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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

This report has been prepared by BirdLife South Africa, with financial support from GEF and FAO
Approved and adopted by workshop participants
on 1 March 2019

With financial support from:



Food and Agriculture Organization
of the United Nations



32 **Workshop Report**

33 **Project:** FAO-GEF Project *Sustainable Management of Tuna Fisheries and Biodiversity Conservation in*
34 *the ABNJ (GCP/GLO/365/GFF)*

35 **Reporting organisation:** BirdLife South Africa

36 **Report prepared by:** BirdLife South Africa

37

38 **Report of the Final Seabird Bycatch Assessment Workshop**
39 **25 February – 1 March 2019**

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

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

51 **Background**

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

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

72 The seabird bycatch component of the Common Oceans Project held a series of workshops to
73 facilitate a collaborative assessment of seabird bycatch, and to address the urge to strengthen
74 national scientist capacity to analyse bycatch data. Three preparatory workshops were held in
75 2017/18 to bring together experts, national scientists and institutions working with seabird bycatch
76 data from vessels operating south of 25°S.

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

79 Workshop Objectives

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

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

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

93 Methods

94 Metadata and descriptive statistics

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

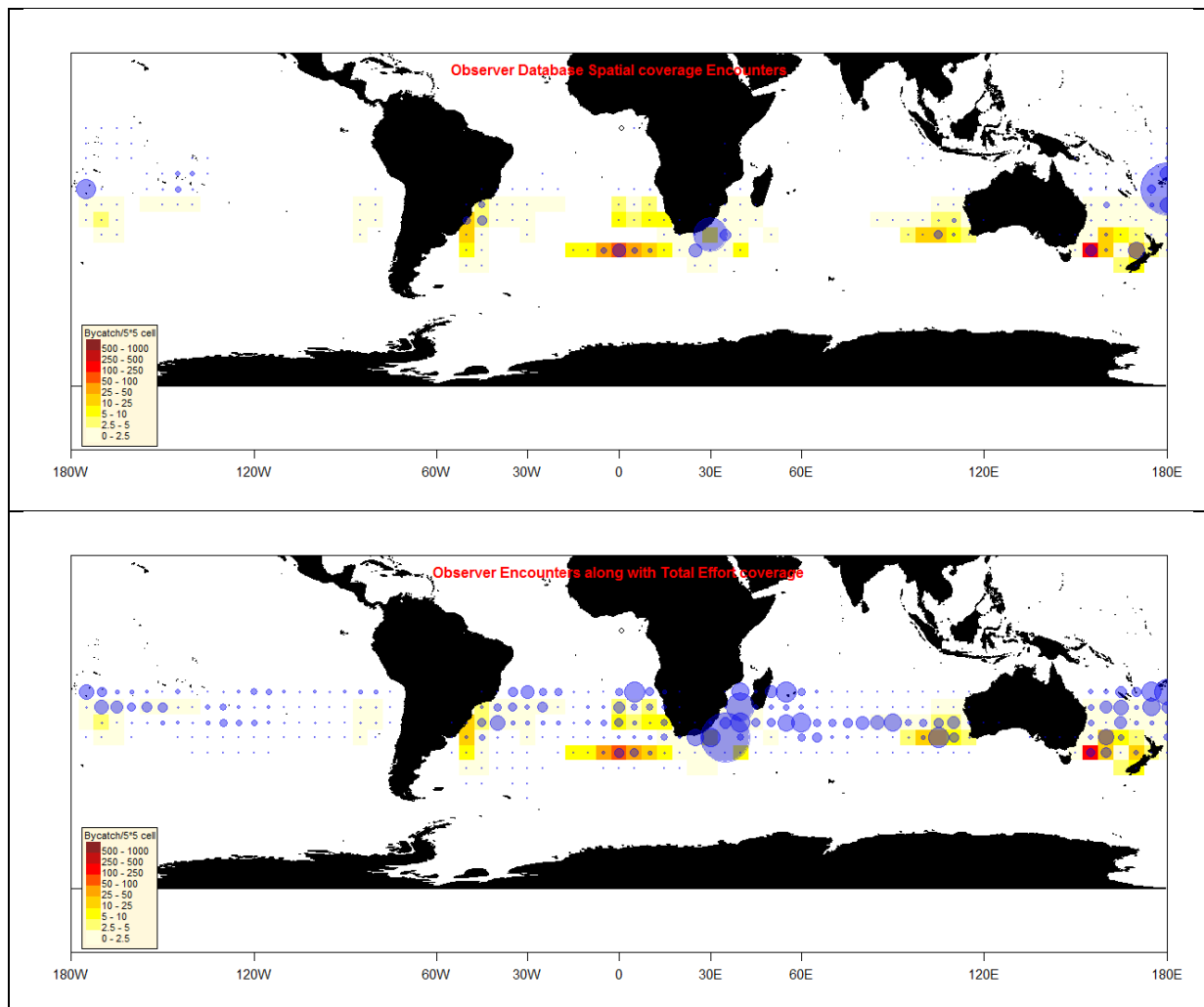
100 Table 1. Summary of data attributes of the JDS that was assembled for the purposes of the
101 workshop, reflecting total and observed surface longline fishing effort (in millions of hooks) south of
102 20°S

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

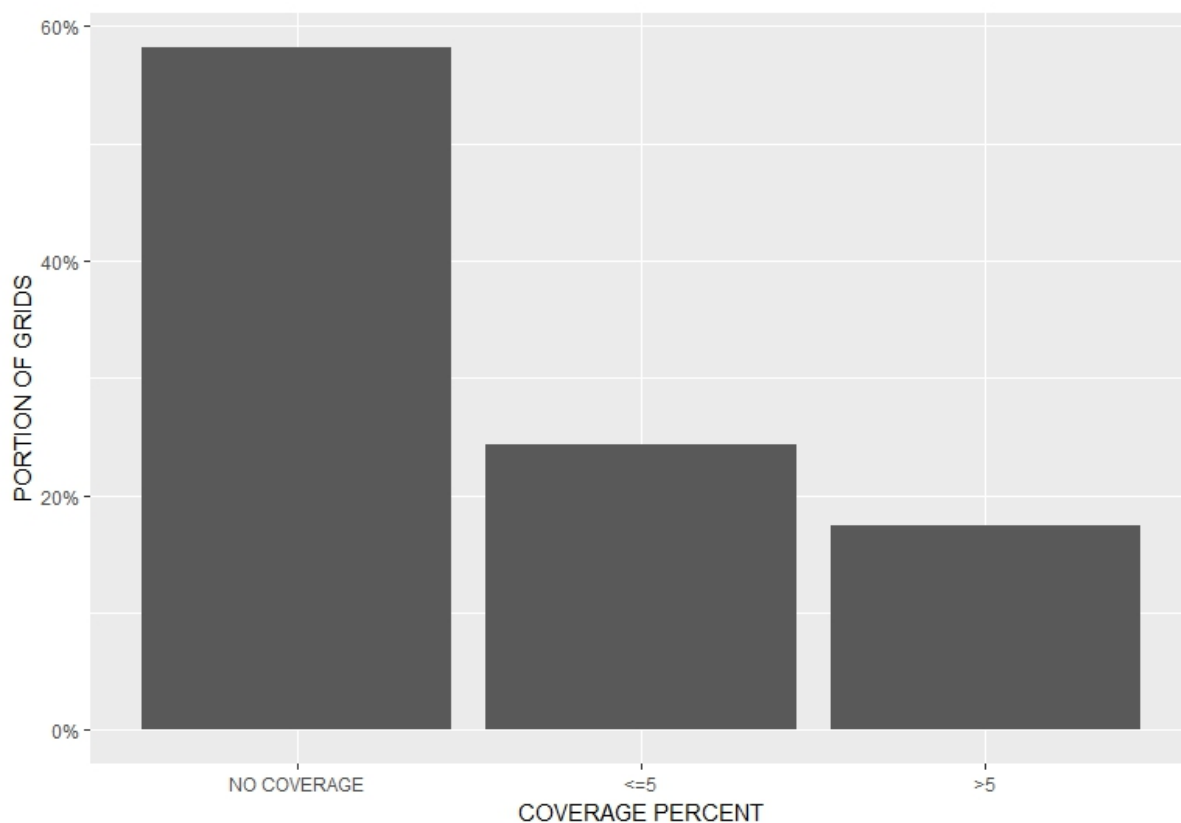
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104 The JDS assembled for the purposes of this workshop represents, to our knowledge, the largest and
105 most comprehensive dataset ever compiled in relation to analysis of seabird bycatch in pelagic
106 longline fisheries. Nevertheless, a comparison between the observed fishing effort, defined as hooks
107 fished with an observer onboard, (Figure 1) identifies that observer data is not proportionally
108 sampled. Overall, only 12% of 5x5 grid cells have observed coverage $\geq 5\%$ of total effort (Figure 2),
109 and coverage is particularly non-representative in the Eastern Pacific Ocean (Figure 1). The temporal

110 coverage has improved over time, and recent coverage is fairly similar across year-quarters (Figure
 111 3). Cells where coverage was $\leq 5\%$ are displayed in Figure 4. It was noted that zero observed effort
 112 would have the most impact when occurring in cells in which there was high fishing effort.



113
 114 **Figure 1: Upper panel shows spatial distribution of total number of observed birds caught (indicated by colour)**
 115 **compared to distribution of observed effort (indicated by size of the blue circle, scaled by 800K hooks), per 5x5 grid cell,**
 116 **for the period between 2012-2016. The lower panel indicates total pelagic longline fishing effort distribution reported by**
 117 **t-RFMOs in the period 2012-2016 (scaled by 5 million hooks), compared to total number of birds caught 2012-2016. Both**
 118 **figures are scaled to the largest circle scaled by circle area.**

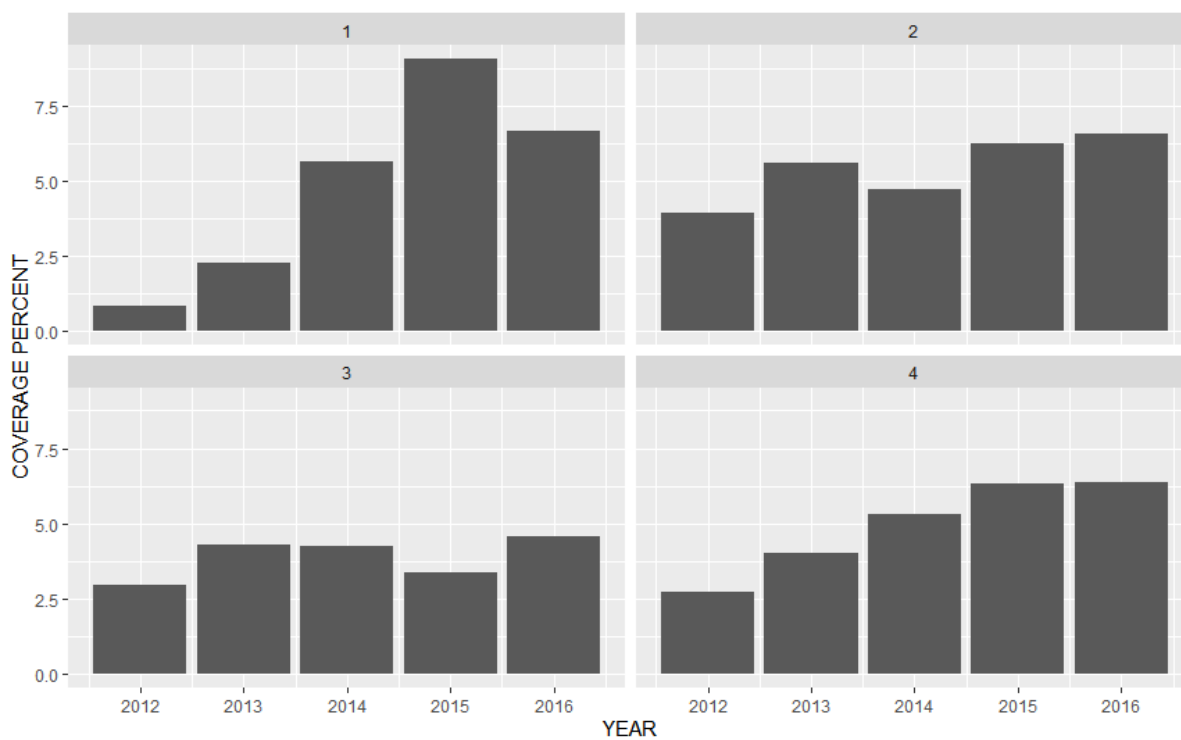


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120

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

121

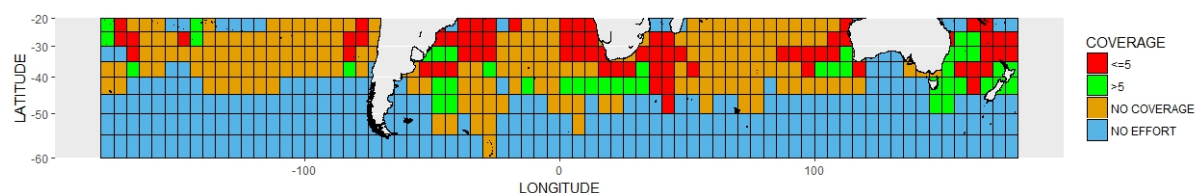


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123

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

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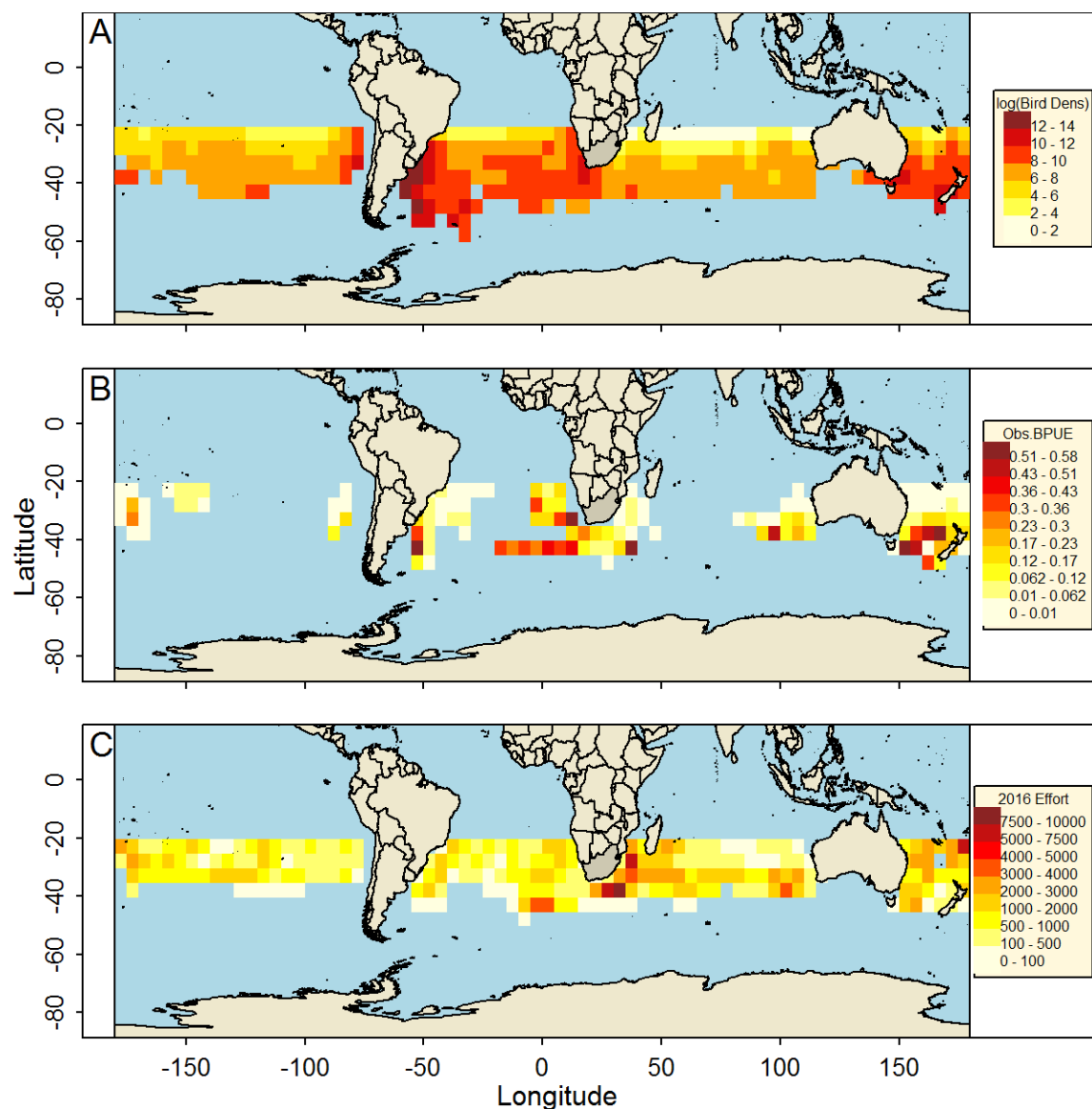


125
126 **Figure 4: Distribution of coverage globally by area indicating where we have observer coverage greater (or less than) 5%**
127 **and where no observer coverage exists on a 5*5 area.**

128

129 **Seabird density surfaces**

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



144
 145 **Figure 5. Comparison of seabird density distribution with total fishing effort and observed seabird bycatch in 2016.**
 146 **Panels indicate seabird density surface from tracking data (A), observed seabird bycatch per 1000 hooks (BPUE) for 2016**
 147 **(B) and total fishing effort by 1000 hooks for 2016 (C).**

148
 149 **Fine-scale observer datasets**

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

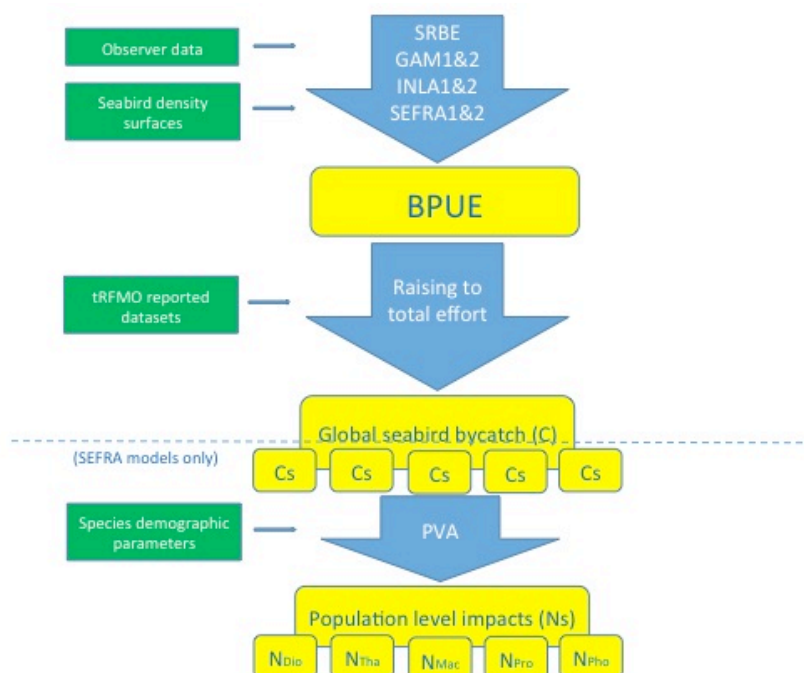
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158 **Data Analysis**

159 The overall assessment approach comprised a number of stages (Figure 6). Firstly, a range of
 160 different methods were used to attempt to generate an estimate of bird bycatch rates (BPUE). This
 161 included the use of a simple Stratified Ratio Based Estimate (SRBE), Generalised Additive Models
 162 (GAMs), Integrated Nested Laplace Approximations (INLA) and a Spatially Explicit Fisheries Risk
 163 Assessment (SEFRA). For each method, the best model was selected (x2 for the GAMs).
 164

165 These estimates of bycatch rates were then scaled to the total effort using effort data reported by
 166 the various tRFMOs, to generate total estimates of the numbers of seabirds caught globally (a
 167 'Global C'. A range of different methods were used to scale the estimates: for SRBE the bycatch of
 168 unobserved fleets was estimated from proxy fleets; for the GAMs, INLA and SEFRA this was
 169 estimated using the Japanese fleet effect (selected based on expert opinion amongst workshop
 170 participants, see Annex 6); and for the INLA and SEFRA methods a random fleet effect was also used
 171 to generate estimates.
 172

173 To assess the population level impacts of these seabird captures, a Population Viability Analysis
 174 (PVA) was used. Species-specific estimates, derived from the SEFRA models, were used as inputs to
 175 PVA models for five key species for which good demographic data were available. The SEFRA
 176 approach uses Population Susceptibility Threshold (PST) values, which estimates risk of negative
 177 population growth.
 178



179
 180 **Figure 6: A flow chart showing the overall assessment approach and various stages followed. SRBE = Stratified Ratio-**
 181 **based Estimate, GAM = Generalized Additive Model, INLA = Integrated Nested Laplace Algorithm, SEFRA = Spatially**
 182 **Explicit Fisheries Risk Analysis, PVA = Population Viability Analysis. Subscripts denote potential taxon-specific estimates.**
 183 **In the case of SEFRA, the model does not estimate a BPUE, but a species-specific vulnerability to being caught.**

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

189

190 **Stratified Ratio-based Estimate (SRBE)**

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

199 **Generalized Additive Models (GAM)**

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

207 **Integrated Nested Laplace Approximation (INLA)**

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

216 **Spatially Explicit Fisheries Risk Assessment (SEFRA)**

217 The seabird risk assessment followed the methods developed for estimating seabird captures in New
218 Zealand fisheries (Spatially Explicit Fisheries Risk Assessment, SEFRA; Sharp 2016, Abraham et al.
219 2017a, b), and subsequently applied to the capture of *Diomedea* albatrosses in southern hemisphere
220 longline fisheries (Ochi et al 2018).

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

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

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

234 Modelling impacts of bycatch on key albatross species/populations

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

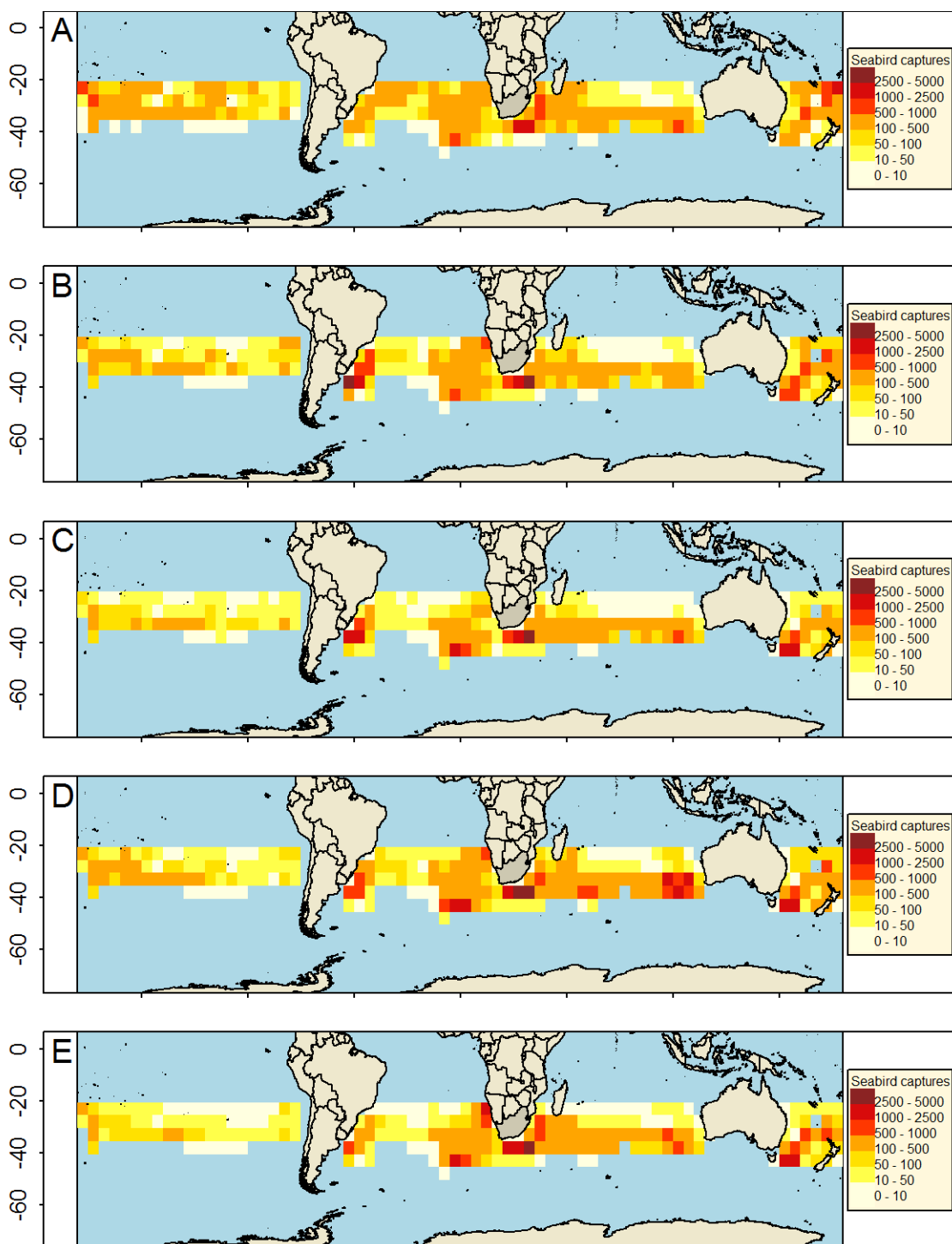
248 Results

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

254 Table 2. Mean estimated seabird bycatch for 2016, with 95% confidence/credible intervals (*). JPN =
255 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

256



257

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

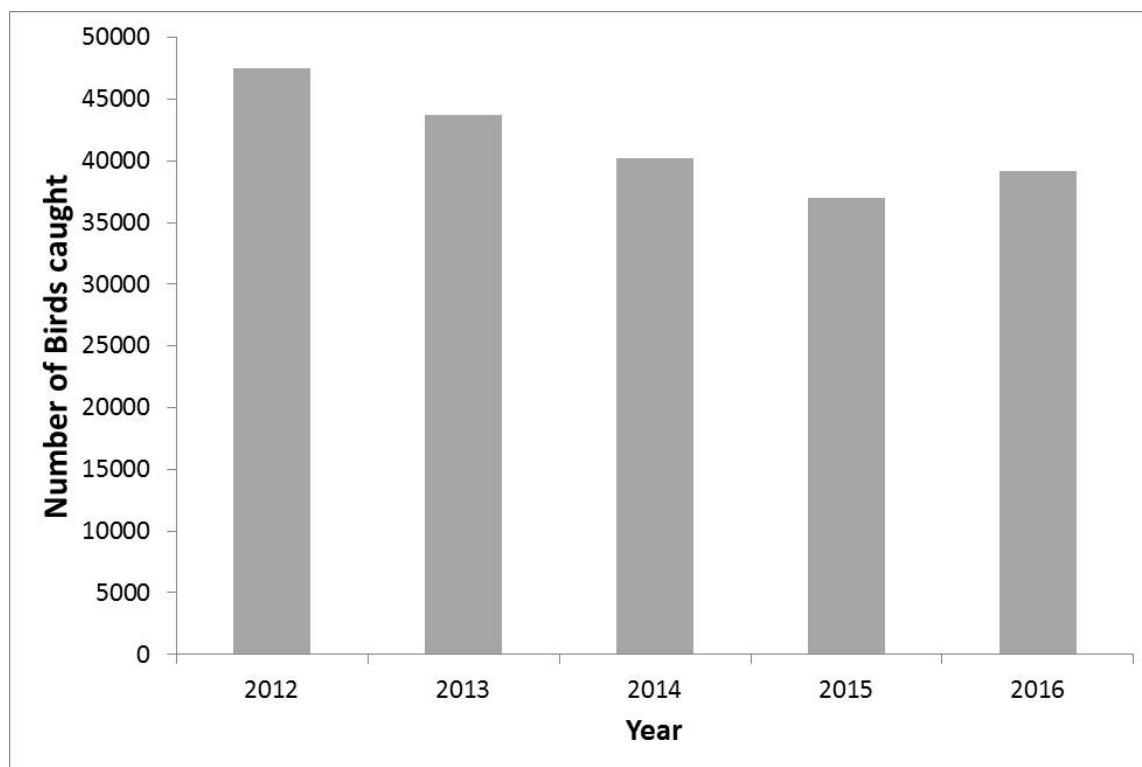
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264

265 **SRBE**

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



268
 269 **Figure 8: Total seabird bycatch from surface longline fisheries south of 20°S, estimated using a stratified ratio-based**
 270 **approach**

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

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

280 **GAMs**

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

285 Estimated BPUE surfaces were multiplied by fishing effort data (number of reported hooks
 286 aggregated by 5x5 grid, fleet, quarter and year) to generate estimates of total bird bycatch numbers.
 287 In GAM1, a parametric bootstrap approach was used to propagate the uncertainty of the BPUE
 288 estimates to the global estimate. It was noted that this generates fairly narrow confidence bounds,

289 which are likely to be an underestimate. In GAM2 a normal approximation to the confidence interval
290 was used.

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

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

300 INLA

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

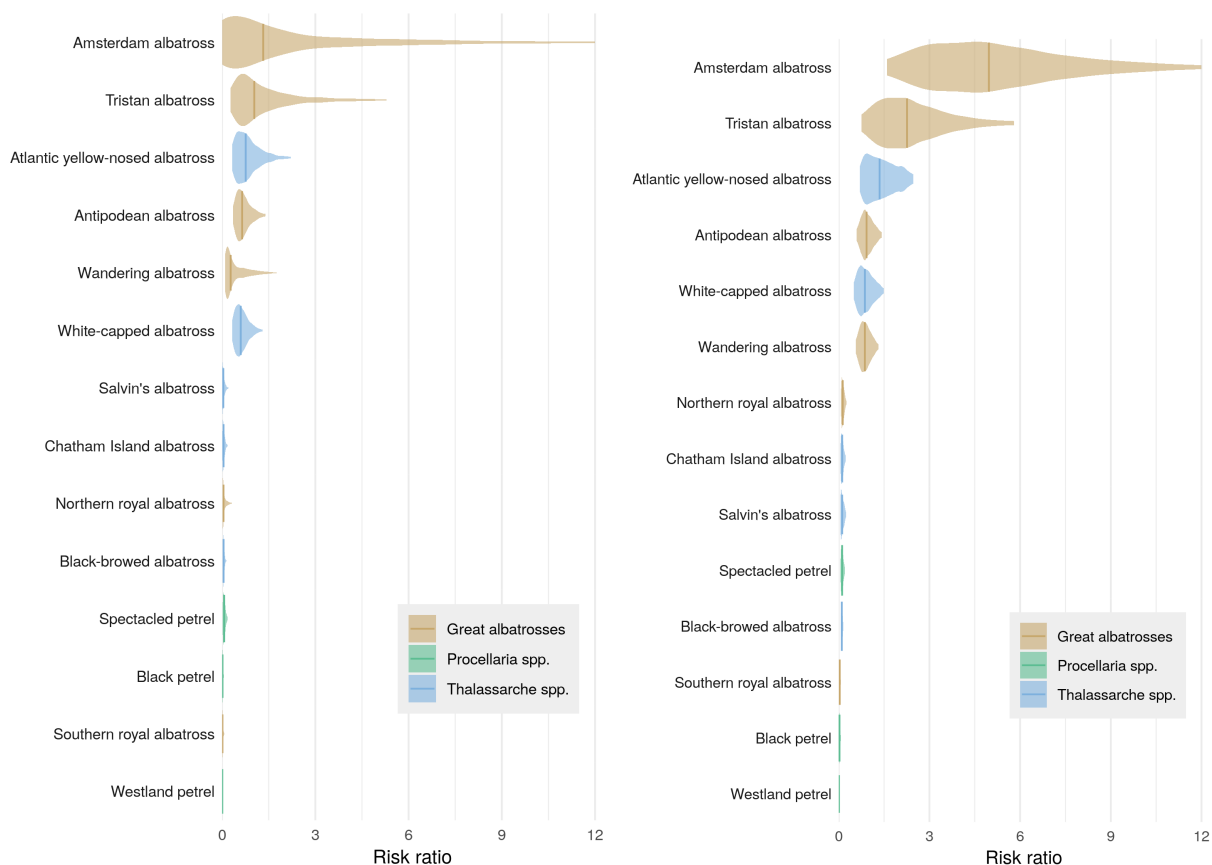
305 Based on this model, two approaches were used to predict seabird bycatch in fleets for which there
306 were no available observer data. The first approach used Japan as a proxy fleet for all unobserved
307 fleets. This resulted in a global estimate of birds caught south of 20°S of 52,487 birds per year (CI
308 24,785, 78,918). The second method was an adaptation of the best model that used random effects
309 in fleets to assign bycatch rates to unobserved fleets, with a global estimate of 33,239 birds per year
310 (CI 22,119, 45,242). This approach likely underestimated total bycatch because the majority of the
311 observed datasets used in the estimation of the random effect are concentrated in relatively small
312 geographical areas. In contrast, the Japanese data set is representative of a large geographical area.

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

317 SEFRA

318 The SEFRA 1 risk assessment model estimated 21,456 seabird captures (CI 12,372-41,476) in 2016
319 (Table 2). The majority of these captures (14,461, CI 8,278-32,194) were of *Thalassarche* albatross
320 species, followed by *Procellaria* petrels, and *Diomedea* albatrosses (Table 3, Figure 9). Under SEFRA
321 2, the estimated captures were higher, at 35,396 (CI 34,244-36,527) (Table 2), and the estimated
322 captures of each genus also increased (Table 3, Figure 9).

323



324

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

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

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

332
 333 The risk assessment model provided estimates of the captures of each species. The species with the
 334 highest estimated captures was white-chinned petrel (SEFRA1: 3939, CI 1980-6414; SEFRA2: 6019, CI
 335 5414-6652). The capture estimates can be compared to an index of population productivity, such as
 336 the Population Sustainability Threshold (PST) . The species with the highest median ratio of captures
 337 to the PST were shy, Amsterdam and Tristan albatrosses (SEFRA1; Figure 9a). When the proxy
 338 method was used for estimating captures on unobserved fleets, sooty albatross had the highest
 339 median ratio (SEFRA2; Figure 9b). Estimated captures of sooty albatross and shy albatross relied on
 340 range maps, and the high apparent ratio of captures to PST for these species may be an artefact of
 341 the use of range maps.

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

347

348 **Modelling impacts of bycatch on key albatross species/populations**

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

355 The PVA model for wandering albatross in South Georgia using no bycatch resulted in population
356 growth of ~0.4% per year. However, under each of the bycatch scenarios the population was
357 predicted to decline (Annex 9, Figure A9-1). The worst-case scenario resulted in annual change of
358 1.9% per year with a 91% probability that the population would decrease to 50% of the initial
359 population size within 50 years.

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

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

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

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

384

385 **Table 4.** Trends in annual change in growth rates for selected populations from the literature and
 386 modelled scenarios. Of the models represented, Actual is the current estimated population growth
 387 rate, which includes any actual bycatch impacts, Baseline removes any bycatch impacts, Scenario 1 is
 388 bycatch numbers as estimated from the SEFRA model using a “fleet average” bycatch rate, Scenario
 389 2 models the addition of cryptic mortality to values used in Scenario 1, Scenario 3 is bycatch
 390 numbers as estimated from the SEFRA model using flag-specific bycatch rates, and Scenario models
 391 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%

392 a. Elliot & Walker 2018
 393 b. Francis et al 2015
 394 c. Wanless et al 2009
 395 d. Poncet et al 2017
 396 e. Weimerskirch et al 2018

397 **Discussion**

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

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

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

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

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

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

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

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

435

436 **Table 5.** Sources of bias that could influence seabird bycatch estimates (not exhaustive). This
 437 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

438

439 **Data limitations**

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

444 **Current reporting requirements within t-RFMOs**

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

448 Data collection and reporting requirements relevant to seabirds vary over time within each t-RMFO,
 449 and among t-RMFOs. For ICCAT, observer program requirements changed slightly between 2015-
 450 2017, but generally some detailed fishing operation level data were collected; but in 2018 the
 451 format of data submissions to the Secretariat was changed to be highly aggregated so that much
 452 information about fishing operations was lost. On account of the current state of the data (and other
 453 reasons), ICCAT could not conduct a seabird bycatch assessment or contribute data on behalf of
 454 CPCs to a regional assessment.

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

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

468 30°S, 30°S to 25°S, 25°S to 23°N and north of 23°N). This includes: the proportion of observed effort
469 with specific mitigation measures; observed bycatch by species; total and observed effort; and,
470 observed bycatch rates. Reporting template guidelines are provided to ensure that information is
471 provided in a consistent format by all CCMs. This information, if reported consistently by relevant
472 parties, could be used annually to perform a stratified ratio estimate of seabird bycatch.

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

477 **Challenges with fishing effort data**

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

484 **Challenges with observer datasets**

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

- 491 1. *Reporting observer coverage:* Some programs require dedicated bycatch observations of hauling
492 operations, whereas others record the proportion of the set observed (bycatch and other duties
493 combined), and others consider coverage to be all effort when an observer is onboard. These
494 approaches introduce potential biases, and standardisation is required.
495
- 496 2. *Observation time bias:* If the entire line hauling is not observed, and setting and hauling
497 observations occur on a regular daily cycle, there is significant risk that a certain portion of the
498 line (e.g. those during night setting) will be missed systematically from observation. While the
499 group acknowledged that this is a serious concern and will have an affect on the outcome of the
500 estimate calculations, it was not possible to correct for this bias in the analyses at this workshop.
501 It was suggested that this is a concern that should be addressed in future.
502
- 503 3. *Data not representative at trip and fleet levels:* The group acknowledged that coverage is
504 frequently biased (in space and time), particularly for seabird bycatch events. Further, coverage
505 of the fleet may be incomplete and there may be some systematic biases in which vessels carry
506 observers. The group agreed that systematic underobserving certain fleet segments/vessels was
507 likely to lead to underestimation (vessels with nothing to hide are less likely to avoid carrying
508 observers) and the group agreed that this concern should be noted in the report.
509
- 510 4. *Behaviours change when observer is/isn't on board:* There is evidence from a diversity of sources
511 that fleet behaviour (e.g. use of mitigation measures, areas fished, etc.) changes when observers
512 are/are not onboard. The workshop agreed that this could lead to a strong bias and
513 underestimation of seabird bycatch when extrapolating. It was also noted that there may be
514 incentives (such as social pressure) on the observer to under-report seabird captures. The

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

518

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

525

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

534

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

538

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

542

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

550

551

552 **Suggestions for future monitoring and assessment in relation to seabird bycatch in global pelagic** 553 **longline fisheries.**

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

560

561 Based on the analyses undertaken in this workshop, participants identified that there is significant
562 value that is gained from undertaking a global collaborative approach to estimating the level and
563 impact of seabird bycatch in pelagic longline fisheries, such as that undertaken at this workshop.
564 Participants unanimously recommended that this process be repeated in the future in order to

565 monitor impacts. Participants also recognised the continuing value in RFMOs undertaking ongoing
566 monitoring of seabird bycatch on a regional basis.

567 **Toolbox**

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

579

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613 **Annex 1. List of participants**

Names	Affiliation
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Mahdi Prasa [^]	Bureau of Agricultural and Resource Economics and Sciences
Zhe Geng [^]	Shanghai Ocean University
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Sebastián Jimenez* [^]	Dirección Nacional de Recursos Acuáticos
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)

614 * Participation funded from other sources

615 [^] Participants who presented during the workshop616 [~] Participant also part of project team

617 **Annex 2. Annotated agenda**

618

- 619 1. **Welcome:** Introductions and explanation of anticipated process and expected outcomes
620
- 621 2. **Review of existing information:** National estimates (data owners), Density surfaces (R
622 Wanless), GAM method, (J Rice), INLA method (R Sant'Ana) and SEFRA work (E Abraham),
623 Species Demographic Model (S Good)
624
- 625 3. **Discussion on estimates presented:** data availability, pros and cons of individual
626 methodologies, what is required to achieve global seabird mortality estimates, how to
627 compare estimates from different approaches, reducing CVs, etc
628
- 629 4. **Approaches for joint analyses:** Discuss and agree on type of analysis to be conducted during
630 the workshop
631
- 632 5. **Data preparation and analyses**
633
- 634 6. **Break-out session:** RFMOs present on reporting requirements and discussion on improving
635 reporting
636
- 637 7. **Discussion 1:** Identifying shortcomings within observer programmes
638
- 639 8. **Report on initial findings,** followed by brief discussion
640
- 641 9. **Presentation of final results**
642
- 643 10. **Discussion 2:** Characteristics of various seabird mortality estimation procedures (general
644 characteristics, data requirement, robustness, impacts of partial data, extrapolation)
645
- 646 11. **Discussion 3:** Estimates of seabird LL bycatch mortality in the Southern Hemisphere
647
- 648 12. **Discussion 4:** How to facilitate future improvements
649
- 650 13. **Final discussion:** Contents to be included in the report, Vortex outcomes, Next steps (RFMO
651 reporting, etc.)
652
- 653 14. **Report adoption**

654

655 **Annex 3. Data request**

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

658
659 This communication is to inform the workshop participants regarding the expected outcomes,
660 intended activities for achieving the goals, and a request for data preparation prior to the meeting.
661 We would like to stress that the workshop itself (i.e the participants) is fully responsible to
662 determine what analyses to do at the workshop, and how to report its outcomes to the outside
663 audience, including the RFMOs.

664
665 **OBJECTIVE**

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

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

690
691 **REQUEST**

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

700

701

702

703 Data formatting guidelines for estimating seabird 704 Bycatch in surface longline fisheries using a species-specific 705 model

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

- 710 • For each 5-degree by 5-degree latitude-longitude cell (with the borders at latitudes and longitudes
711 evenly divisible by 5);
- 712 • For each year (up to 2016, and covering the period when seabird captures, across all
713 species, are considered to be reliably recorded);
- 714 • For each quarter (where Quarter 1 is January to March, Quarter 2 is April to June, Quarter
715 3 is July to September, and Quarter 4 is October to December);
- 716 • For each surface longline fishery that should be treated distinctly (for example, due to
717 target species, or vessel size, this should group together effort that has similar
718 characteristics from the point of view of potential seabird bycatch);
- 719 • The total number of hooks observed;
- 720 • The total number of seabirds observed caught;
- 721 • For each species or species-group code that you have in your data, a column giving the
722 total number observed caught. Use FAO species codes where possible, or provide a
723 description of the species codes that you have used, so that they can be analysed together
724 with other datasets.

725
726 ACAP have published a useful guide that includes the species codes¹.
727 Please include all seabirds reported caught.

728

729 Example format

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

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

744

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

746 Help

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

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

750

751 **Annex 4. Seabird tracking data meta data table**

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

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

Species	Population	Population for which tracking data were available	
		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

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764 **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.

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768 **Annex 6. GAM**

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

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

Name of method	Generalized Additive Models (GAM)
Brief description of method	<p>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.</p> <p>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.</p> <p>GAM 1: $BPUE \sim s(\text{density} \text{quarter}) + \text{flag}$.</p> <p>GAM 2: $BPUE \sim s(\text{latitude} \text{season}) + s(\text{density}) + \text{flag}$</p>
Data input	<p>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.</p>
Assumptions	<p>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.</p>
Strengths in relation to seabird bycatch estimation	<p>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.</p>
Weaknesses/ limitations in relation to seabird bycatch estimation	<p>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</p>

	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.

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783 **Annex 7. INLA**

Name of method	Integrated Nested Laplace Approximations (INLA)
Brief description of method	<p>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.</p>
Data input	<p>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.</p> <p>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 <i>year</i> variable, this variable was used as a replication of the spatial correlations between years, without any temporal correlation structure beyond them. For the variable <i>season</i>, it was used as a group variable with a temporal autoregressive structure between the seasons.</p>
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.

785 **Annex 8. SEFRA**

786 In this application of the risk assessment method, the susceptibility was assumed to be the same for
 787 all seabirds within each of five genera (*Diomedea*, *Thalassarche*, *Phoebetria*, *Procellaria*, and
 788 *Macronectes*). The catchability expresses how likely different fleets are to catch seabirds.
 789 Catchability was assumed to be the same for all fishing by vessels of each fleet. Population
 790 productivity was estimated as the Population Sustainability Threshold (PST; Sharp 2016). This
 791 measure is $0.25 r_{max} N$, where r_{max} is the maximum population growth rate, and N is the total
 792 population size. The PST was derived from the Potential Biological Removals (PBR) measure
 793 developed in the United States for managing the impacts of fishing on marine mammals (Wade
 794 19XX), and applied to seabirds by Dillingham (20XX).

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

Name of method	Spatially Explicit Seabird Risk Assessment (SEFRA)
Brief description of method	<p>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 <i>Diomedea</i> 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.</p> <p>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.</p>
Data input	<ul style="list-style-type: none"> ● Observed fishing effort ● Observed seabird captures, by species ● Total fishing effort <p>All data were aggregated by five-degree cell, by quarter, and by flag.</p>
Assumptions	<p>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 susceptibility, and a catchability. The susceptibility expresses how likely different groups of seabirds are to be caught in fisheries. In this application of the risk assessment method, the susceptibility was assumed to be the same for all seabirds within each of five genera (<i>Diomedea</i>, <i>Thalassarche</i>, <i>Phoebetria</i>, <i>Procellaria</i>, and <i>Macronectes</i>). 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.</p> <p>The overlap between seabirds and fisheries was calculated using seabird distributions derived from tracking data, where they were available (A Carneiro <i>in litt</i>). Range maps provided by BirdLife International were used in place of distributions for Indian yellow-</p>

	<p>nosed <i>Thalassarche steadi</i>, grey-headed <i>T. chrysostoma</i>, Campbell black-browed <i>T. impavida</i>, Buller's <i>T. bulleri</i>, shy albatross <i>T. cauta</i>, sooty <i>Phoebastria fusca</i>, and light-mantled <i>P. palpebrata</i> albatrosses, southern giant <i>Macronectes giganteus</i>, northern giant <i>M. halli</i>, white-chinned <i>Procellaria aequinoctialis</i> and grey <i>P. cinerea</i> 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 <i>Diomedea sanfordi</i>, however northern royal albatross <i>D. epomophora</i> was used as a proxy. For Atlantic yellow-nosed albatross <i>T. chlororhynchos</i>, the tracking distribution from Gough Island was used to represent the distribution of birds from Tristan da Cunha.</p> <p>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).</p> <p>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.</p>
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	<p>The approach is strongly dependent on accurate seabird distributions, which are not available for many species, or for all life stages.</p> <p>The approach requires accurate seabird identification data, which is not currently available for many fleets.</p>
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	<ul style="list-style-type: none"> ● 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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801 **Annex 9. Population modelling**

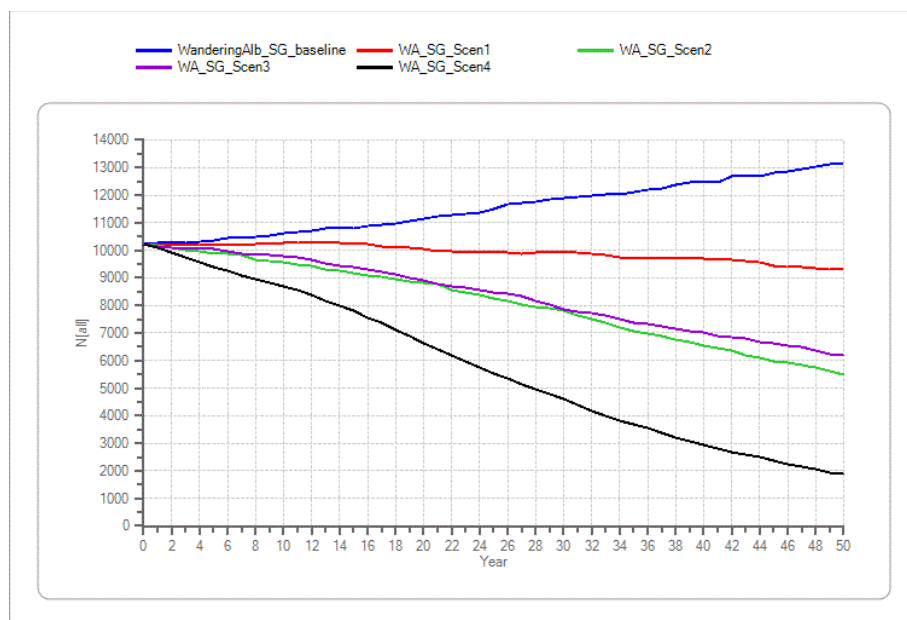
Name of method	Population Viability Analysis (PVA) in VORTEX v10
Brief description of method	<p>Bycatch impacts were modelled for five albatross populations where good demographic information was available using the PVA tool VORTEX (v10, Lacy and Pollack 2014). The VORTEX program simulates the effects 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.</p> <p>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.</p>
Data input	<p>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)</p> <p>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.</p>
Assumptions	<p>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.</p> <p>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.</p>
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.

802

803 *Wandering albatross – South Georgia*

804 A PVA model for Wandering albatross in South Georgia using optimal adult survival (Richard et al.
 805 2017) and no bycatch resulted in population growth of ~0.4% per year. However, under each of the
 806 bycatch scenarios the population would decline (Figure A9-1). The worst-case scenario resulted in
 807 annual change of -1.9% per year with a 91% probability that the population would decrease to 50%
 808 of the initial population size within 50 years.



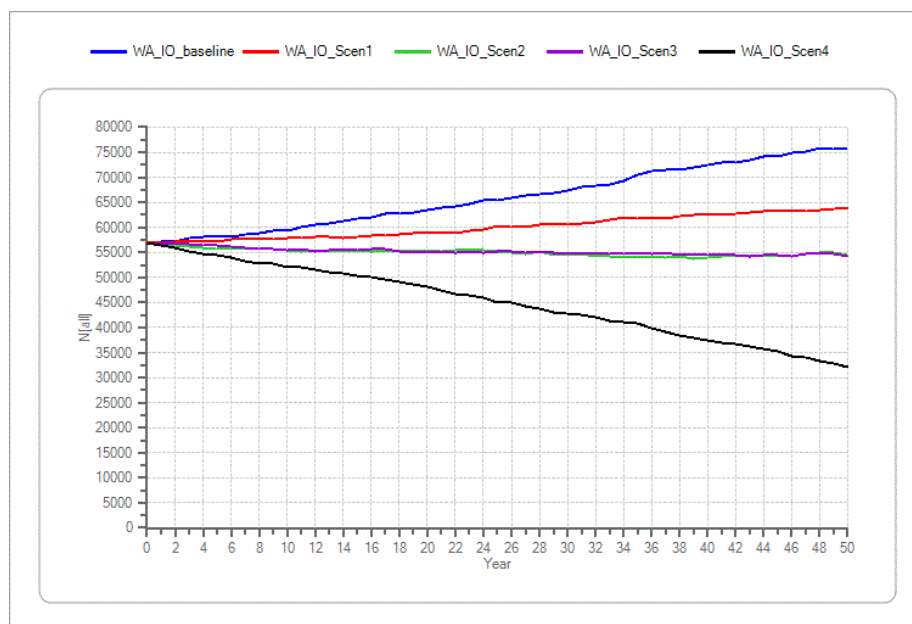
809

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

814

815 *Wandering albatross – Indian Ocean*

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

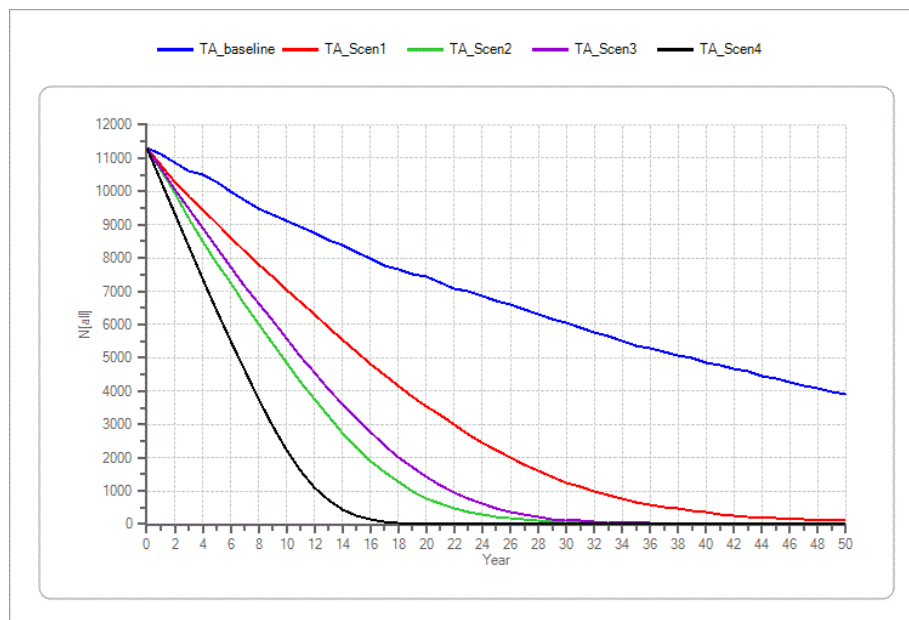


821
 822 Figure A9-2. Population size of Wandering albatross breeding in the Indian Ocean over 50 years in
 823 five scenarios: Baseline (no bycatch), Scenario 1 (Fleet average mean, n=220), Scenario 2 (Fleet
 824 average including cryptic, n=440), Scenario 3 (Flag-specific mean, n=399), Scenario 4 (Flag-specific
 825 mean including cryptic, n=798).

826

827 *Tristan albatross*

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

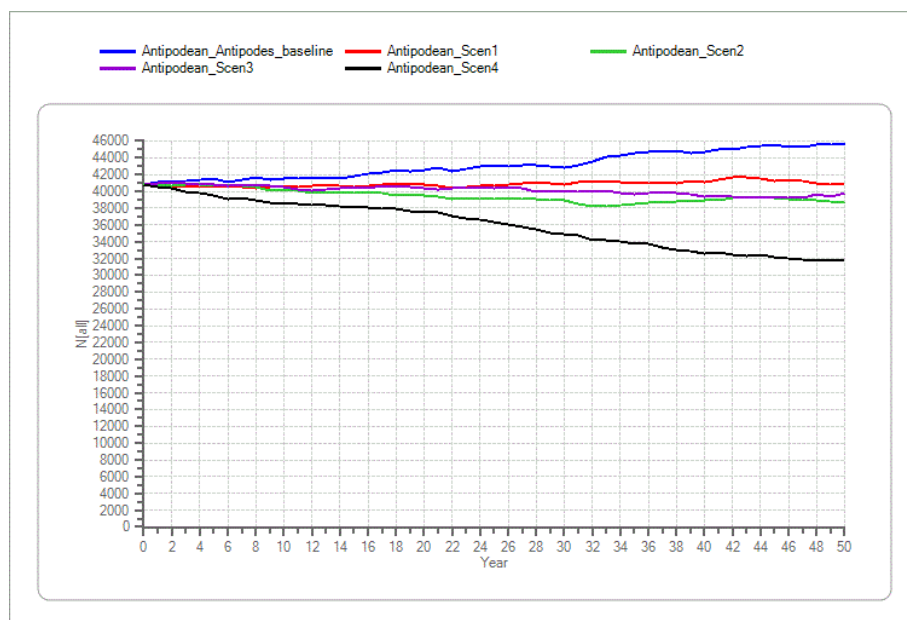


832
 833 Figure A9-3. Population size of Tristan albatross over 50 years in five scenarios: Baseline (no
 834 bycatch), Scenario 1 (Fleet average mean, n=238), Scenario 2 (Fleet average including cryptic,
 835 n=476), Scenario 3 (Flag-specific mean, n=395), Scenario 4 (Flag-specific including cryptic, n=790).

836

837 *Antipodean albatross (Antipodes Island)*

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

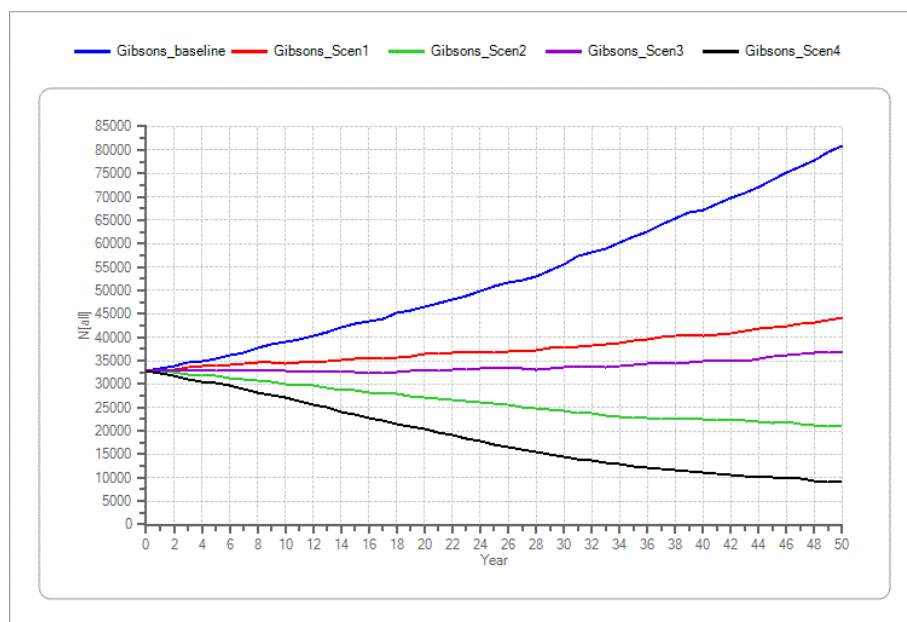


841
 842 Figure A9-4. Population size of Antipodean albatross breeding at Antipodes over 50 years in five
 843 scenarios: Baseline (no bycatch), Scenario 1 (Fleet average mean, n=98) Scenario 2 (Fleet average
 844 including cryptic, n=196), Scenario 3 (Flag-specific mean, n=156), Scenario 4 (Flag-specific Japan
 845 including cryptic, n=312).

846

847 *Antipodean albatross (Gibson’s albatross)*

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



853
 854 Figure A9-5. Population size of Antipodean (Gibson’s) albatross over 50 years in five scenarios:
 855 Baseline (no bycatch), Scenario 1 (Fleet average mean, n=402) Scenario 2 (Fleet average including
 856 cryptic, n=804), Scenario 3 (Flag-specific mean, n=514), Scenario 4 (Flag-specific including cryptic,
 857 n=1028)