is April to June, Quarter 3 is July to September, and Quarter 4 is October to December);
- For each surface longline fishery that should be treated distinctly (for example, due to target species, or vessel size, this should group together effort that has similar characteristics from the point of view of potential seabird bycatch);
- The total number of hooks observed;
- The total number of seabirds observed caught;
- For each species or species-group code that you have in your data, a column giving the total number observed caught. Use FAO species codes where possible, or provide a description of the species codes that you have used, so that they can be analysed together with other datasets.

ACAP have published a useful guide that includes the species codes[1].
Please include all seabirds reported caught.

Example format

Provide the data as a CSV format file, e.g. 'nz_captures.csv', with the following columns:

Latitude: the latitude of the center of the cell, e.g. 162.5
Longitude: the longitude of the center of the cell, e.g. -47.5
Year: the calendar year, e.g. 2014
Quarter: the quarter of the year, e.g. 2
Fishery: A description of the fishery, e.g. ‘small vessel albacore’
Observed hooks: The total number of hooks recorded by observers, e.g. 16500
total seabirds: The total number of seabirds captures observed in the area and time-period, e.g. 3
DIM: The number of black-browed albatross captures observed, e.g. 0
ALZ: The number of unidentified albatross captures observed, e.g. 2
MAH: The number of northern giant petrel captures observed, e.g. 1
(… add more columns for each species or species-group recorded by observers, these columns should add to `total_seabirds`)

Please also provide a short description of the species codes used, and of the fisheries.

Help

Contact Edward Abraham (edward@dragonfly.co.nz) for assistance with preparing the data; to check your data before the meeting; or if you have any questions about the analysis.

[1] https://www.ccamlr.org/en/system/files/ACAP_Bycatch_ID_Guide_A5_EN_WEB_August_1.pdf

Annex 4. Seabird tracking data meta data table

The proportion of seabird populations for which tracking data area available are shown in Table 6 for each of the 25 species included in the analysis. The number of breeding pairs was obtained from information provided by the Association for the Conservation of Albatrosses and Petrels (ACAP; see https://www.acap.aq). Note that for some species, such as white-chinned petrel, there are further colonie, with unknown numbers of breeding pairs, that were not included in the estimate of the total number of breeding pairs.

Table 6. Availability of seabird tracking data: population size (annual breeding pairs) for the species included in the analysis; the number of breeding pairs at colonies that were included in the tracking distributions; and the proportion of the total population (%) that were at colonies that were included in the tracking distributions.

Species	Population	Population for which tracking data were available	
	Pairs	Pairs	Percentage
Amsterdam Albatross	46	46	100.0
Antipodean Albatross	8175	8167	99.9
Atlantic Yellow-nosed Albatross	28388	38	0.1
Black Petrel	1059	1059	100
Black-browed Albatross	501249	361863	72.2
Buller's Albatross	22254	1022	4.6
Campbell Albatross	21648	0	0.0
Chatham Albatross	5245	5245	100
Grey Petrel	77603	48960	63.1
Grey-headed Albatross	93077	43046	46.2
Indian Yellow-nosed Albatross	28952	0	0.0
Light-mantled Albatross	9103	445	4.9
Northern Giant Petrel	9617	623	6.5
Northern Royal Albatross	5781	5744	99.4
Salvin's Albatross	41214	1213	2.9
Shy Albatross	13834	0	0.0
Sooty Albatross	8440	2766	32.8
Southern Giant Petrel	46978	2306	4.9

Southern Royal Albatross	7929	0	0.0
Spectacled Petrel	14400	14400	100
Tristan Albatross	1108	1106	99.8
Wandering Albatross	8176	4321	52.8
Westland Petrel	2827	2827	100
White-capped Albatross	95917	95894	100
White-chinned Petrel	935096	642783	68.7
Total	1988116	1243874	62.6

Annex 5. SBRE

Name of method	Stratified Ratio Based Estimator
Brief description of method	Bycatch data was estimated by fleet and ocean based on the combined dataset or literature if the stratification was missing. Associated fleets BPUE were applied to other fleets where data were not available.
Data input	Set-level observer data: flag; location; and, year. This was either estimated using the combined dataset produced at the Kruger meeting or through the dataset generated at the South Africa meeting or through literature based estimates.
Assumptions	Observed bycatch rates are representative of unsampled fleet and strata. Set-level observations within trips are independent.
Strengths in relation to seabird bycatch estimation	Homogenous variance across cells, and only variables explaining changes are the fleet and ocean stratification. Parsimonious and easy to implement as effort data is readily available.
Weaknesses/ limitations in relation to seabird bycatch estimation	Coarse scale assumptions used. I would not recommend this method over INLA or GAM or SEFRA as that estimates BPUE based on other covariates, and the data available and applies spatial structure to the missing cells. This assumes variance is homogenous across cells, and is explained by 2 variables, fleet and ocean and though parsimonious may not capture the true dynamics.
Impacts of input data granularity e.g. set by set or 5x5	NA
Impacts of limited temporal/ spatial coverages for estimation	NA
Potential areas for improvement	Further stratification could occur but coverage for most fleets is limited, and literature based data doesn't specify seasonality in most cases. Hence a coarse annual scale estimation was used. At the very least, stratifying by quarter and breeding season would be useful to include.

Annex 6. GAM

Variations of these and other models treating fishery and flag as random effects were also examined, but these models did not converge.

These model formulations include a flag effect which creates a challenge of how to appropriately assign the flag-effect to fleets with no observer data. Japan's bycatch data were selected to represent unobserved fleets on the basis that this was the only available dataset with wide geographic coverage that provided contrast in BPUE across longitude and latitude gradients. Residuals indicate a reasonably good fit for both models overall. Both models indicated that the low bycatch events were best estimated and the models had poorer ability to predict high bycatch events, which is to be expected. Nevertheless, the influence of relying on a strong assumption about a fixed flag effect to predict BPUE for unobserved fleets was noted to be a source of uncertainty can cause bias. Estimated BPUE had high variability within year-quarter 1.

Name of method	Generalized Additive Models (GAM)
Brief description of method	The bycatch rate model was fitted to aggregated dataset distributed between 20° and 60° S, across all oceans. The data set was aggregated per 5° by 5°, season, year, quarter, and fleet flag. Tweedie errors were assumed, with a log link function. The response variable was the observed seabird bycatch rate (number of total seabirds caught per 1000 hooks) for that (area, season, year, and fleet) strata. Two GAMs were fit to the data set with the following forms, with GAM 1 modelling the response variable (BPUE) as a function of density by quarter and flag, and GAM 2: modelled BPUE as a function of latitude by season plus density and flag effect. In both cases density was log transformed, and Tweedie errors were assumed. GAM 1: BPUE ~ s(density| quarter) + flag. GAM 2: BPUE ~ s(latitude | season) + s(density) +flag
Data input	Aggregated-level observer data: flag; location latitude, longitude (at 5° resolution); year; season; seabird density distribution; seabird bycatch rate (number of birds per 1000 hooks). Explanatory variables that were coded as a factor included flag; season, year, a smooth function for seabird density distribution and latitude was used.
Assumptions	Observed bycatch rates are representative of total bycatch rates for a given fleet operating in a location and season. The observed fleets are a good and representative sample of the seabird bycatch capacity of the non-observed fleets.
Strengths in relation to seabird bycatch estimation	The distinct approaches used leads to very close estimations, this pattern could provide some reliability of the results observed here. The possibility in to use the seabird density distribution was a good proxy to the explanations of seabird bycatch.
Weaknesses/ limitations in relation to seabird bycatch estimation	The approach relies on observer data to inform spatial and seasonal variation in bycatch, so bycatch rates may be less accurate in regions with limited observer coverage. The

	aggregations in dataset could implies in misunderstandings of specific patterns in seabird bycatch. Using aggregated dataset, some possible influences in maximizations or minimizations effects in seabird bycatch could be lost.
Impacts of input data granularity e.g. set by set or 5x5	The aggregations in dataset could implies in misunderstandings of specific patterns in seabird bycatch (daylight influences, moon illumination, mitigation measures and others). Using aggregated dataset, some possible influences in maximizations or minimizations effects over seabird bycatch probably could be lost.
Impacts of limited temporal/ spatial coverages for estimation	The temporal fluctuations were not applied in the models. The spatial distribution could be improved to areas that was knew that exist important fisheries and seabirds interactions and were not included in these models but were predicted to.
Potential areas for improvement	If data were available about the catch composition relating to the observer data set, a more detailed analysis of fleet level effects could refine the estimate. This could provide more information to the models which in turn could increase the understandings of the fleet/fishery level effects on seabird bycatch. The exercise could be repeated by ocean basin, or smaller study areas.

783 ## Annex 7. INLA

Name of method	Integrated Nested Laplace Approximations (INLA)
Brief description of method	The INLA is a Bayesian approach proposed to perform fast Bayesian inference in Latent Gaussian Models. The model complexity of considering spatial and spatial-temporal structures with large datasets could lead to several time of computational work, principally if was used some kind of simulations. The Integrated Nested Laplace Approximation uses numeric integration methods to get marginals distributions to posteriors and thus fixing most of the computational problems involved in complex spatial or spatial-temporal models. The bycatch rate model was fitted to aggregated dataset distributed between 20° and 60° S and extended over all oceans. The data set was aggregated per 5° by 5°, season, year and fleet flag. Negative binomial errors were assumed, with a log link function. The response variable was the number of total seabirds caught by the observed fleets and combined in one unique discrete random variable.
Data input	Aggregated-level observer data: flag; location (5° x 5°); year; season; seabird density distribution; number of hooks. Explanatory variables included: flag; a Besag spatial structure of order 2 between the 5° by 5° square locations; a smooth function for seabird density distribution. Season and year were not directed used as explanatory variables in models. They were used as proxies to changes in spatial correlations. In the case the *year* variable, this variable was used as a replication of the spatial correlations between years, without any temporal correlation structure beyond them. For the variable *season*, it was used as a group variable with a temporal autoregressive structure between the seasons.
Assumptions	Observed bycatch rates are representative of total bycatch rates for a given fleet operating in a location and season. The observed fleets are a good and representative sample of the seabird bycatch capacity of the non-observed fleets.
Strengths in relation to seabird bycatch	The distinct approaches used leads to very close estimations, this pattern could provide some reliability of the results observed here. The use of the seabird density distribution was

estimation	a good proxy to the explanations of seabird bycatch.
Weaknesses/ limitations in relation to seabird bycatch estimation	The approach relies on observer data to inform spatial and seasonal variation in bycatch, so bycatch rates may be less accurate in regions with limited observer coverage. The aggregations in dataset could imply misunderstandings of specific patterns in seabird bycatch. Using aggregated dataset, some possible influences in maximizations or minimizations effects in seabird bycatch could be lost.
Impacts of input data granularity e.g. set by set or 5x5	The aggregations in dataset could imply misunderstandings of specific patterns in seabird bycatch (daylight influences, moon illumination, mitigation measures and others). Using aggregated dataset, some possible influences in maximizations or minimizations of these effects on seabird bycatch probably could be lost.
Impacts of limited temporal/ spatial coverages for estimation	The temporal fluctuations were not applied in the models. The spatial distribution could be improved to areas that was knew that exist important fisheries and seabirds interactions and were not included in these models but were predicted to.
Potential areas for improvement	Set-level data could be used along with the same global effort used here. This could provide more information to the models that could be possible to maximize the understandings of the effects in seabirds bycatch. The exercise could be repeated but the models could be longitudinal segregated.

Annex 8. SEFRA

In this application of the risk assessment method, the susceptability was assumed to be the same for all seabirds within each of five genera (*Diomedea, Thalassarche, Phoebetria, Procellaria*, and *Macronectes*). The catchability expresses how likely different fleets are to catch seabirds. Catchability was assumed to be the same for all fishing by vessels of each fleet. Population productivity was estimated as the Population Sustainability Threshold (PST; Sharp 2016). This measure is 0.25 rmax N, where rmax is the maximum population growth rate, and N is the total population size. The PST was derived from the Potential Biological Removals (PBR) measure developed in the United States for managing the impacts of fishing on marine mammals (Wade 19XX), and applied to seabirds by Dillingham (20XX).

Care was taken to account for birds that were only identifed as seabird, albatross , or petrel captures. Within the estimation, these were imputed to the species level, following methods similar to those used for unidentifed marine mammals (Abraham 20XX).

Name of method	Spatially Explicit Seabird Risk Assessment (SEFRA)
Brief description of method	The seabird risk assessment followed the methods developed for estimating seabird captures in New Zealand fisheries (Spatially Explicit Fisheries Risk Assessment, SEFRA; Sharp 2016, Abraham et al 2017a, b), and subsequently applied to the capture of Diomedea species in southern hemisphere longline fisheries (Ochi et al 2018). The risk assessment estimates the capture of each species in fisheries, based on the overlap between seabird distributions and fishing effort. The estimated captures are then related those to a measure of seabird population productivity, allowing for the impact of fishing on each species to be quantified. The model was fitted as a Bayesian hierarchical model, using the Stan modelling language. The model code used for this analysis (but not the data) is openly available online.
Data input	• Observed fishing effort • Observed seabird captures, by species • Total fishing effort All data were aggregated by five-degree cell, by quarter, and by flag.
Assumptions	The core assumption of the method was that the capture of seabirds is proportional to the overlap between seabird distributions and fishing effort—seabird captures do not occur where there is no fishing, nor do they occur where seabirds are not present. The constant of proportionality is given by the product of a susceptability, and a catchability. The susceptability expresses how likely different groups of seabirds are to be caught in fisheries. In this application of the risk assessment method, the susceptability was assumed to be the same for all seabirds within each of five genera (*Diomedea*, *Thallasarche*, *Phoebetria*, *Procellaria*, and *Macronectes*). The catchability expresses how likely different fleets are to catch seabirds. In this application, the catchability was assumed to be the same for all fishing by vessels of each flag. The overlap between seabirds and fisheries was calculated using seabird distributions derived from tracking data, where they were available (A Carneiro *in litt*). Range maps provided by BirdLife International were used in place of distributions for Indian yellow-

	nosed *Thalassarche steadi*, grey-headed *T. chrysostoma*, Campbell black-browed *T. impavida*, Buller's *T. bulleri*, shy albatross *T. cauta*, sooty *Phoebetria fusca*, and light-mantled *P. palpebrata albatrosses*, southern giant *Macronectes giganteus*, northern giant *M. halli*, white-chinned *Procellaria aequinoctialis* and grey *P. cinerea* petrels. While distributions derived from tracking data were available for white-chinned petrel, Buller's, light-mantled and sooty albatrosses, more than 10% of the observed captures of these species in the combined data were outside of the range of the distributions, so they were replaced with range maps. No tracking data were available for southern royal albatross *Diomedea sanfordi*, however northern royal albatross *D. epomophora* was used as a proxy. For Atlantic yellow-nosed albatross *T. chlororhynchos*, the tracking distribution from Gough Island was used to represent the distribution of birds from Tristan da Cunha. Unlike applications of the SEFRA method within New Zealand, survivability was not considered (so all live released birds were assumed to die), and no cryptic mortality was included (i.e. no allowance was made for birds that may have been caught during setting but fallen off the hook before the haul). Estimates were made of the annual average captures during 2016 for each seabird species, using two different methods for extrapolating to unobserved fleets: SEFRA1, the flag-specific method, assuming that fishing by unobserved fleets has the same catchability as one of the fleets; or SEFRA2. the fleet-averaged method, randomly assigning an observed fleet to fishing by unobserved fleets.
Strengths in relation to seabird bycatch estimation	They key strength of the method was that it allowed for estimating the bycatch of each species, and allowed for the impact of the bycatch to be estimated.
Weaknesses/ limitations in relation to seabird bycatch estimation	The approach is strongly dependent on accurate seabird distributions, which are not available for many species, or for all life stages. The approach requires accurate seabird identification data, which is not currently available for many fleets.
Impacts of input data granularity e.g. set by set or 5x5	The method is straightforwardly applied to aggregated data.
Impacts of limited temporal/ spatial coverages for estimation	The model may not accurately separate inter-fleet variation and spatial / seasonal variation.
Potential areas for improvement	• Including a species-specific susceptibility, which would require resolving issues related to unidentified captures. • Improving seabird distribution information • Improving resolution of fleets, to allow for variation of catchability between fleets that use different mitigation, for example.

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Name of method	Population Viability Analysis (PVA) in VORTEX v10
Brief description of method	Bycatch impacts were modelled for five albatross populations where good demographic information was available using the PVA tool VORTEX (v10, Lacy and Pollack 2014). The VORTEX program simulates the effects of deterministic forces as well as stochastic events on wildlife populations using the Monte Carlo method (Lacy et al 2018). For this analysis, population-level models were run with 1000 iterations. Demographic stochasticity was not considered but annual fluctuations in birth and death rates due to environmental variation were included. Five scenarios were examined for each population – a baseline scenario using estimates of adult survival with no anthropogenic impacts and four scenarios with removal of individuals based on the outputs of the SEFRA model, including two where a multiplier was applied to account for cryptic mortalities.
Data input	Demographic information: Maximum age reproduction, Maximum lifespan, Maximum broods per year, Maximum progeny per brood, Mate monopolization, Age for first offspring, Sex ratio at birth, Percent females breeding (breeding frequency), Age-based mortality rates, Starting population size (no. individuals) Bycatch information: Capture numbers per population from SEFRA model are treated as mortalities. To account for cryptic mortality a multiplier of 2 was applied to the bycatch total for the population (based on Brothers et al 2010). The total bycatch was split into age-and-sex-class mortalities according to the proportion of each in the overall population in all cases except for Wandering albatross from South Georgia, where information from studies on age and sex bias in tropical longline fisheries for this species (taken from Gianuca et al 2017) was used to assign proportion.
Assumptions	Demographic information: Demographic rates inputted from the literature are accurate. Adult mortality levels used from allometric modelling (Ochi et al 2018) do not already include anthropogenic mortality, so are near 'optimal' for that population. Populations modelled using stable age distributions. Environmental variability applied to each demographic parameter is appropriate. There are not strong impacts from density dependence or carrying capacity, as these are not accounted for in the model. Bycatch information: Number of captures are equal to number of mortalities. The cryptic mortality multiplier of 2 is appropriate. Age and sex bias in the bycatch information is as described. Bycatch rates per year are stable over time.
Strengths in relation to seabird bycatch estimation	Allows comparison of potential impacts on a population in different scenarios (i.e. with different levels of mortalities). Allows sensitivity testing of parameters applied. Open-source software that has been previously used to estimate anthropogenic impacts for marine

	megafauna, including seabirds.
Weaknesses/ limitations in relation to seabird bycatch estimation	There are a number of assumptions (see above) that mean the results should be viewed with these in mind.
Impacts of input data granularity e.g. set by set or 5x5	NA
Impacts of limited temporal/ spatial coverages for estimation	NA
Potential areas for improvement	Calibrate results with outputs from other models, including PST and risk ratios per species from SEFRA model.

Wandering albatross – South Georgia

A PVA model for Wandering albatross in South Georgia using optimal adult survival (Richard et al. 2017) and no bycatch resulted in population growth of ~0.4% per year. However, under each of the bycatch scenarios the population would decline (Figure A9-1). The worst-case scenario resulted in annual change of -1.9% per year with a 91% probability that the population would decrease to 50% of the initial population size within 50 years.

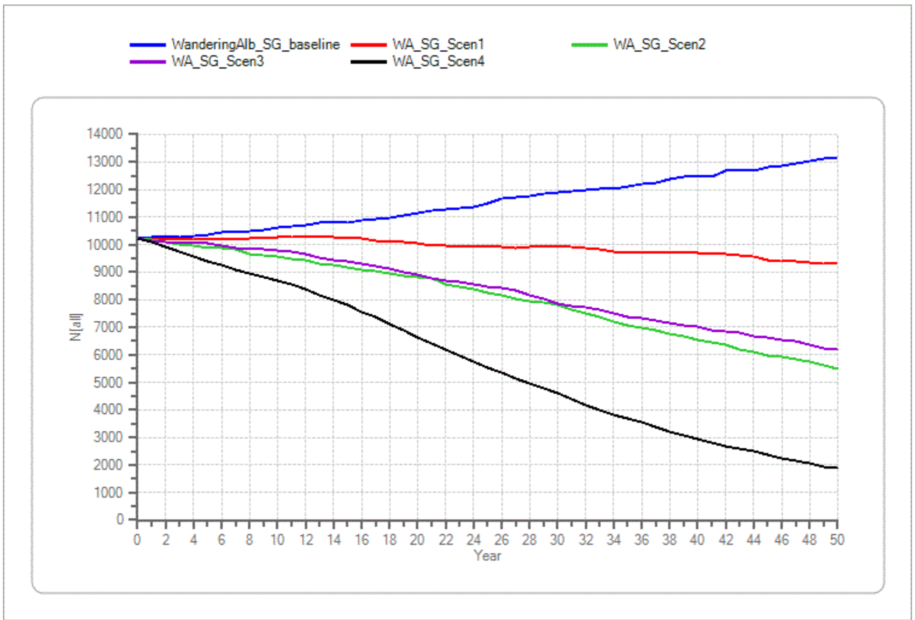

Figure A9-1. Population size of Wandering albatross breeding at South Georgia over 50 years in five scenarios: Baseline (no bycatch), Scenario 1 (Fleet average mean, n=54), Scenario 2 (Fleet average including cryptic, n=108), Scenario 3 (Flag-specific mean, n=98), Scenario 4 (Flag-specific including cryptic, n=196).

Wandering albatross – Indian Ocean

Wandering albatross breeding in the Indian Ocean at Crozet, Kerguelen and Prince Edward Islands were assessed together. The optimal demographic parameter and no bycatch model indicated that this population has a slight growth of 0.4% per year (Figure A9-2). Under bycatch scenario 1 the population would still have a slight growth. The other three scenarios would lead to population declines of -0.1 to -0.8%.

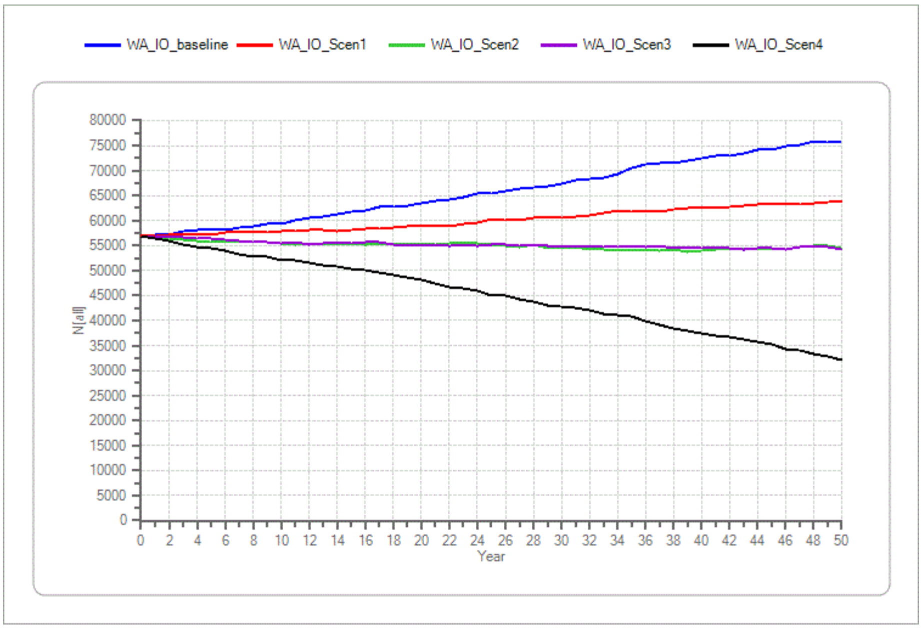

Figure A9-2. Population size of Wandering albatross breeding in the Indian Ocean over 50 years in five scenarios: Baseline (no bycatch), Scenario 1 (Fleet average mean, n=220), Scenario 2 (Fleet average including cryptic, n=440), Scenario 3 (Flag-specific mean, n=399), Scenario 4 (Flag-specific mean including cryptic, n=798).

Tristan albatross

The Tristan albatross is the only species included in this analysis that starts with a negative growth rate in the scenario with no bycatch. This is because of the very high mortality of chicks due to mouse predation (Wanless et al. 2009). Any additional mortality simply causes a steeper decline. Scenarios 2-4 indicate that the species c become extinct within 50 years (Figure A9-3).

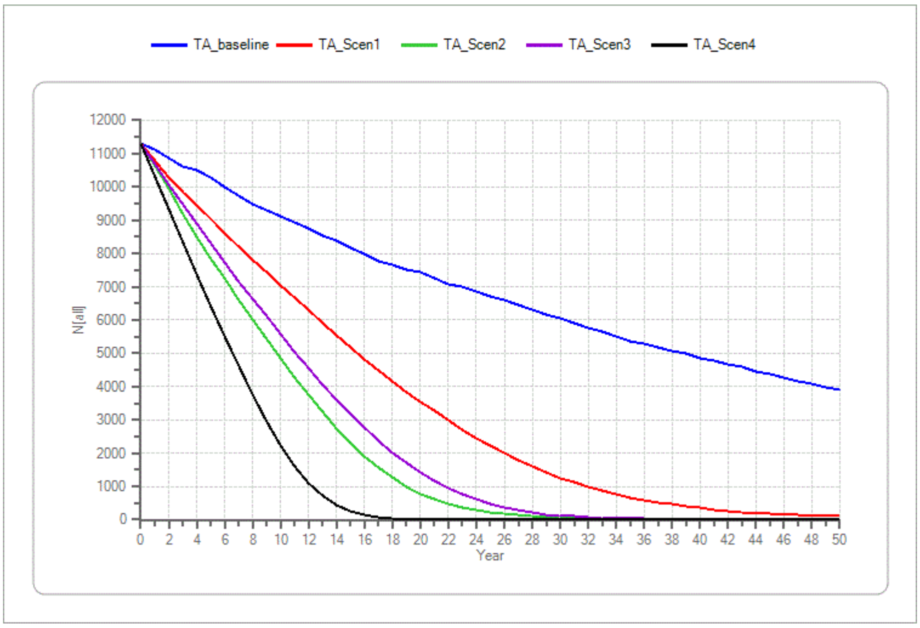

Figure A9-3. Population size of Tristan albatross over 50 years in five scenarios: Baseline (no bycatch), Scenario 1 (Fleet average mean, n=238), Scenario 2 (Fleet average including cryptic, n=476), Scenario 3 (Flag-specific mean, n=395), Scenario 4 (Flag-specific including cryptic, n=790).

Antipodean albatross (Antipodes Island)

The population of Antipodean albatross breeding at the Antipodes Island had a positive growth rate of 0.25% per year in the baseline scenario (Fig A9-4). Scenarios 1 and 3 also had a positive growth rate but scenarios 2 was stable and scenario 4 had a negative growth rate of -0.27% per year.

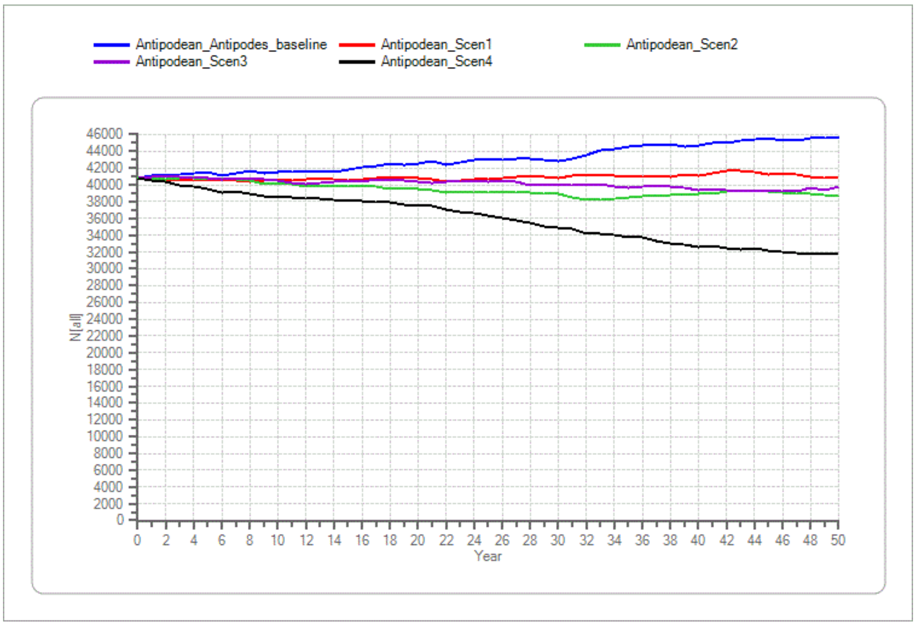

Figure A9-4. Population size of Antipodean albatross breeding at Antipodes over 50 years in five scenarios: Baseline (no bycatch), Scenario 1 (Fleet average mean, n=98) Scenario 2 (Fleet average including cryptic, n=196), Scenario 3 (Flag-specific mean, n=156), Scenario 4 (Flag-specific Japan including cryptic, n=312).

Antipodean albatross (Gibson's albatross)

The SEFRA method and dataset did not discriminate between Antipodean and Gibson's albatrosses, but the "Antipodean" bycatch estimate was disaggregated post-hoc to provide colony-specific bycatch numbers. Under the baseline scenario there was a population growth rate of ~1.5% per year. Under bycatch scenarios 2 and 4, however, the model indicates a decline of -0.62% and -1.6% respectively (Figure A9-5).

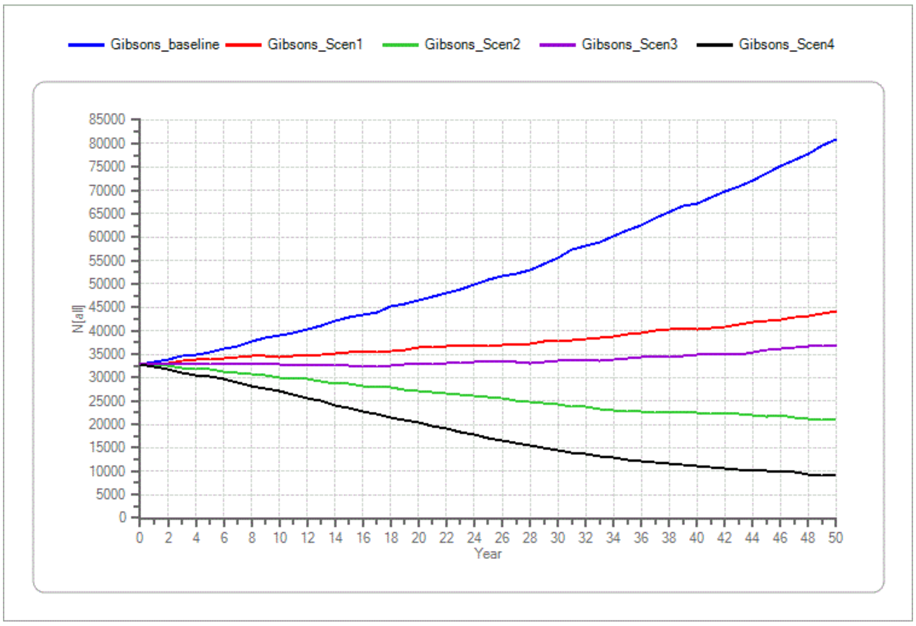

Figure A9-5. Population size of Antipodean (Gibson's) albatross over 50 years in five scenarios: Baseline (no bycatch), Scenario 1 (Fleet average mean, n=402) Scenario 2 (Fleet average including cryptic, n=804), Scenario 3 (Flag-specific mean, n=514), Scenario 4 (Flag-specific including cryptic, n=1028)