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Quantitative Risk Assessment of Threats to New Zealand Sea Lions

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A quantitative risk assessment of threats to the New Zealand sea lion (*Phocarctos hookeri*) was undertaken to inform the development of a Threat Management Plan for the species. Separate demographic assessment models were developed for females at the Auckland Islands and Otago Peninsula populations, integrating information from mark-recapture observations, pup census and the estimated age distribution of lactating females (Auckland Islands only). With respect to the Auckland Islands assessment, good fits were obtained to all three types of observation and the model structure and parameter estimates appeared to be a good representation of demographic processes that have affected population decline there (primarily low pup survival and low adult survival). The Otago Peninsula assessment made use of a much smaller number of observations, however still produced good estimates of all key demographic rates, with much higher pup survival relative to the Auckland Islands population.

A 2-stage assessment of the effects of threats was undertaken where the consequences of removing the effects of a threat was estimated in terms of the population growth rate of mature individuals in 2037 (λ_{2037}). This used threat-specific mortality estimates at age (provided by MPI/DOC subsequent to two dedicated TMP workshops), in which:

1. "Triage" projections were undertaken for all assessed threats using the upper bound estimates of threat-related mortality to screen out threats that had little effect on projected growth rate;
2. "Best-estimate" projections were undertaken using the best estimate of threat-specific mortality for all threats that passed through the Triage stage.

For the Auckland Islands population, best-estimate projections were undertaken for commercial trawl-related mortality, *Klebsiella pneumoniae*-related mortality of pups, trophic effects (food limitation), pups drowning in wallows, male aggression and hookworm mortality and these were compared with the base run – a continuation of demographic rates since 2005 (λ_{2037} = 0.961, 95% CI 0.890–1.020). A positive growth rate was obtained only with the alleviation of *Klebsiella* (λ_{2037} = 1.005, 95% CI 0.926–1.069). When assuming the most pessimistic view of cryptic mortality (all interactions resulted in mortality and associated death of pups), alleviating the effects of commercial trawl-related mortality resulted in an increased population growth rate relative to the base run, but did not reverse the declining trend (λ_{2037} = 0.977, 95% CI 0.902–1.036). The alleviation of trophic effects (food limitation) had the next greatest effect (λ_{2037} = 0.974, 95% CI 0.905–1.038) and all other threats had a minor effect relative to the base run projection (increase in λ_{2037} of less than 0.01).

For the Otago Peninsula population, similar effects were estimated with the alleviation of any of the threats that passed through Triage: commercial setnet fishery related mortality; direct human mortality; pollution-related entanglement; and male aggression, relative to the base run projection (λ_{2037} = 1.070, 95% CI 1.053–1.087). Deliberate human mortality was estimated to have the greatest effect on projected population size (λ_{2037} = 1.093, 95% CI 1.075–1.112).

For the Auckland Islands population (the largest for the species), it is likely that the site-specific 20-year TMP goals would be difficult to achieve with the complete alleviation of a single threat and natural processes affecting sea lion habitat (including prey) may make this even more difficult to attain. As such, the most effective approach to meeting the goals of the TMP may be to spread the management effort across the suite of key perceived threats identified from this assessment. This should be complemented by the development of tools for monitoring the effects of management interventions on threat-specific mortality and influential demographic rates.

The assessment for some of the key threats was hampered by incomplete information for estimating threat-specific mortality, e.g., relating to the causes of pup mortality during the *entire* first year of life and of potential cryptic commercial trawl related mortality. The separate assessment of climate and fishery effects on food limitation and population growth rate was not attempted for any population. In addition, a lack of demographic observations for the Campbell Island and Stewart Island populations (the second and third largest breeding populations, respectively) precluded the development of comprehensive quantitative risk assessments for these populations. These are all issues that can be addressed with the aim of developing improved assessments in the future.

1. INTRODUCTION

1.1 New Zealand sea lions

The New Zealand (NZ) sea lion is endemic to NZ and has an extremely concentrated breeding distribution with about 98% of annual pup production at the Auckland Islands and Campbell Island in the NZ Sub-Antarctic region (Childerhouse et al. 2015, Department of Conservation unpublished data, Maloney et al. 2012, Sealiontrust.org.nz 2015) (Figure 1). The largest breeding population at the Auckland Islands has declined by about 50% since the late-1990s (Childerhouse et al. 2015). The protracted decline of this population led to the species' designation in NZ as "Nationally Critical", the highest domestic threat rating. Declines have been observed at all four breeding rookeries of the Auckland Islands: Dundas, Sandy Bay, Figure of Eight Island and Southeast Point – the latter of was abandoned as a breeding site in 2012/13 (hereafter referred to by the end year, e.g. "2013") (Childerhouse et al. 2015). The Campbell Island population has undergone a period of rapid population growth and small but growing populations are recolonising the Otago Peninsula and Stewart Island (Figure 2). The causes of contrasting population trends are not well-understood, though a number of threats have been identified for each population, including: incidental mortality in commercial trawl nets (e.g., in SQU 6T and SCI 6A around the Auckland Islands) (Thompson et al. 2013), disease-related pup mortality (Castinel et al. 2007; Roe et al. 2015), food limitation (Augé 2010; Roberts & Doonan 2014; Stewart-Sinclair 2013) – which could have climate or fishery drivers – deliberate human mortality, habitat alteration and others (Roberts 2015; Robertson & Chilvers 2011).

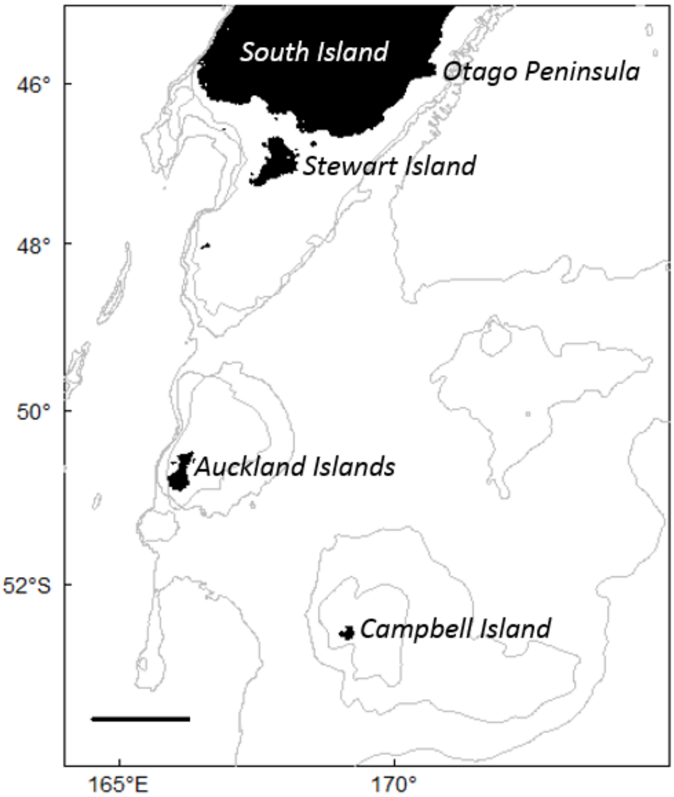


Figure 1: Location of New Zealand sea lion breeding populations. Grey lines represent the 200 m, 500 m and 1000 m bathymetric contours; scale bar = 100km.

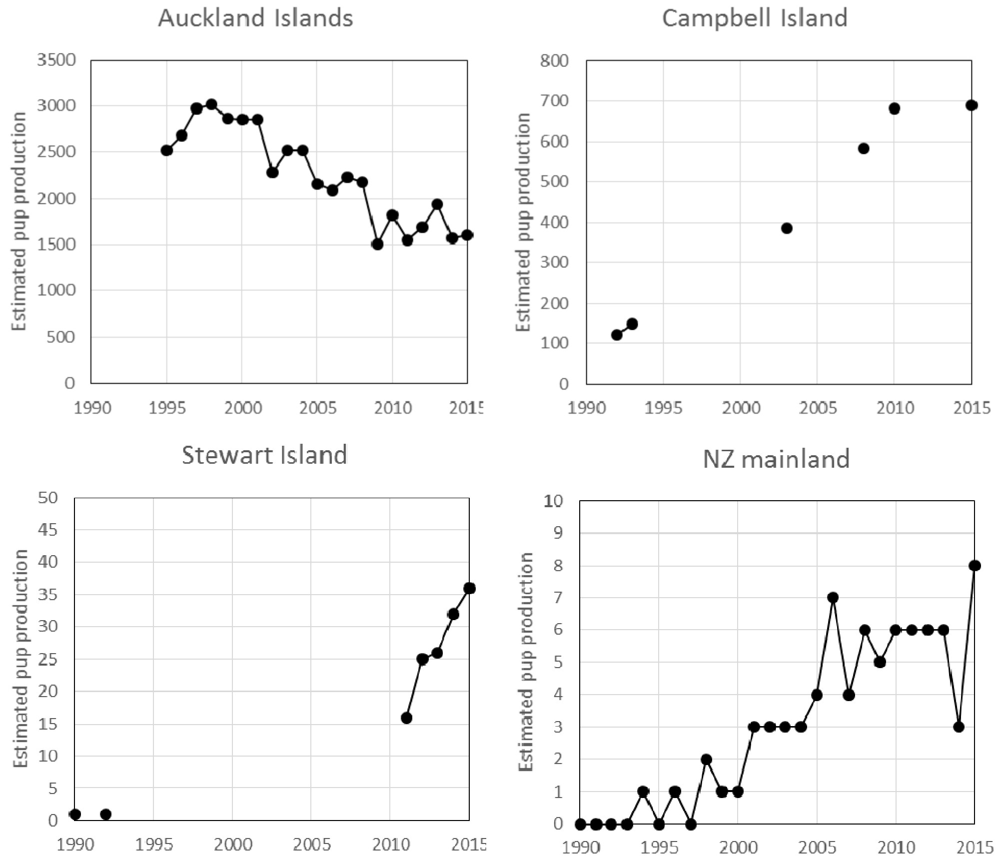


Figure 2: Annual pup census estimates of the main breeding populations of NZ sea lions. Observations reported by Childerhouse & Gales 1998, Childerhouse et al. 2015, Department of Conservation unpublished data, Maloney et al. 2010, Maloney et al 2012, Sealiontrust.org.nz (2015).

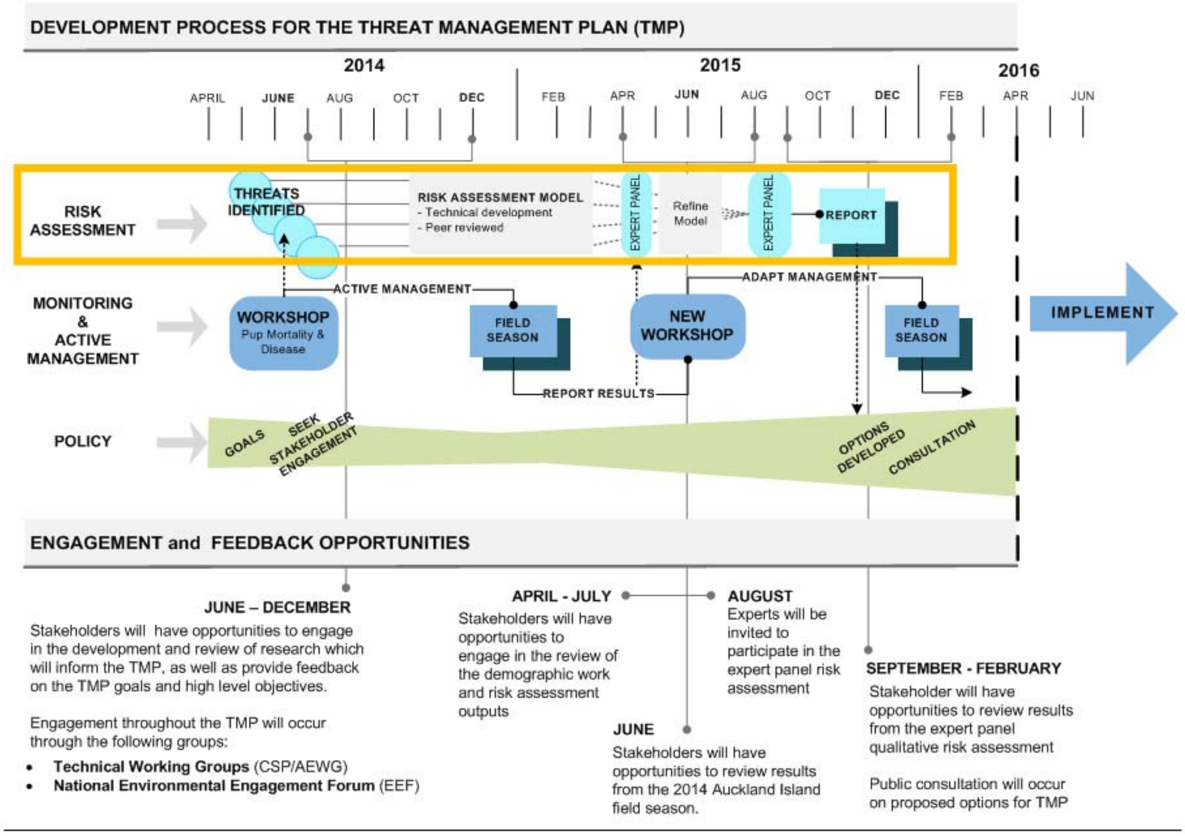
1.2 Threat Management Plan

A low pup census estimate at the Auckland Islands in 2014 triggered the development of a Threat Management Plan (TMP) for the species by the Ministry for Primary Industries (MPI) and the Department of Conservation (DOC). The TMP will provide a 5-year programme aimed at reducing the rate of population decline of the species with an aspirational goal "to promote the recovery and ensure the long term viability of New Zealand sea lions" (MPI/DOC, 2015).

The TMP has a broad scope including an assessment of *all* threats to NZ sea lion populations and will ultimately prioritise threats for management/mitigation of impacts on all sub-populations and breeding sites of the species (MPI/DOC 2015). The TMP population goals are structured into 5 and 20-year goals:

- **20-year goal**
  - The overall population is above 2017 levels and shows signs of ongoing improvement
  - Site-specific goals –
    - Stop/reverse the decline at the Auckland Islands
    - Evidence of population growth is present on the Mainland, Stewart Island, and Campbell Island
- **5-year goal**: The overall population shows progress towards achieving the 20-year goal (demographic rates after 5 years are consistent with achieving the 20-year goal).

The work components and timeline for the development of the TMP are shown in Figure 3. The quantitative risk assessment of threats to NZ sea lions described in this document is a central component of the development of the TMP and the assessment has been structured to relate to the TMP population goals listed above.



JUNE – DECEMBER
Stakeholders will have opportunities to engage in the development and review of research which will inform the TMP, as well as provide feedback on the TMP goals and high level objectives.

Engagement throughout the TMP will occur through the following groups:

- **Technical Working Groups** (CSP/AEWG)
- **National Environmental Engagement Forum** (EEF)

APRIL - JULY
Stakeholders will have opportunities to engage in the review of the demographic work and risk assessment outputs

AUGUST
Experts will be invited to participate in the expert panel risk assessment

JUNE
Stakeholders will have opportunities to review results from the 2014 Auckland Island field season.

SEPTEMBER - FEBRUARY
Stakeholder will have opportunities to review results from the expert panel qualitative risk assessment

Public consultation will occur on proposed options for TMP

Figure 3: **Overview of the NZ sea lion Threat Management Plan Process. The risk assessment modelling component reported on here is contained within the orange box.**

1.3 Quantitative Risk Assessment

The quantitative risk assessment uses an integrated demographic assessment model created with the SeaBird demographic assessment software (Francis & Sagar 2012) and fit to demographic observations including mark-recapture data, pup census data and proportion-at-age estimates. The development of the Auckland Islands assessment has been informed by experience from previous demographic/population assessments using various subsets of the same data (e.g., Breen et al. 2012; MacKenzie 2012; Meyer et al. 2015) and was initially based on the model structure developed by Roberts et al. (2014). In addition, we describe a fully quantitative risk assessment for the Otago Peninsula population. Although the demographic data were insufficient to develop fully quantitative assessments for the Campbell Island and Stewart Island populations, a brief assessment was conducted for Campbell Island (Appendix 10) and threats to minor populations are discussed where relevant.

The development of the quantitative risk assessment described here has been reviewed by an Expert Panel of international experts with guidance from advisors from within New Zealand at two workshops over seven days; and also reviewed at multiple meetings of DOC's Conservation Services Programme (CSP) and MPI's Aquatic Environment Working Group (AEWG).

2. METHODS

2.1 Assessment methodology

A fully quantitative risk assessment was undertaken for female NZ sea lions tagged as pups at the Auckland Islands and Otago Peninsula. The assessment can be divided in to two modelling steps:

1. **Development of a demographic assessment model** – using the SeaBird demographic modelling software (Francis & Sagar 2012; Roberts et al. 2014). The purpose of this modelling step was to estimate the current age distribution by breeding state and recent demographic parameter distributions for initialising simulation models developed in the next modelling step.

2. **Population projections assessing the effects of threats** – The operating model developed in step 1 was then used to undertake a quantitative assessment of the risk posed by identified threats to NZ sea lions. Population-specific estimates of age distribution and demographic parameter distributions were used to conduct population projections for the period (2017–2037). This allowed the assessment of the population consequences of alleviating a threat, in terms of projected mature *N*. It also allowed an assessment of the population effects of assuming a particular set of demographic rates, i.e. how future mature numbers will be affected by variation in key demographic rates, e.g., pup or adult survival or pupping rate (referred to later as “demographic scenarios").

A lack of mark-recapture observations at Campbell Island and Stewart Island precluded a fully quantitative assessment of threats using the methodology described above. Pup censuses have been undertaken at Campbell Island since at least the early 1990s (with varying methodologies) and these observations were used to conduct a simple analysis of the effect of increasing pup survival on population growth rate (see Appendix 10). For Stewart Island, there was a total lack of biological and demographic observations, with the exception of pup census estimates since 2011 and no quantitative risk assessment was undertaken for this population.

2.2 Observations

Pup census

Annual pup census estimates have been made at all Auckland Islands breeding rookeries in all years since 1995 and on the Otago Peninsula and the Catlins since breeding resumed there in 1994 and 2001 respectively (Childerhouse et al. 2015; Department of Conservation unpublished data; Maloney et al. 2010; Maloney et al 2012; Sealiontrust.org.nz 2015) (Table 1). All pup census estimates at Auckland Islands and Otago Peninsula since 1995 were deemed of sufficient quality (with respect to timing, completeness and consistency of methodology) by the TMP Working Group for use in demographic assessment models. All census estimates were multiplied by 0.5 to give an estimate of female pup production. As such, both the Auckland Islands and Otago Peninsula models were of the entire female population at each breeding site. A census CV of 3% gave a standard deviation of normalised residuals of 1.25 (a common procedure is to weight datasets to obtain a value close to 1, e.g., Haist et al. 2015).

Pup census estimates have also been made at Stewart Island since 2011, but were late in the season (about 3–4 months after the probable pupping period) and are only thought to be relatively complete in the latest three seasons (since 2013). Occasional pup censuses have been conducted at Campbell Island since 1995: including the years 2003, 2008, 2010 and 2015 and these assessments have varied with respect to timing, methodology and area searched, but were deemed by the TMP Working Group to be of sufficient quality for a simple population assessment (Table 1).

Table 1: **Pup census estimates for all known breeding populations of NZ sea lions since 1994/95. Observations reported by Childerhouse & Gales 1998, Childerhouse et al. 2015, Department of Conservation unpublished data, Maloney et al. 2010, Maloney et al. 2012, Sealiontrust.org.nz (2015). "D" = Dundas and "SB" = Sandy Bay rookeries at the Auckland Islands. Years with no census estimate were left blank (i.e. blanks do not necessarily indicate that no pups were born at that location in that year).**

Pupping season (end year)	Annual pup census estimate						
	Auckland Islands			Campbell Island	Otago Peninsula	Catlins	Stewart Island
	D	SB	All				
1995	1 837	467	2 518		0		
1996	2 017	455	2 685		1		
1997	2 260	509	2 975		0		
1998	2 373	477	3 021		2		
1999	2 186	513	2 867		1		
2000	2 163	506	2 856		1		
2001	2 148	562	2 859		3		
2002	1 756	403	2 282		3		
2003	1 891	488	2 516	385	3		
2004	1 869	507	2 515		3		
2005	1 587	441	2 148		4		
2006	1 581	422	2 089		6	1	
2007	1 693	437	2 224		3	1	
2008	1 635	448	2 175	583	5	1	
2009	1 132	301	1 501		4	1	
2010	1 369	385	1 814	681	5	1	
2011	1 089	378	1 550		5	1	16
2012	1 248	361	1 684		4	2	25
2013	1 491	374	1 940		5	1	26
2014	1 213	290	1 575		3	1	32
2015	1 230	286	1 576	696	8	0	36

Mark-resighting

Mark-resighting observations were extracted from the NZ sea lion demographics database maintained by Dragonfly Science (downloaded 24/06/2015) (Data.dragonfly.co.nz, 2015). Because we were attempting to estimate tag loss, observations were only used if the "tag" records indicated that both the left and right flippers were checked (e.g., "L1,R1", as opposed to "L?,R1"). In event of multiple statuses (e.g., observations of 1 and 2 tags for the same individual in the same year), the maximum number of tags within a year was used. Mark recapture observations used in the Auckland Islands are shown in Table 2 and Figure 4.

Table 2: **Number of females tagged in each study year from 1990–2014 grouped by mark type.**

Pupping season (end year)	Tagged females		
	Flipper-tagged only	Chipped but not branded	Branded
1990	148	0	0
1991	191	0	0
1992	226	0	0
1993	194	0	0
1994	0	0	0
1995	0	0	0
1996	0	0	0
1997	0	0	0
1998	0	255	0
1999	0	211	0
2000	0	104	136
2001	0	270	0
2002	0	159	0
2003	204	0	0
2004	233	0	0
2005	222	0	0
2006	209	0	0
2007	196	0	0
2008	208	0	0
2009	150	0	0
2010	0	170	0
2011	0	179	0
2012	0	181	0
2013	0	168	0
2014	0	157	0

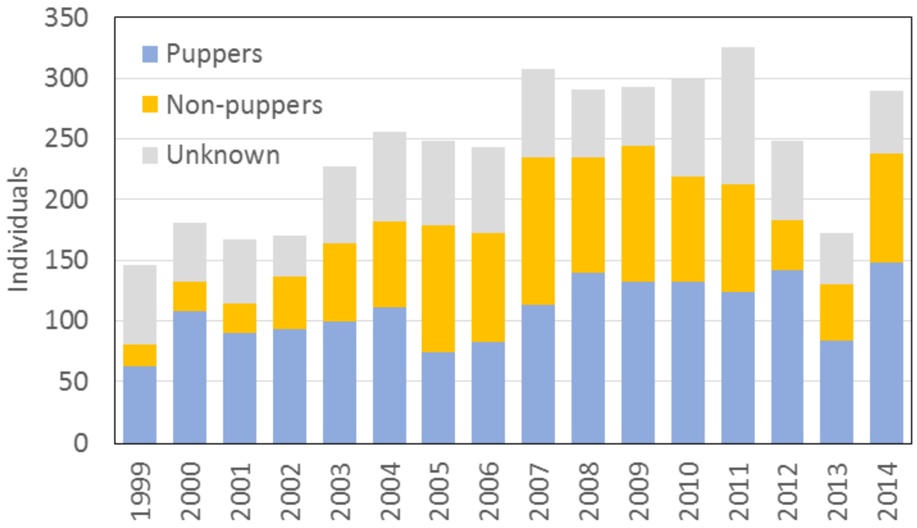


Figure 4: **Summary of mark-resighting observations used in the Auckland Islands demographic assessment – all females tagged and resighted at Sandy Bay.**

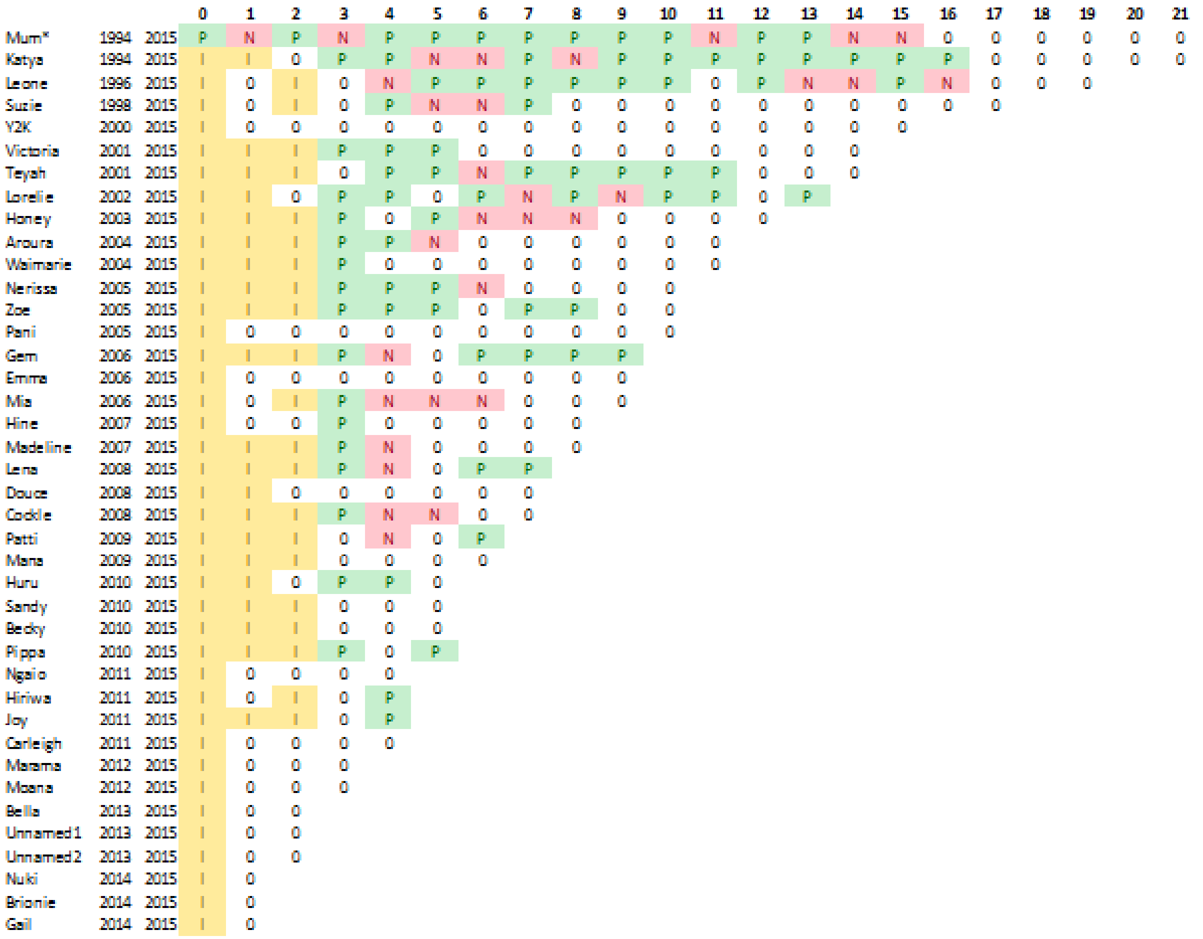
A number of pups are reported as dead at the time of tagging. Not accounting for these would cause survival at age 0 to be overestimated. For each year a number of "phantom tags" were therefore assigned to these dead pups and included in the mark-recapture observations as not observed in all subsequent years of resighting effort. Because unobserved tags are indicative of mortality, this allowed observations of dead pups to be included in the model and used to inform estimation of survival. At Sandy Bay the annual number of phantom tags was assumed to be 50% of the number of pups reported dead at the time of tagging each season (Childerhouse et al. 2015), to give the female component of dead pups. Counts of dead pups were not routinely conducted in tagging years 1990–1993 and the population-specific pup mortality rate averaged across 1998–2012 (7.3%) was used to obtain the number of phantom tags from the number of individuals tagged in these earlier years (Table 3).

Table 3: Estimated annual number of female pups that died prior to tagging at Sandy Bay; and calculated number of "phantom tags" that were added to mark recapture observations and classed as not seen in any subsequent resighting year.

Tag year	Phantom tags
1990	11*
1991	14*
1992	16*
1993	14*
1994	0
1995	0
1996	0
1997	0
1998	5
1999	16
2000	11
2001	17
2002	33
2003	33
2004	16
2005	15
2006	19
2007	10
2008	11
2009	6
2010	9
2011	9
2012	9
2013	8
2014	3

*Average pup mortality rate across years 1998–2014 (7.3%) was used to derive the number of phantom tags in 1990–1993, given the number of sea lions tagged in these years.

Mark recapture observations for the Otago Peninsula were collated from the family tree compiled by the Sea Lion Trust, which gave the years in which female sea lions produced a pup (Sealiontrust.org.nz, 2015). The photo-ID database maintained by DOC (DOC unpublished data) was then used to determine whether non-puppers were observed in a particular year. The 1st December was taken as the cut-off date for observing a female in a season (i.e. if seen on or after the 1st December 2011 then the observation was allocated to the 2012 season). All mark recapture observations used in the Otago Peninsula model are presented in Figure 5.



			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Mum*	1994	2015	P	N	P	N	P	P	P	P	P	P	P	N	P	P	N	N	0	0	0	0	0	0
Katya	1994	2015	I	I	0	P	P	N	N	P	N	P	P	P	P	P	P	P	P	0	0	0	0	0
Leone	1996	2015	I	0	I	0	N	P	P	P	P	P	P	0	P	N	N	P	N	0	0	0		
Suzie	1998	2015	I	0	I	0	P	N	N	P	0	0	0	0	0	0	0	0	0	0				
Y2K	2000	2015	I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
Victoria	2001	2015	I	I	I	P	P	P	0	0	0	0	0	0	0	0	0							
Teyah	2001	2015	I	I	I	0	P	P	N	P	P	P	P	P	0	0	0							
Lorelie	2002	2015	I	I	0	P	P	0	P	N	P	N	P	P	0	P								
Honey	2003	2015	I	I	I	P	0	P	N	N	N	0	0	0	0									
Aroura	2004	2015	I	I	I	P	P	N	0	0	0	0	0	0										
Waimarie	2004	2015	I	I	I	P	0	0	0	0	0	0	0	0										
Nerissa	2005	2015	I	I	I	P	P	P	N	0	0	0	0											
Zoe	2005	2015	I	I	I	P	P	P	0	P	P	0	0											
Pani	2005	2015	I	0	0	0	0	0	0	0	0	0	0											
Gem	2006	2015	I	I	I	P	N	0	P	P	P	P												
Emma	2006	2015	I	0	0	0	0	0	0	0	0	0												
Mia	2006	2015	I	0	I	P	N	N	N	0	0	0												
Hine	2007	2015	I	0	0	P	0	0	0	0	0													
Madeline	2007	2015	I	I	I	P	N	0	0	0	0													
Lena	2008	2015	I	I	I	P	N	0	P	P														
Douce	2008	2015	I	I	0	0	0	0	0	0														
Cockle	2008	2015	I	I	I	P	N	N	0	0														
Patti	2009	2015	I	I	I	0	N	0	P															
Mana	2009	2015	I	I	I	0	0	0	0															
Huru	2010	2015	I	I	0	P	P	0																
Sandy	2010	2015	I	I	I	0	0	0																
Becky	2010	2015	I	I	I	0	0	0																
Pippa	2010	2015	I	I	I	P	0	P																
Ngaio	2011	2015	I	0	0	0	0																	
Hiriwa	2011	2015	I	0	I	0	P																	
Joy	2011	2015	I	I	I	0	P																	
Carleigh	2011	2015	I	0	0	0	0																	
Marama	2012	2015	I	0	0	0																		
Moana	2012	2015	I	0	0	0																		
Bella	2013	2015	I	0	0																			
Unnamed1	2013	2015	I	0	0																			
Unnamed2	2013	2015	I	0	0																			
Nuki	2014	2015	I	0																				
Brionie	2014	2015	I	0																				
Gail	2014	2015	I	0																				

Figure 5: **Summary of all mark-resighting observations used in the Otago Peninsula demographic assessment. Individual names are those provided by the Sea Lion trust (Sealiontrust.org.nz 2015) and also in the DOC-maintained photo-ID database (DOC, unpublished data). "I" = immature individual (all observed at ages 1–3); "P" = pupper; "N" = non-pupper; "0" = unobserved. All were first observed as pups, with the exception of "Mum" which was first included in the dataset as a pupper in 1994.**

Age distribution

Childerhouse et al. (2010) estimated the age distribution of lactating females at Sandy Bay and Dundas at the Auckland Islands in all years from 1998–2001 (Table 4). An annual combined series of age distribution estimates was obtained by multiplying the estimated proportion-at-age with the estimated pup production for each respective rookery by year (Table 1), summing these (to estimate the total number of breeders by age) then recalculating proportions-at-age for the years 1998–2001. The combined proportions-at-age estimates (i.e. for Sandy Bay and Dundas) were used in all projection runs.

Threat-specific mortality with respect to population, age and year are given in Appendix 1. These values were provided by MPI/DOC in consultation with the TMP Expert Panel and advisors attending the first TMP workshop.

Table 4: **Estimated age distribution of lactating NZ sea lions at Sandy Bay and Dundas at the Auckland Islands in all years from 1998–2001 (Childerhouse et al. 2010) and the estimated age distribution for Sandy Bay and Dundas.**

Estimated age	Sandy Bay				Dundas				Sandy Bay and Dundas			
	1998	1999	2000	2001	1998	1999	2000	2001	1998	1999	2000	2001
3	0.000	0.007	0.007	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.014	0.007	0.014	0.036	0.021	0.034	0.034	0.030	0.020	0.029	0.030
5	0.000	0.041	0.022	0.021	0.071	0.036	0.034	0.047	0.059	0.037	0.032	0.043
6	0.067	0.130	0.043	0.035	0.107	0.086	0.054	0.034	0.100	0.094	0.052	0.034
7	0.467	0.137	0.123	0.042	0.107	0.057	0.060	0.074	0.167	0.071	0.071	0.068
8	0.000	0.151	0.181	0.168	0.071	0.121	0.081	0.060	0.059	0.127	0.097	0.078
9	0.000	0.103	0.174	0.175	0.107	0.107	0.114	0.114	0.089	0.107	0.124	0.124
10	0.067	0.062	0.101	0.168	0.179	0.079	0.054	0.074	0.160	0.076	0.062	0.090
11	0.067	0.082	0.051	0.077	0.036	0.114	0.094	0.087	0.041	0.110	0.087	0.086
12	0.133	0.041	0.029	0.028	0.071	0.029	0.067	0.087	0.082	0.031	0.061	0.077
13	0.133	0.068	0.058	0.042	0.036	0.079	0.081	0.067	0.052	0.077	0.077	0.063
14	0.000	0.034	0.014	0.014	0.071	0.050	0.034	0.047	0.059	0.048	0.030	0.041
15	0.000	0.055	0.036	0.035	0.036	0.050	0.054	0.047	0.030	0.051	0.051	0.045
16	0.000	0.027	0.029	0.035	0.071	0.014	0.040	0.054	0.059	0.017	0.038	0.051
17	0.067	0.007	0.022	0.021	0.000	0.036	0.060	0.027	0.011	0.031	0.054	0.026
18	0.000	0.007	0.022	0.014	0.000	0.021	0.020	0.047	0.000	0.019	0.020	0.041
19	0.000	0.014	0.029	0.028	0.000	0.029	0.034	0.034	0.000	0.026	0.033	0.033
21	0.000	0.007	0.014	0.028	0.000	0.021	0.013	0.013	0.000	0.019	0.014	0.016
22	0.000	0.014	0.014	0.014	0.000	0.007	0.013	0.020	0.000	0.008	0.014	0.019
23	0.000	0.000	0.000	0.021	0.000	0.007	0.013	0.013	0.000	0.006	0.011	0.015
24	0.000	0.000	0.014	0.007	0.000	0.000	0.027	0.020	0.000	0.000	0.025	0.018
25	0.000	0.000	0.007	0.000	0.000	0.021	0.000	0.000	0.000	0.018	0.001	0.000
26	0.000	0.000	0.000	0.007	0.000	0.007	0.007	0.000	0.000	0.006	0.006	0.001
Sample size	15	146	138	143	28	140	149	149				

2.3 Model structure

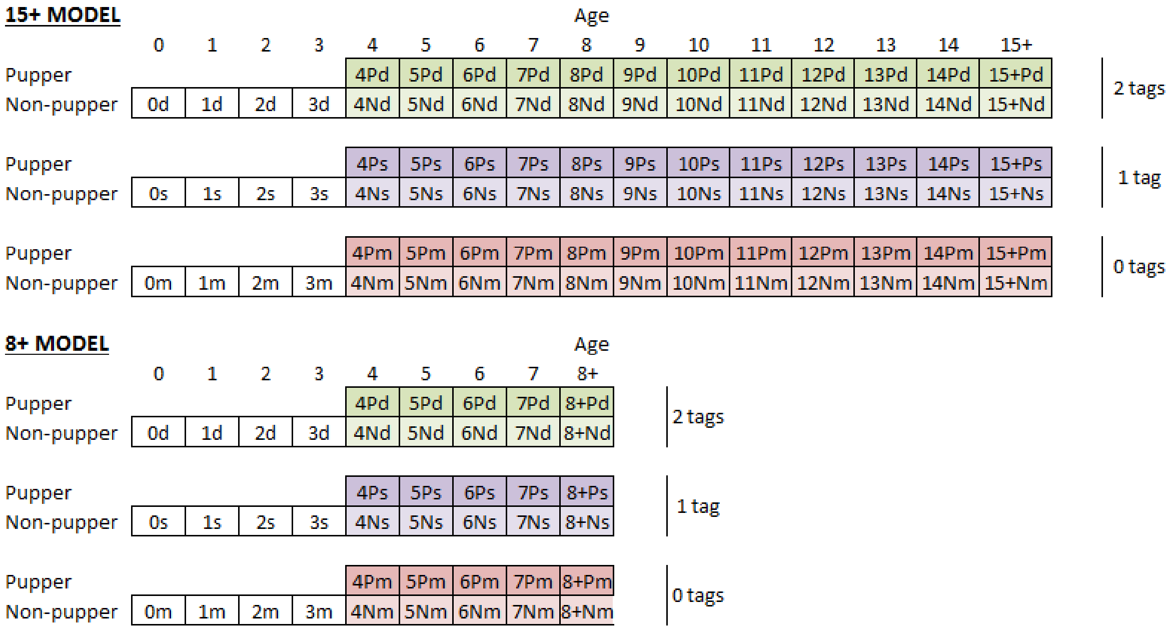
Partitioning

The set of states that any sea lion can be in for a particular year is called the partition. The model partitioned the population into ages 1 to 15+ (for the 15+ partitioning) or 8+ (for the 8+ partitioning), with the last age class being a plus group. Each age class was further partitioned into a number of states depending on pupping status and the number of flipper tags at observation. The partition therefore accounted for numbers of sea lions by age, pupping status and number of flipper tags within an annual cycle, where movement between partition states was determined by the transition parameters. Sea lions entered the partition as pups and were removed by mortality.

Two partition schemes were used (Figure 6):

- The **15+ Partitioning** considered that sea lions between ages 0 to 7 are "immature" if they had never pupped (sea lions were assumed not to pup until age 4); a sea lion between age 4 and 15+ became a "pupper" if she produced a pup in that year. A sea lion that never produced a pup was considered as "immature" before age 7, or a "non-pupper" if between age 8 and 15+. With this partition scheme, the model was able to estimate the probability of first-time pupping at age. Plus group at age 15+.
- The **8+ Partitioning** was as the 15+ Partitioning (above), except that the plus group was at age 8+.

Accordingly each re-sighting observation in the mark-recapture dataset was assigned a state based on age and pupping status (as well as the number of remaining tags for the tag-loss model). The pupping status was derived from observations in the "behaviour" field of the mark-recapture data extract and used the strict definition of puppers as described by Mackenzie (2012), i.e. if during a particular year an individual was observed giving birth, nursing a pup, or was observed a minimum of three times with a pup, then a "pupper" status was ascribed in that year; if an individual was observed three times without a pup then a "non-pupper" status was ascribed. If an individual was observed, but the pupping status could not be ascribed according to these rules above, then "unknown" pupper status was ascribed to that observation (a composite class of puppers and non-puppers; not shown in the partition diagram below). All individuals aged 3 or less were assumed to be unable to produce a pup.



15+ MODEL

	Age 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	
Pupper					4Pd	5Pd	6Pd	7Pd	8Pd	9Pd	10Pd	11Pd	12Pd	13Pd	14Pd	15+Pd	2 tags
Non-pupper	0d	1d	2d	3d	4Nd	5Nd	6Nd	7Nd	8Nd	9Nd	10Nd	11Nd	12Nd	13Nd	14Nd	15+Nd	
Pupper					4Ps	5Ps	6Ps	7Ps	8Ps	9Ps	10Ps	11Ps	12Ps	13Ps	14Ps	15+Ps	1 tag
Non-pupper	0s	1s	2s	3s	4Ns	5Ns	6Ns	7Ns	8Ns	9Ns	10Ns	11Ns	12Ns	13Ns	14Ns	15+Ns	
Pupper					4Pm	5Pm	6Pm	7Pm	8Pm	9Pm	10Pm	11Pm	12Pm	13Pm	14Pm	15+Pm	0 tags
Non-pupper	0m	1m	2m	3m	4Nm	5Nm	6Nm	7Nm	8Nm	9Nm	10Nm	11Nm	12Nm	13Nm	14Nm	15+Nm	

8+ MODEL

	Age 0	1	2	3	4	5	6	7	8+	
Pupper					4Pd	5Pd	6Pd	7Pd	8+Pd	2 tags
Non-pupper	0d	1d	2d	3d	4Nd	5Nd	6Nd	7Nd	8+Nd	
Pupper					4Ps	5Ps	6Ps	7Ps	8+Ps	1 tag
Non-pupper	0s	1s	2s	3s	4Ns	5Ns	6Ns	7Ns	8+Ns	
Pupper					4Pm	5Pm	6Pm	7Pm	8+Pm	0 tags
Non-pupper	0m	1m	2m	3m	4Nm	5Nm	6Nm	7Nm	8+Nm	

Figure 6: 15+ (top) and 8+ Partitioning (bottom) for demographic assessment models documented in this report. Cell notation is <age><breeding status><number of tag code>, where breeding status is N (did not pup in year+1), and P (pupped in year+1), and the number of tags is coded as "d" = double (2 tags); "s" = single (1 tag); "m" = missing (0 tags). Transitions were permitted to any class of age+1 (or from and to the age plus group), except where the number of tags increased post-transition.

Both the 8+ and 15+ partitionings were trialled for the Auckland Islands assessment with the 8+ partitioning used as a sensitivity analysis, whereas the Otago Peninsula assessment always used the 15+ partitioning.

Time steps

There can be one or more time steps within a year, with the observation of state at time step t_{trans}. This allowed various process to occur before and after the time of observations, such as recruitment, transition processes, or mortality relating to a particular threat.

The symbols, n_{ity} and n'_{ity} represent the number of sea lions in the *i*th class of the partition at time step *t* in year *y* before and after the partition process, respectively.

Transitions

Transitions move sea lions from one class of the partition to another as they develop or age (i.e. increase from age *n* to age *n*+1), change behaviour (e.g., do not pup in one year, then produce a pup in the next) or lose tags.

Transitions were achieved using simple matrix multiplication $n'_{ity} = Tn_{ity}$, where *T*, referred to as the *transition matrix*, is a matrix in which T_{ij} is the probability that an individual in partition class *i* will move to class *j*.

2.4 Parameter estimation

Survival

Survival s_{iy}, is the proportion of sea lions in the *i*th partition class that survive natural mortality to the end of year *y*. Potentially we can define f_t, the fraction of the annual natural mortality that occurs before time step t in each year, which gives s_{iy}^{ft}. Because there can be threat-related mortality, SeaBird uses $s_{iy} = \prod_t s_{iy}^{ft}$ for annual survival in the likelihood.

Proportional mortality: the user can specify that an observation in time step t in year y occurred part-way through the mortality that occurred in that time step. Thus, if p is the proportion of that mortality had occurred before the observation we need to define $n_{ity;p}$, the number of individuals in the ith class at the time of the observation.

Here $n_{ity;p}$ was calculated as the weighted sum:

$$n_{ity;p} = (1-p)n_{ity} + pn'_{ity} = (1-p+pT_{ity})n_{ity}$$

where n_{ity} and n'_{ity} ($= s_{ity}n_{ity}$) are the numbers before and after the mortality in this time step.

Objective function

Parameter estimation was by maximum likelihood. The objective function was given by:

$$-\sum_i \log\left[L(\mathbf{p} \mid O_i)\right]$$

where **p** is a vector of the free parameters, L the likelihood function and O_i the ith observation.

For Bayesian fitting the objective function was:

$$-\sum_i \log\left[L(\mathbf{p} \mid O_i)\right] - \log\left[\pi(\mathbf{p})\right]$$

where π is the joint prior density of the parameters **p**.

Likelihoods for mark-recapture observations

Symbols used in likelihood equations are presented in Table 5.

Table 5: Symbols used in likelihood equations.

Symbol	Comment
b	Unique tag code
$y_{b,\mathrm{tag}}$	The year the b^{th} sea lion was tagged
$y_{b,\mathrm{last}}$	The last year that the b^{th} sea lion was observed
O_{by}	Observed state for the b^{th} sea lion in year y
L_{by}	Likelihood of the observation in year y given the observation in year y–1
t_{trans}	Time within a year that the state of a sea lion is observed
X_{iyj}	The probability that a sea lion in stage i in year y will be alive and in stage j in the following year
$s_{\mathrm{tot},ity}$,	Survival of a sea lion during time step t in stage i in year y, includes fishery mortality, if used
p	The proportion of the mortality that had occurred before an observation in a time step. Thus, we have subscripts like $n_{ity;p}$, to denote the number of individuals in the ith class at the time of the observation. For survival, we have $s_{\mathrm{tot},ity;p} = 1 - p + ps_{\mathrm{tot},ity}$.

$r_{j,y}$	Resight probability, the probability of seeing a tagged individual in year *y*, given that it is alive and in the *i*th partition class
P_{biy}	The probability, given the observations on the sea lion with tag number *b* up to and including year *y*, that this sea lion is in non-composite stage *i*
Nstage	The number of stages

Mark recapture observations were input as a series of observations of individual tagged sea lions, including for each sea lion: the tag number *b* (a unique sea lion number), the year tagged $y_{b,\mathrm{tag}}$, the last year of observation $y_{b,\mathrm{last}}$, and the 'state' of the sea lion O_{by} in each year from $y_{b,\mathrm{tag}}$ to $y_{b,\mathrm{last}}$, where the 'state' indicates whether the sea lion was observed and, if so, which class of the partition the sea lion was in.

The negative log-likelihood for the sea lion with tag number *b* is given by $-\Sigma_y \log(L_{by})$, where the summation is over $y_{b,tag} < y \le y_{b,last}$ and L_{by} is the likelihood of the observation in year *y* given the observation in year y–1. The likelihood calculation is a generalization of that used in the Cormack-Jolly-Seber model (Cormack 1964). Specifically, when the model partition is of size 1 (so the mark-recapture observations are simply presence/absence) the calculated likelihood is exactly the same as in the Cormack-Jolly-Seber model. SeaBird generalizes this likelihood by allowing multi-state observations (partition size greater than 1) and uncertainty about state (as expressed in composite observations).

Let X_{iyj} be the probability that a sea lion in stage *i* in year *y* will be alive and in stage *j* in the following year. This may be calculated by multiplying the overall survivals ($s_{\mathrm{tot},ity}$) for each time step between the observations together with the transition probability. The equation for this depends on the relationship between the time step, *t*, for the mark-recapture observations, and that for the transition process, t_{trans}:

$$X_{iyj} = \begin{cases} \dfrac{s_{\mathrm{tot},ity}}{s_{\mathrm{tot},ity;p}} \left[\prod_{t'>t} s_{\mathrm{tot},it'y} \right] \left[\prod_{t' \le t_{trans}} s_{\mathrm{tot},it',y+1} \right] \left[\prod_{t_{trans} < t' < t} s_{\mathrm{tot},jt',y+1} \right] s_{\mathrm{tot},jt,y+1;p} T_{y+1,ij} & \text{if } t > t_{trans} \\ \dfrac{s_{\mathrm{tot},ity}}{s_{\mathrm{tot},ity;p}} \left[\prod_{t < t' \le t_{trans}} s_{\mathrm{tot},it'y} \right] \left[\prod_{t' > t_{trans}} s_{\mathrm{tot},jt'y} \right] \left[\prod_{t' < t} s_{\mathrm{tot},jt',y+1} \right] s_{\mathrm{tot},jt,y+1;p} T_{yij} & \text{if } t \le t_{trans} \end{cases}$$

where we use the convention that 'empty' products are equal to 1 (e.g., the first product in the upper formula will be empty if *t* is the last time step).

To calculate the likelihoods L_{by}, we needed to define P_{biy} to be the probability, given the observations on the sea lion with tag number *b* up to and including year *y*, that this sea lion was in a non-composite stage *i* in that year. Obviously, if this sea lion was observed in non-composite stage *j* in year *y*, then

$$P_{biy} = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{if } i \ne j \end{cases}$$

Otherwise, P_{biy} was calculated recursively as follows. If the observed stage at tagging (i.e., in year $y = y_{b,tag}$) was composite then

$$P_{biy} = \begin{cases} \dfrac{n_{ity;p} r_{iy}}{\sum_{i' \in O_{by}} n_{i'ty;p} r_{i'y}} & \text{if } i \in O_{by} \\ 0 & \text{if } i \notin O_{by} \end{cases}$$

where $n_{ity;p}$ are the numbers of sea lions at the time of the observations. If the observed stage in year y+1 (i.e., $O_{b,y+1}$) is composite, or ≤ 0, then

$$P_{bj,y+1} = \begin{cases} \dfrac{\sum_{i\in O_{by}} P_{biy} X_{iyj} r_{j,y+1}}{\sum_{i\in O_{by}} P_{biy} \sum_{j'\in O_{b,y+1}} X_{iyj'} r_{j',y+1}} & \text{if } O_{b,y+1} > 0 \text{ and } j \in O_{b,y+1} \\ 0 & \text{if } O_{b,y+1} > 0 \text{ and } j \notin O_{b,y+1} \\ \dfrac{\sum_{i\in O_{by}} P_{biy} X_{iyj} \left(1 - r_{j,y+1}\right)}{1 - \sum_{i\in O_{by}} P_{biy} \sum_{j'} X_{iyj'} r_{j',y+1}} & \text{if } O_{b,y+1} = 0 \\ \sum_{i\in O_{by}} P_{biy} X_{iyj} & \text{if } O_{b,y+1} = -1 \end{cases}$$

where, for $O_{by} \le 0$ the notation $\sum_{i\in O_{by}}$ implies a sum over all non-composite stages (i.e., from 1 to Nstage), as does $\sum_{j'}$.

The likelihoods are calculated as:

$$L_{b,y+1} = \begin{cases} \sum_{i\in O_{by}} P_{biy} \sum_{j\in O_{b,y+1}} X_{iyj} r_{j,y+1} & \text{if } O_{b,y+1} > 0 \\ \left(1 - \sum_i P_{biy}\right) + \sum_{i\in O_{by}} P_{biy} \left[1 - \sum_j X_{iyj} r_{j,y+1}\right] & \text{if } O_{b,y+1} = 0 \\ 1 & \text{if } O_{b,y+1} = -1 \end{cases}$$

The total log-likelihood associated with a tagged sea lion depends very little, if at all, on the numbers of individuals in the partition. These numbers enter the likelihood calculation for a tagged sea lion only if the initial observation, $O_{by_{b,band}}$, is a composite stage, in which case $P_{biy_{b,band}}$ depends on the number of partitions.

Likelihoods for absolute abundance, by-catch or parameter observations

For these observations, the likelihood is a formula involving the observation, *O*, and the population model's expected value, *E*, for the observation. The form of the formula depended on the error distribution assumed for the observation (Table 6).

Table 6: Formulae for calculating negative-log likelihoods for different error distributions. CV is denoted by "c", standard deviation by "s", and the robustification constant by "r".

Error distribution	**Parameter(s)**	**Negative-log likelihood**
normal	c	$\log(cE) + 0.5[(O–E)/(cE)]^2$
normal-by-stdev	s	$\log(s) + 0.5[(O–E)/s]^2$
lognormal	c^1	$\log(\sigma) + 0.5[0.5\sigma + \log(O/E)/\sigma]^2$
normal-log	c^1	$\log(\sigma) + 0.5[\log(O/E)/\sigma]^2$
robustified-lognormal	$c^{1,}\ r$	$\log(\sigma) - \log\left(\exp\left[-0.5\left(\dfrac{\log(O/E)}{\sigma} + \dfrac{\sigma}{2}\right)^2\right] + r\right)$

[1] In the likelihood, $\sigma = [\log(1+c^2)]^{0.5}$

Likelihoods for age distribution observations

Age distributions were fitted in the Auckland Islands assessments using a likelihood based on the multinomial distribution.

Let $\boldsymbol{O}$ be a vector of observations of proportions-at-age for a single year that sum to 1; let $\boldsymbol{E}$ be the corresponding fitted values; let N be the "effective sample size" parameter. Then the multinomial likelihood for that year, which is expressed on the objective-function scale of $-\log(L)$, is:

$$-\log(L) = -\log(N!) + \sum_i \left[\log\left((NO_i)!\right) - NO_i \log\left(Z(E_i, r)\right)\right]$$

where $Z(x,r)$ is a robustifying function, defined as:

$$Z(x,r) = \begin{cases} x \text{ where } x \geq r \\ r/(2 - x/r) \text{ otherwise} \end{cases}$$

Here, r was set to 0 so $Z(x,r) = x$. N was set to 200 and 1000 for the 1998 and 1999–2001 estimates, respectively.

2.5 Threat-related mortality

The mortality process associated with a threat-mortality f occurring at time step t in year y is defined by $n'_{ity} = n_{ity} - C_{ify}$, where $C_{ify} = U_{fy} S_{if} n_{ity}$, S_{if} is the selectivity function for this threat, U_{fy} is the exploitation rate in year y, given by $U_{fy} = \min\left[U_{\max,f} C_{fy} \Big/ \sum_j \left(S_{jf} n_{jty}\right)\right]$, $U_{\max,f}$ is the maximum achievable mortality rate, and C_{fy} is the specified mortality.

2.6 Demographic model development/selection process

SeaBird provides a flexible modelling platform for trialling variation in model structure and parameterisation, such that a wide array of model configurations can be developed. Roberts et al. (2014) developed an optimised demographic assessment model for females at the Auckland Islands using SeaBird and model run 7 of that assessment (the base run) was adopted as the initial model structure in this assessment.

A sequential model optimisation process was adopted in which the model with the lowest Akaike information criterion (AIC – a likelihood based measure of goodness-of-fit.) was sought. The model structure at each step of the optimisation process is described in Appendix 6. The final parameterisation for the 15+ model was as follows (the 8+ model run did not estimate $Surv_{15+}$):

Initial population size:

- N_{1990} Mature female N in 1990

Year-varying rates:

- $Surv_{0}$ Annual survival age 0 (1990–1993, 1994–2004, then all to 2014)
- $Surv_{6\text{-}14}$ Annual survival age 6–14 (1990–1998, 1999–2004, then all to 2014)
- Pr_{P} Annual probability of pupping age 8+ (1990–1997, 1998–2004, then all to 2014)
- Res_{N} Annual resighting probability of non-puppers (1999, 2000–2001, 2002–2012, 2013, 2014–2015)
- Res_{Ptag} Annual resighting probability of tag marked puppers (1999, 2000–2001, 2002–2012, 2013, 2014–2015)
- Res_{Pchip} Annual resighting probability of chip-marked puppers (1999, 2000–2001, 2002–2012, 2013, 2014–2015)

Constant with respect to year:

$Surv_{1}$	Annual survival age 1
$Surv_{2\text{-}5}$	Annual survival age 2–5
$Surv_{15+}$	Annual survival age 15+
Mat_{4}	Probability of pupping at age 4 (relative to Pr_{P})
Mat_{5}	Probability of pupping at age 5 (relative to Pr_{P})
Mat_{6}	Probability of pupping at age 6 (relative to Pr_{P})
Mat_{7}	Probability of pupping at age 7 (relative to Pr_{P})
$Res_{1\text{-}2}$	Annual resighting probability at age 1–2
Res_{3}	Annual resighting probability at age 3
Res_{Pbrand}	Annual resighting probability of branded puppers (fixed to 1)
Pr_{T10}	Annual probability of losing a single tag in the first year
Pr_{T1a}	Functional form parameter that gives the probability of losing 1 tag in a year (1)
Pr_{T1b}	Functional form parameter that gives the probability of losing 1 tag in a year (2)
Pr_{T2}	Annual probability of losing two tags in a year

Uniform priors were used for all estimated parameters, which were bounded between 0 and 1, with the exception of Survival parameters (0 and 0.99) and N_{1990} (100 and 4000). The 2008 cohort was marked with flipper-tags that had a high pull-out rate (DOC unpublished data). As such, the 2008 value of $Surv_{0}$ was fixed to 0.4 – approximately equal to the mean of 2007 and 2009 values.

The final model parameterisation for the Otago Peninsula assessment was as follows:

N_{1990}	Number of breeders in 1990
$Surv_{0}$	Survival to age 1
$Surv_{1\text{-}5}$	Survival age 1 to age 6
$Surv_{6\text{-}14}$	Survival age 6 to age 15
$Surv_{15+}$	Survival age 15+
Pup_{7+}	Pupping rates age 7+
$Mat_{4\text{-}6}$	Relative pupping rate age 4–6
Res_{ImNP}	Annual resighting probability immature and non-puppers

The probability of resighting puppers was fixed to 1. Uniform priors were used for all estimated parameters.

2.7 MCMC

The Metropolis–Hastings algorithm was used. The number of chains, iterations, sample spacing, and the total number of samples for the Otago Peninsula and Auckland Islands runs are given in Table 7. As a preliminary step to improve mixing for the Auckland Islands MCMC run, the covariance matrix (used to generate the proposal distribution) was recalculated empirically from the first 10 000 iterations, which were then discarded. This step was undertaken twice, with only a small improvement in mixing observed after the second recalculation.

Table 7: Overview of MCMC sampling for all model runs

Model run	Number of chains	Chain iterations (burn-in)	Total iterations (excluding burn-in)	Sample spacing	Total samples
Auckland Islands (15+ run)	5	210 000 (10 000)	1 million	1/100th	10 000
Auckland Islands (8+ run)	3	343 333 (10 000)	1 million	1/100th	10 000
Otago Peninsula	3	1 010 000 (10 000)	3 million	1/100th	30 000

2.8 Population projections assessing the effects of threats

The operating model and the sets of parameter distribution were used to assess the effect of alternative threat scenarios on projected mature *N* from 2017–2037 (hereafter referred to as *N, i.e.* $N_{2017\text{-}2037}$). A 2-stage approach was used to conduct the assessment of threats:

1. Triage projection runs were undertaken using the upper-bound estimates of threat-specific mortality (Table 15, Table 16 and Table 19) to screen out threats that have a very small effect on projected mature numbers; then
2. Key threats were then carried forward to an MCMC projection run using the best-estimate of threat related mortality at age (Table 17, Table 18 and Table 20).

The two projection steps differed in terms of the number of runs and how demographic rates were sampled (Table 8). A fundamental difference was the way in which year-varying demographic rates were used in projections – they both used the same period of estimates ($Surv_0$–2005–2012; $Surv_{6\text{-}14}$–2005–2014; Pr_P–2005–2014), but where the best-estimate projection runs randomly sampled from the annual estimates, the Triage projection runs used the mean across all annual estimates from the sampled period.

Mature *N* was determined from model estimates of population size by status. This was calculated as the model estimate of *N* at ages 8+ (all assumed to be mature from age 8) plus *N* at ages 4–7 times the relative pupping rate estimate at ages 4–7 (Mat_4, Mat_5, Mat_6 and Mat_7), e.g., mature *N* at age 5 was calculated as N_{age5} times Mat_5, etc. The population effect of a threat was measured in terms of the estimated population growth rate in 2037 (λ_{2037}), which was calculated as N_{2037}/N_{2036}. In addition the population status in 2037 was calculated as N_{2037}/N_{2017} (%).

Table 8: Aspects of methodology for triage and best-estimate projection runs.

Projection type	Threat estimate	Model run	Projections *N*	How year-varying demographic rates are used for projections
Triage projection	Upper bound estimates	MPD	1	Mean of annual estimates
Best-estimate projection	Best estimates	MCMC	1 million (Auckland Islands) 3 million (Otago Peninsula)	Random sampling from annual estimates

3. RESULTS

3.1 Auckland Islands demographic Assessment

The MPD and MCMC outputs are described below for the 15+ model run.

MPD Runs

The Auckland Islands base model produced good fits to all three observation types: mark-recapture (Figure 7), pup census (Figure 8) and the age distribution of reproductive females (Figure 9). The good fit to pup census observations suggests that the model parameterisation and parameter estimates are sufficient to explain the observed population decline at the Auckland Islands (Figure 8). With respect to the mark-recapture observations, good fits were obtained regardless of mark-type, i.e. flipper-tag only, brand or chip-marked (Figure 7). There was also a good fit to the observed proportion of lactating females at age 15+, indicating that the parameterisation of survival-at-age produced realistic numbers of individuals in the plus group, with no conflict with the mark-recapture observations (comparing Figure 7 and Figure 9).

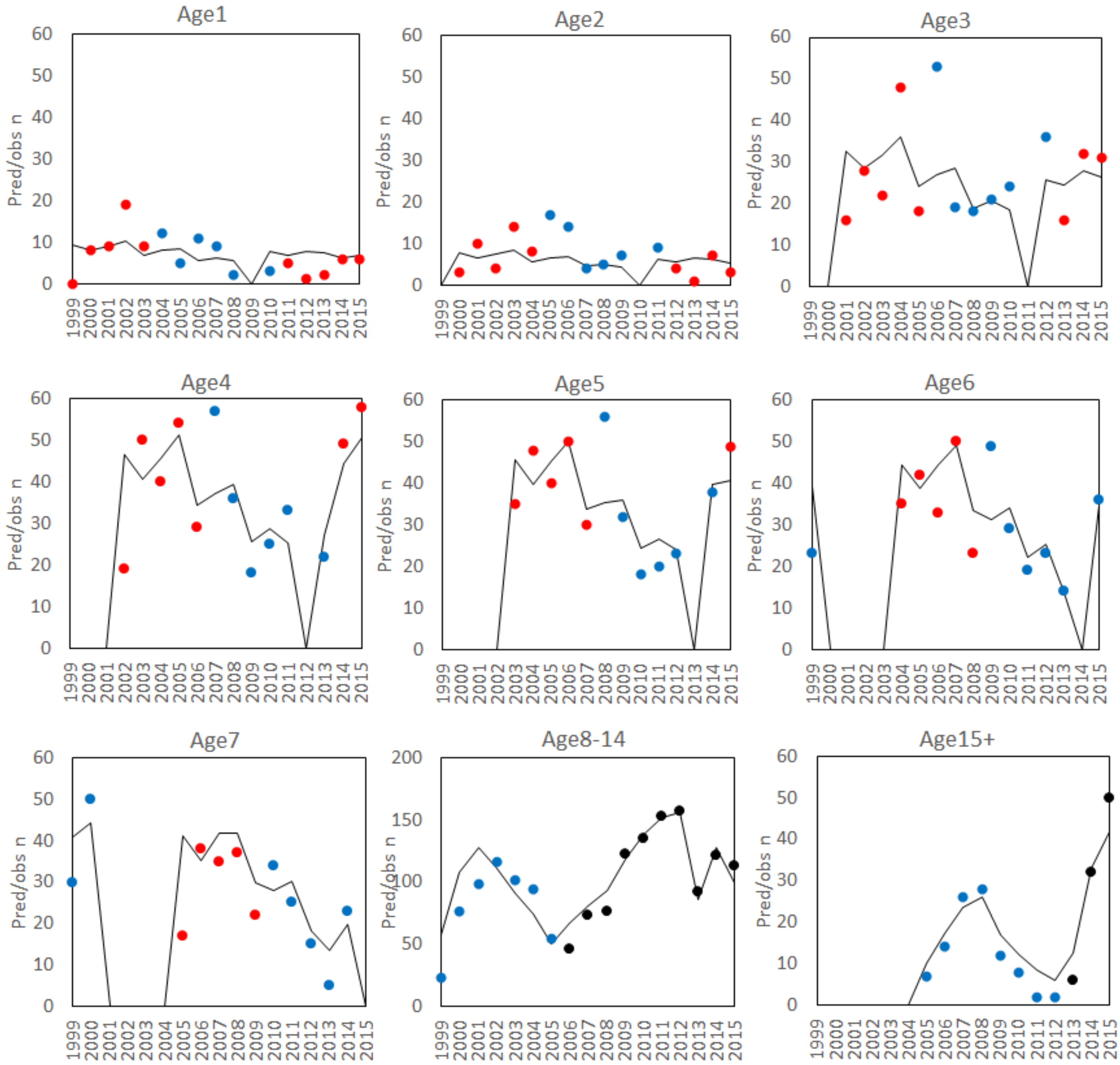


Figure 7: Base run fits (lines) to mark-recapture observations (points) of individuals tagged as pups at the Auckland Islands in 1990–1993 and 1998–2014 in each resighting year (1999–2015, along the x-axis), resighted from ages 1 (top-left) to 15+ (bottom-right). Cohorts that were brand or chip-marked are coloured red; flipper-tagged only are blue; mixture of mark types are black.

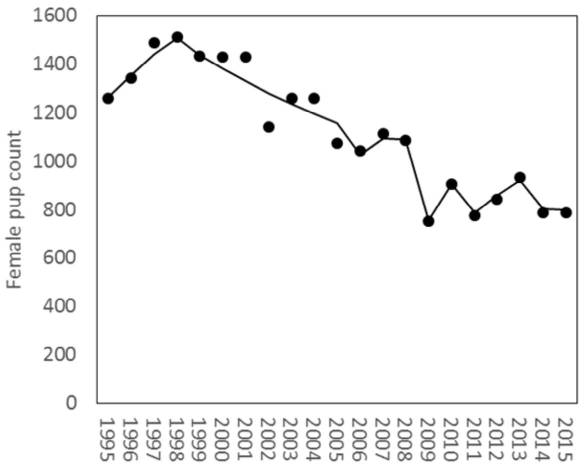


Figure 8: Base run fits (lines) to female pup census observations (points) at the Auckland Islands.

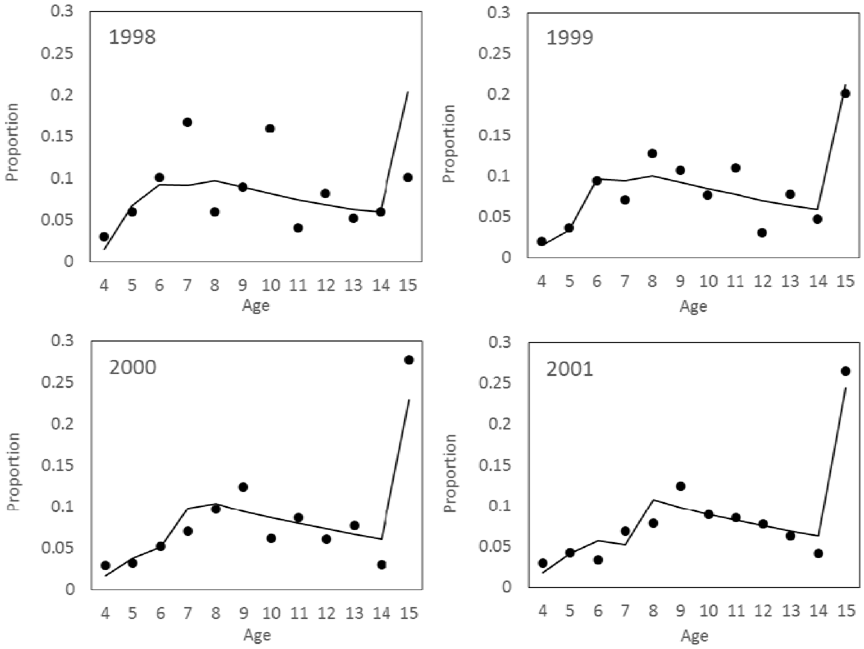


Figure 9: **Base run fits (lines) to proportion at age observations (points) of lactating females at the Auckland Islands.**

Focussing on the year-varying demographic rates (*Surv*$_0$, *Surv*$_{6\text{-}14}$ and *Pr*$_P$), the MPD estimates indicate that a major decline in pup survival occurred after 1993 (*Surv*$_0$ = 0.79 in 1990–1993; 0.38 in 1994–2004) and has remained relatively low since, with evidence for a single-year increase in 2009 (*Surv*$_0$ = 0.54). MPD estimates of survival at ages 6–14 (*Surv*$_{6\text{-}14}$) have generally been low since 2005 (mean = 0.882; range = 0.820–0.933), compared with the preceding 1990–1993 (0.971) and 1999–2004 period (0.911). This suggests that a decline in adult survival has occurred, with some years of very low survival in some recent years (less than 0.85 in 2007, 2011, 2013 and 2014). The MPD run estimates of pupping rate (*Pr*$_P$ – corresponds with pupping in year+1) are highly variable with low estimates (less than 0.65) in 2005, 2008 and 2010 and high estimates (more than 0.75) in all years since 2011.

The functional form for the probability of losing one tag indicates that tag loss rate is high up to age 1 (0.17), very low from age 1 to 2 (0.01), then increases rapidly with age in a concave manner until age 15 (0.21 at this age). The age-constant probability of losing two tags in a year was 0.03 (Figure 10).

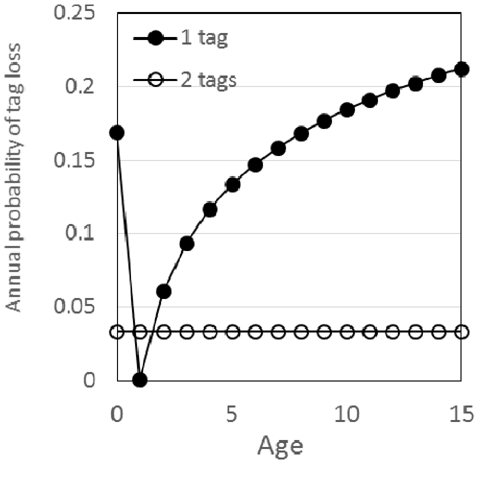


Figure 10: **Age effect on the probability of annual tag loss, derived from MPD parameter estimates from the Auckland Islands base model (15+).**

MCMC runs

The MCMC chains took a long time to complete (about 4 days and about 15 days for 200 000 iterations with the 8+ and 15+ model, respectively). The 8+ model had approximately half the number of classes and the run time was approximately a quarter, as expected (as there were about a quarter the possible number of transitions between states). A visual inspection of the trace plots for the 15+ model suggests that the method of empirically recalculating the covariance matrix used to generate the MCMC proposal distribution was effective in giving an acceptable degree of mixing for all estimated parameters (Figure 24 to Figure 32). Also there was good agreement in the distribution of estimates obtained from different chains (Figure 33 and Figure 35). Some parameters were strongly correlated (Pearson product-moment correlation coefficient less than -0.6 or more than 0.6), including demographic rates estimates in the period prior to the start of consistent resighting effort (before 1999) (Table 21). However, the posterior distributions (Figure 36 to Figure 46) indicate that all estimated parameters were strongly identifiable, with the exception of $Surv_0$ in 2013 and 2014. These individuals would be age 2 and 1 in the terminal year of the assessment (2015) and there was low resighting probability at these ages ($Res_{1\text{-}2} = 0.09$, C.I. 0.08 – 0.10), so we should expect the last two pup survival parameters (2013 and 2014) to be weakly identifiable.

The MCMC estimates of year-varying demographic rates are shown in Figure 11 to Figure 14 and all parameters estimates for the base run are tabulated in (Table 22). The median estimates are close to the MPD point estimate for all parameters and the description of year varying trends from the MPD estimates (above) also apply for the MCMC estimates.

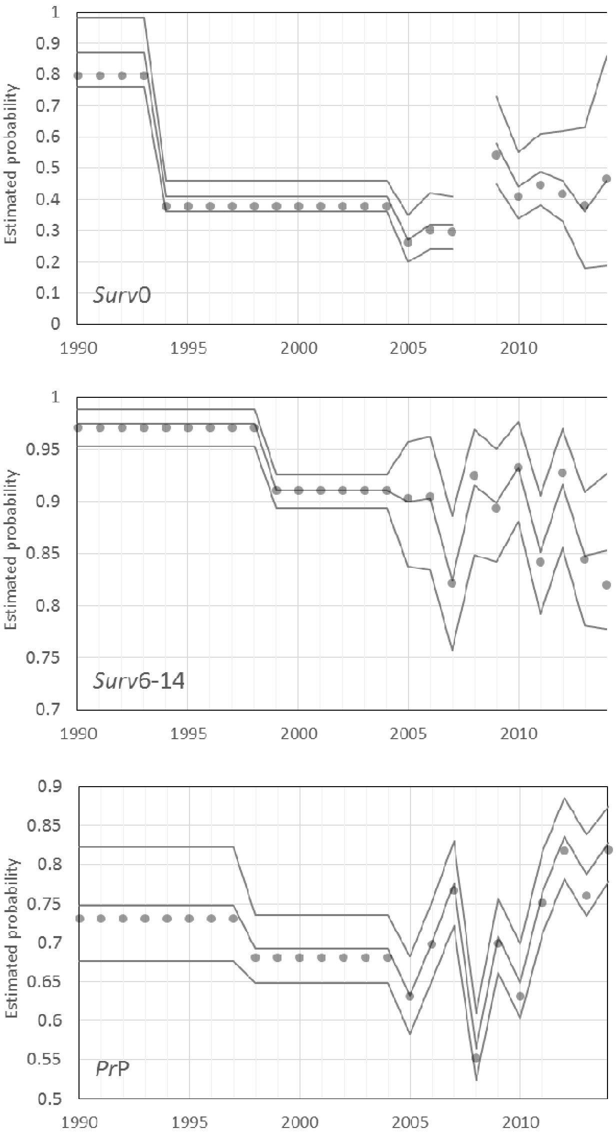


Figure 11: **Auckland Islands base model (15+) MCMC annual estimates of $Surv_0$ (top), $Surv_{6\text{-}14}$ (middle), Pr_P (bottom). Lines are the median and 95% credible interval for each respective parameter; closed circles are the MPD point estimates. $Surv_0$ in 2008 is fixed at 0.4 because the tag data for this year were not reliable.**

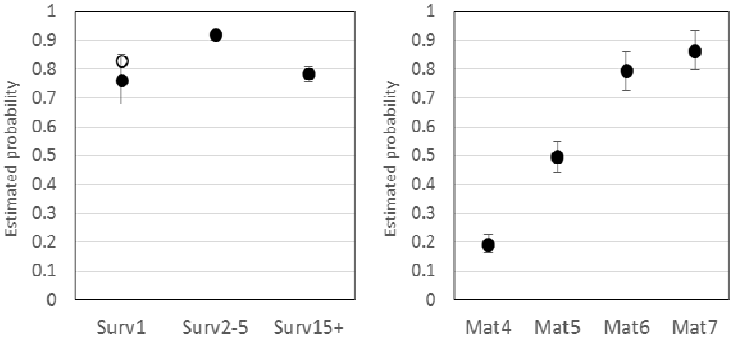


Figure 12: **Auckland Islands base model (15+) MCMC estimates of annual survival at all other ages (left) and relative pupping rate at maturation ages (right). Filled circles and bars are the median and 95% credible interval for each parameter; open circles are the MPD point estimates.**

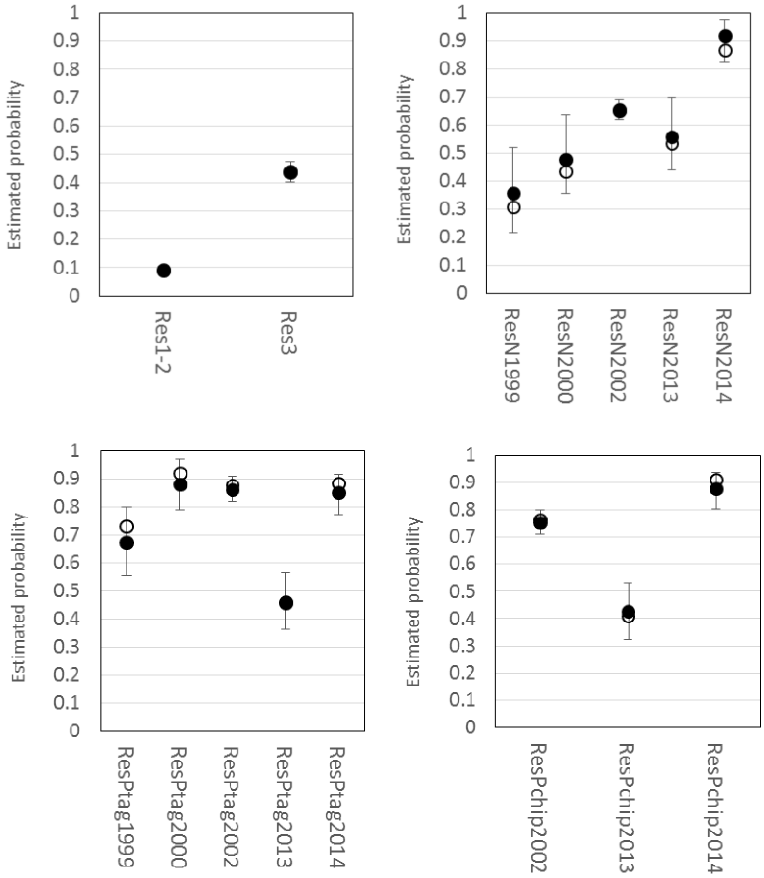


Figure 13: **Auckland Islands Base model (15+) MCMC estimates of annual resighting probability parameters. Filled circles and bars are the median and 95% credible interval for each parameter; open circles are the MPD point estimates. Year labels 1999, 2000, 2002, 2013 and 2014 correspond with the periods 1999, 2000–01, 2002–2012, 2013 and 2014–15, respectively.**

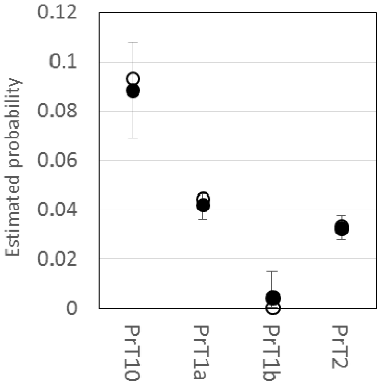


Figure 14: **Auckland Islands Base model (15+) MCMC estimates of annual resighting probability parameters. Filled circles and bars are the median and 95% credible interval for each parameter; open circles are the MPD point estimates.**

Triage projections

Triage runs used the upper bound threat level for an array of scenarios supplied by MPI/DOC (Table 15 and Table 16). Triage model run projection outputs for the Auckland Islands using the 15+ model configuration are shown in Table 9 and Figure 15. These figures effectively represent the maximum future effect on mature numbers of totally alleviating each threat in turn from 2017. These are presented alongside the base model projection, which gives projected mature N with a continuation of demographic rates since 2005 ($\lambda_{2037} = 0.96, N_{2037}/N_{2017} = 0.49$).

Two threats stand out as having a potentially large effect (given the upper bound values of threat-related mortality for each): *Klebsiella* mortality of pups ($\lambda_{2037} = 1.01, N_{2037}/N_{2017} = 1.44$) and commercial trawl-related mortality of individuals age 3+ and associated pup mortality ($\lambda_{2037} = 1.01, N_{2037}/N_{2017} = 1.36$). A continuation of the declining trend up to 2017 (i.e. $N_{2037}/N_{2017} < 1$) was predicted when alleviating the upper bound of threat-related mortality of all other threats (Figure 15). Threats carried forward to best-estimate projection were *Klebsiella*, commercial trawl-related mortality, male aggression, trophic effect – food limitation, hookworm mortality and drowning in wallows (Table 9).

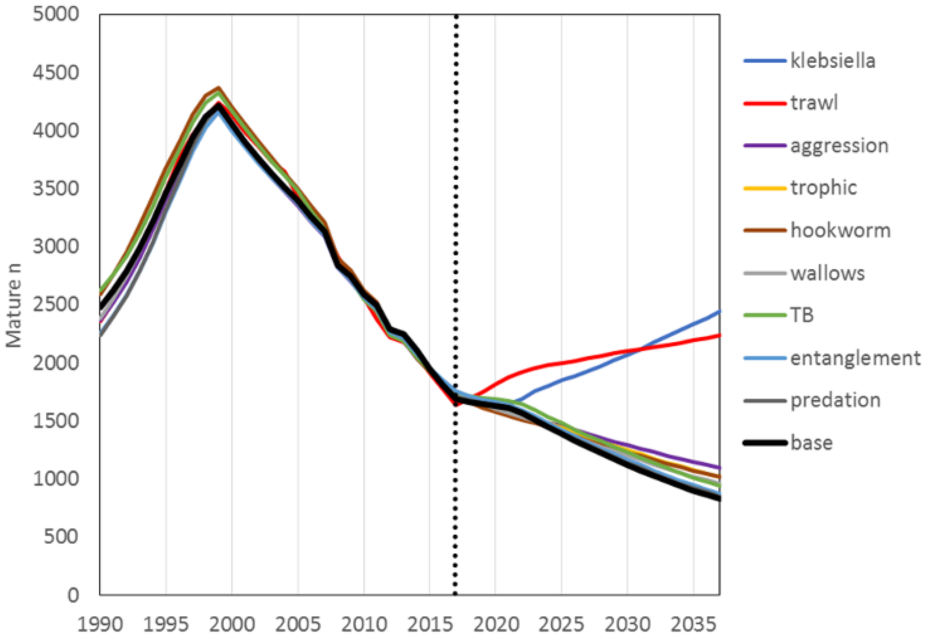


Figure 15: **Triage projections of model estimated mature *N* at the Auckland Islands in the period 1990–2037, using upper values of threat mortality. Black line = with all threats (base run).**

Table 9: Auckland Islands triage model run estimates of mature female λ_{2037} and N_{2037}/N_{2017} for all threat scenarios, using upper values of threat mortality. *Threat scenarios carried forward to best-estimate projection.

Threat scenario	λ_{2037}	N_{2037}/N_{2017}
Klebsiella*	1.02	1.44
Commercial trawl*	1.01	1.36
Male aggression*	0.98	0.63
Trophic – prey*	0.97	0.60
Hookworm*	0.97	0.59
Wallows*	0.97	0.55
Tuberculosis	0.96	0.54
Entanglement	0.96	0.50
Shark predation	0.96	0.50
Base	0.96	0.49

Best-estimate projections

As with the Triage projections, these give the effect on predicted mature *N* of alleviating each threat in turn, except that the best-estimates of threat-related mortality are used (Table 17 and Table 18, supplied by MPI/DOC) and an MCMC run is undertaken to assess the uncertainty of model estimates. All parameter estimates for the base run and threat scenario runs are tabulated in Table 22 to Table 32. The results of the best-estimate projections using the 15+ model configuration are given in Table 10, Table 11, Figure 16 and Figure 17. Two reference population projections are given: the base run (a continuation of demographic rates since 2005) ($\lambda_{2037} = 0.961$, 95% CIs 0.890–1.020; $N_{2037}/N_{2017} = 0.47$, 95% CIs 0.32–0.67) and the “max growth” scenario, which used the 1990–1993 estimate of $Surv_0$, the 1990–1998 estimates of $Surv_{6\text{-}14}$ and the 1990–1999 estimate of Pr_P (i.e. resulting in the population growth of mature N from 1990 to the late-1990s) (λ_{2037} = 1.069, 95% CIs 1.051–1.084; N_{2037}/N_{2017} = 3.40, 95% CIs 2.39–4.60).

Klebsiella was the only threat for which complete alleviation led to a positive growth rate (λ_{2037} = 1.005, 95% CIs 0.926–1.038), although mature N_{2037} was lower than N_{2017} with the alleviation of any threat. An increase in projected growth rate was obtained with each incremental increase in mortality associated with commercial trawl fishery related mortality (i.e. from only captures resulting in mortality – no cryptic SLED mortality - up to all interactions resulting in mortality). The effects of assuming intermediate levels of commercial trawl mortality was assessed using alternative values of the SLED discount rate (a trawl management setting which gives a "discounted" strike rate to apply to all tows when an approved SLED is used; i.e. there is a decrease in mortality with increasing discount rate) from 20% to 82%, the value that is currently used. As expected, incremental decreases in discount rate gave incremental reductions in projected population growth rate with the alleviation of this threat. With the alleviation of the best-estimate of the maximum level of mortality associated with the commercial trawl fishery (i.e. all interactions resulted in mortality and associated pup mortality) a declining trend in projected population growth rate was still obtained (λ_{2037} = 0.977, 95% CIs 0.902–1.038) (Table 10 and Figure 16).

The 8+ model configuration produced slightly more pessimistic estimates of mature N and population growth rate in 2037 relative to the 15+ model (Table 10 and Table 11). The precise reasons for this are not known, though it is likely to relate to differences in the parameterisation of survival at older ages comparing the two model configurations (i.e. it is effectively year-varying in the 8+ model versus constant in the 15+ model).

Table 10: **Auckland Islands model estimates of mature female λ_{2037} for all threat scenarios. Values are median and 95% credible intervals.**

Threat Scenario	λ_{2037}	
	15+ model	8+ model
Base	0.961 (0.89 – 1.02)	0.958 (0.865 – 1.048)
Wallows	0.965 (0.891 – 1.027)	0.963 (0.868 – 1.052)
Hookworm	0.967 (0.894 – 1.026)	0.963 (0.872 – 1.051)
Aggression	0.969 (0.895 – 1.029)	0.966 (0.873 – 1.054)
Trophic	0.974 (0.905 – 1.038)	0.979 (0.893 – 1.066)
Klebsiella	1.005 (0.926 – 1.069)	0.997 (0.909 – 1.084)
Trawl captures	0.964 (0.89 – 1.025)	0.962 (0.867 – 1.052)
Trawl 82% discount	0.965 (0.891 – 1.024)	0.963 (0.866 – 1.055)
Trawl 35% discount	0.971 (0.899 – 1.031)	0.969 (0.874 – 1.062)
Trawl 20% discount	0.973 (0.898 – 1.032)	0.971 (0.876 – 1.063)
Trawl interactions	0.977 (0.902 – 1.036)	0.973 (0.879 – 1.066)
Max growth	1.069 (1.051 – 1.084)	1.088 (1.065 – 1.110)

Table 11: Auckland Islands model estimates of mature female N_{2037}/N_{2017} for all threat scenarios. Values are median and 95% credible intervals.

Threat scenario	N_{2037}/N_{2017}	
	15+ model	8+ model
Base	0.47 (0.32 – 0.67)	0.38 (0.25 – 0.58)
Wallows	0.51 (0.35 – 0.74)	0.41 (0.28 – 0.61)
Hookworm	0.52 (0.36 – 0.75)	0.43 (0.29 – 0.63)
Aggression	0.54 (0.38 – 0.77)	0.44 (0.3 – 0.65)
Trophic	0.59 (0.36 – 0.96)	0.56 (0.37 – 0.85)
Klebsiella	0.93 (0.67 – 1.26)	0.75 (0.53 – 1.06)
Trawl captures	0.49 (0.34 – 0.72)	0.41 (0.27 – 0.62)
Trawl 82% discount	0.5 (0.35 – 0.73)	0.42 (0.27 – 0.62)
Trawl 35% discount	0.58 (0.4 – 0.84)	0.48 (0.32 – 0.72)
Trawl 20% discount	0.6 (0.41 – 0.88)	0.51 (0.33 – 0.76)
Trawl interactions	0.64 (0.44 – 0.92)	0.53 (0.35 – 0.79)
Max growth	3.4 (2.39 – 4.60)	4.41 (2.88 – 6.74)

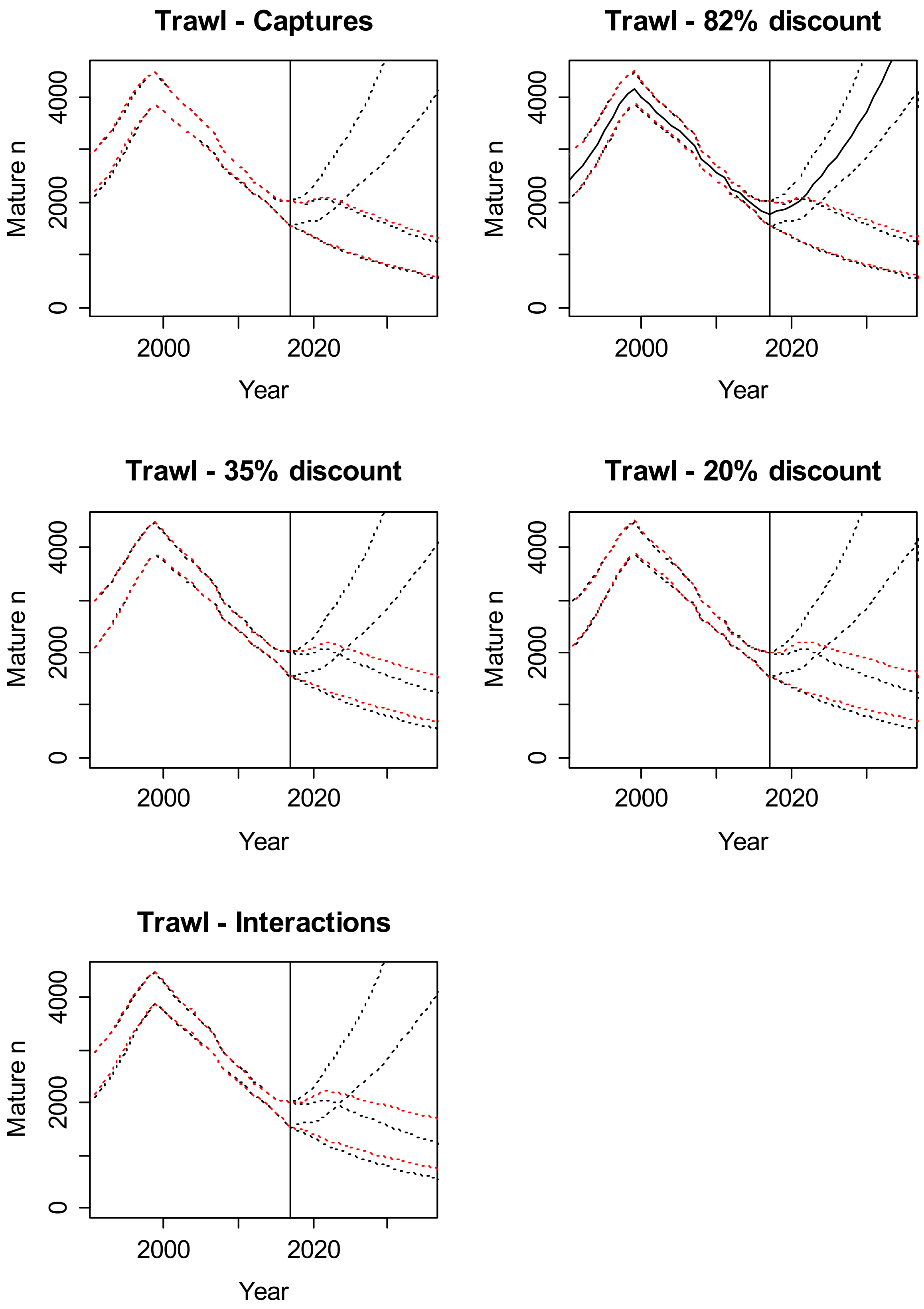


Figure 16: 15+ model estimates of mature n at the Auckland Islands in the period 1990–2037 for trawl fishery mortality scenarios. Lower black lines are with all threats (base run); upper black lines are with the "max growth" scenario (1990–1993 estimate of $Surv_0$, 1990–1998 estimates of $Surv_{6-14}$ and 1990–1999 estimate of Pr_P; red lines are with a threat alleviated.

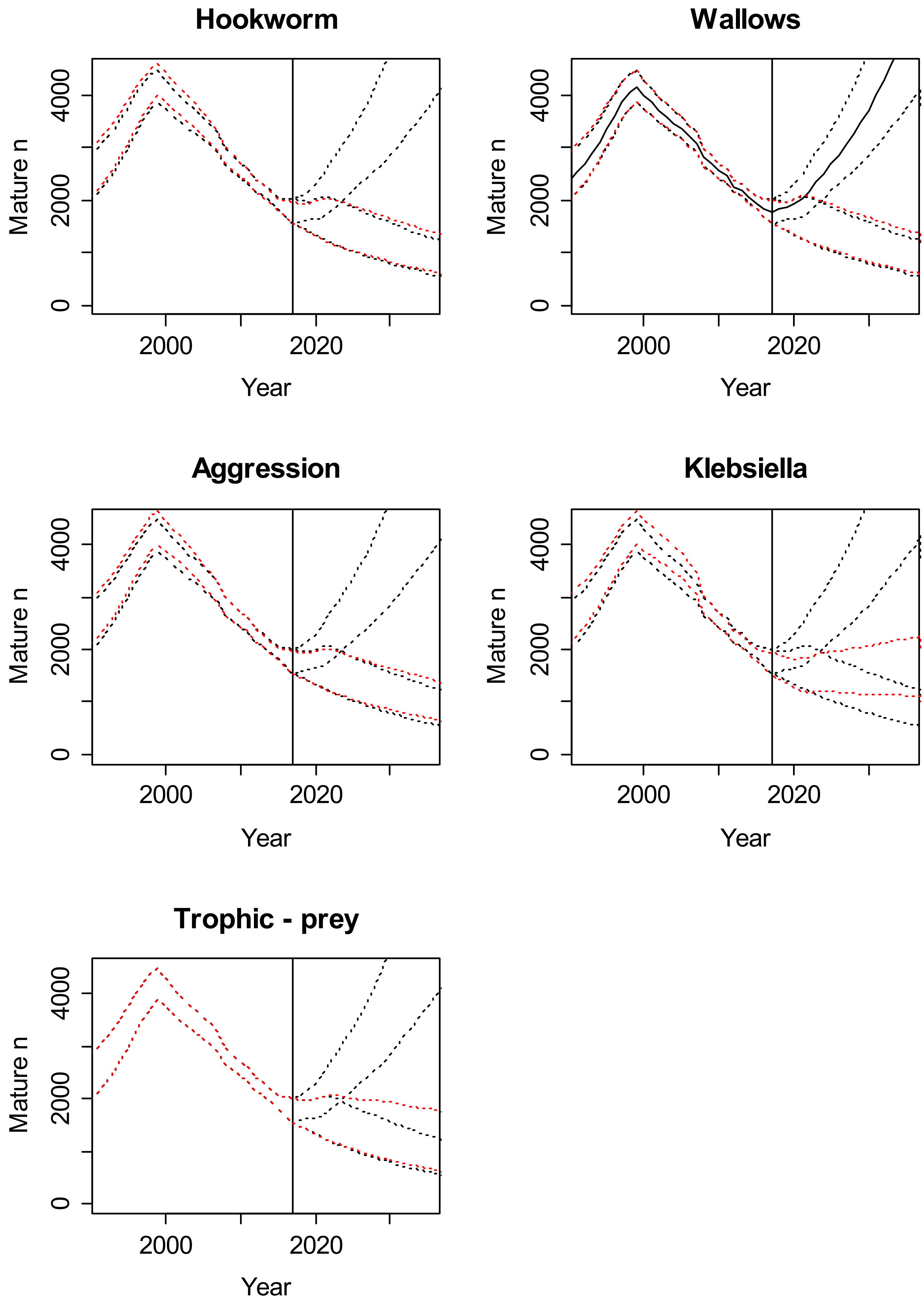


Figure 17: 15+ model estimates of mature n at the Auckland Islands in the period 1990–2037 for all other threat scenarios. Lower black lines are with all threats (base run); upper black lines are with the "max growth" scenario (1990–1993 estimate of $Surv_0$, 1990–1998 estimates of $Surv_{6\text{-}14}$ and 1990–1999 estimate of Pr_P; red lines are with a threat alleviated.

Demographic scenario projections

Population projections were undertaken using MPD runs with the 15+ model to investigate the effect of assuming alternative values of $Surv_0$, $\mathrm{Surv}_{6\text{-}14}$, or Pr_P on the projected population growth rate of mature N. The projection using the base run was used as a reference point, i.e. a continuation of estimated demographic rates since 2005 ($\lambda_{2037} = 0.96, N_{2037}/N_{2017} = 0.49$). Stable population size was achieved when increasing $Surv_0$ to 0.6 (relative to the mean of 0.38 for the period 2005–2012), increasing $Surv_{6\text{-}14}$ to 0.98 (0.88 from 2005–2014) and could not quite be achieved with maximum possible pupping rate ($Pr_P = 1$, $\lambda_{2037} = 0.99$) (0.71 from 2005–2014) (Figure 18 and Table 12).

Table 12: **Auckland Islands triage model run estimates of mature female λ_{2037} and N_{2037}/N_{2017} for all demographic rate scenarios. * indicates value when using the mean of each respective demographic rate from 2005–2012 for $Surv_0$ and 2005–2014 for $Surv_{6\text{-}14}$ and Pr_P.**

$Surv_0$	N_{2037}/N_{2017}	λ_{2037}	$Surv_{6\text{-}14}$	N_{2037}/N_{2017}	λ_{2037}	Pr_P	N_{2037}/N_{2017}	λ_{2037}
0	0.04	0.78	0.8	0.22	0.92	0.5	0.32	0.93
0.1	0.12	0.87	0.82	0.27	0.93	0.6	0.40	0.94
0.2	0.23	0.91	0.84	0.32	0.94	0.7	0.48	0.96
0.3	0.36	0.94	0.86	0.39	0.95	0.71*	0.49	0.96
0.38*	0.49	0.96	0.88	0.48	0.96	0.8	0.56	0.97
0.4	0.51	0.96	0.88*	0.49	0.96	0.9	0.66	0.98
0.5	0.70	0.98	0.9	0.58	0.97	1	0.76	0.99
0.6	0.92	1.00	0.92	0.71	0.98			
0.7	1.17	1.01	0.94	0.86	0.98			
0.8	1.45	1.02	0.96	1.05	0.99			
0.9	1.77	1.04	0.98	1.27	1.00			
1	2.12	1.05	1	1.55	1.01			

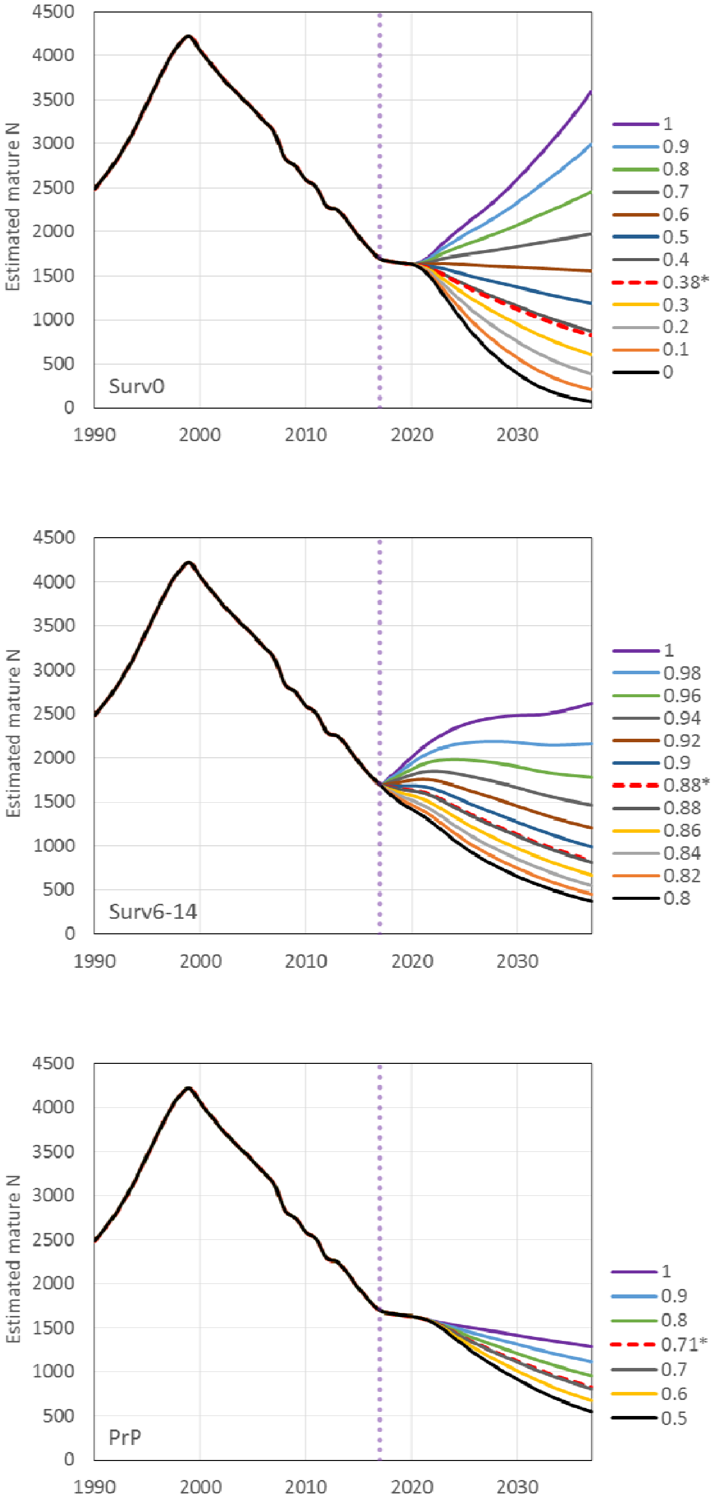


Figure 18: **Demographic rate scenario projections of model estimated mature *N* at the Auckland Islands in the period 1990–2037, with varying $Surv_0$ (top), $Surv_{6\text{-}14}$ (middle), Pr_P (bottom). Dashed red lines are projections using the mean of each respective demographic rate (indicated by a *) from 2005–2012 for $Surv_0$ and 2005–2014 for $Surv_{6\text{-}14}$ and Pr_P.**

3.2 Otago Peninsula demographic Assessment

MPD Runs

The Otago Peninsula assessment used mark-resighting observations of a much smaller number of individuals relative to the Auckland Islands. The fits to mark-recapture observations were reasonable up to age 3. However, at ages 4–14 the predicted number of resightings generally exceeded what was actually observed and there were very few observations of individuals age 15+ from which to estimate survival of the plus group (Figure 19). The fits to census were reasonable (Figure 20). The MPD parameter estimates were extremely close to the median MCMC estimates and are described in the next sub-section.

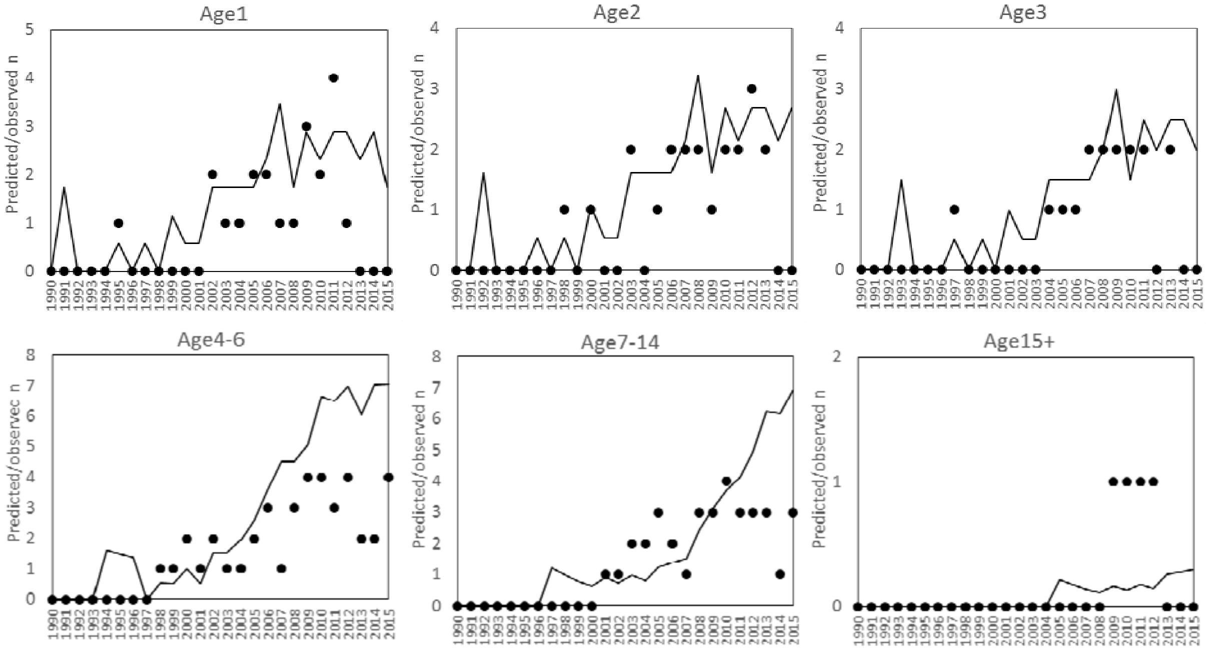


Figure 19: **Otago Peninsula base run fits (lines) to female mark-recapture observations (points).**

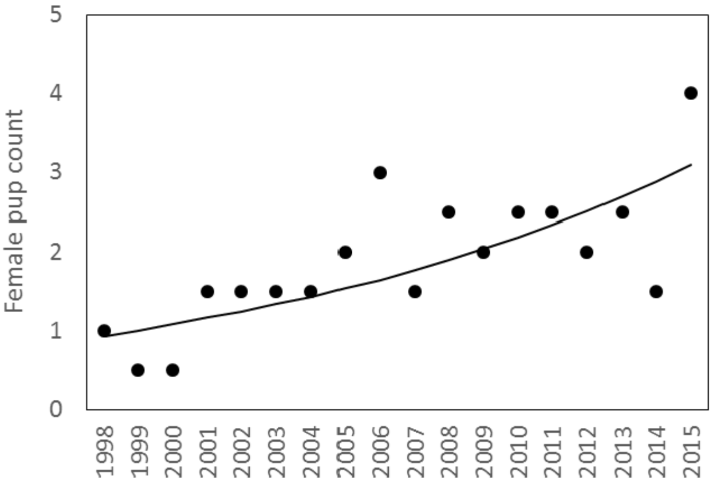


Figure 20: **Otago Peninsula base run fits (lines) to female pup census observations (points).**

MCMC runs

The Otago Peninsula MCMC runs completed quickly (about 1 day for 1 million iterations). A visual inspection of the trace plots suggests that the degree of mixing was very good for all estimated parameters (Figure 47) and there was good agreement between the parameter distributions obtained for each chain (Figure 48). None of the parameter pairings was strongly correlated (Table 33) and the posteriors indicated that all parameters were strongly identifiable (Figure 49), with the exception of $Surv_{15}$, which had a wide 95% credible interval (0.54–0.94) and also relative pupping rate at ages 4–6 ($Mat_{4\text{-}6}$, 95% CI 0.47–0.88).

All parameter estimates for the base run and threat scenario runs are tabulated in Table 34 to Table 38 and are plotted here for the base run (Figure 21). For the base run, $Surv_0$ was 0.79 (95% CI 0.66–0.90), which compares with base run estimate of $Surv_0$ at the Auckland Islands in the 1990–1993 period (0.87, 95% CI 0.76–0.98). The relative pupping rate at age 4–6 ($Mat_{4\text{-}6}$) was high (0.66, 95% CI 0.47–0.88), compared with a mean of Mat_4, Mat_5 and Mat_6 at the Auckland Islands of 0.49 (MPD base run). This suggests that females begin breeding at a younger age at the Otago Peninsula (as previously highlighted by Augé, 2010 and Lalas & Bradshaw, 2003). Adult survival ($Surv_{6\text{-}14}$) was also relatively high (0.92, 95% CI 0.86–0.96) compared with estimates for the Auckland Islands since 2005 (mean of 0.88 for the period 2005–2014 from the MPD run).

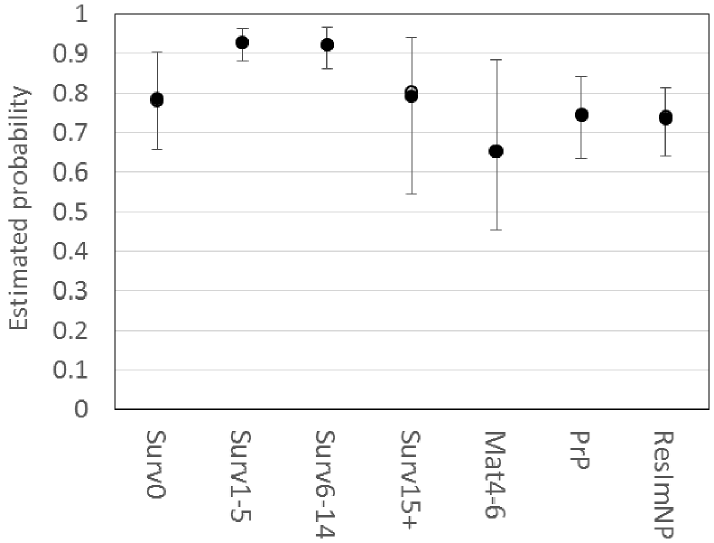


Figure 21: **Otago Peninsula base model MCMC estimates of all estimated parameters, except N_{1990} (MPD estimate 1.10; MCMC median 1.13; 95% C.I. 0.86–1.50). Filled circles and bars are the median and 95% credible interval for each parameter; open circles are the MPD point estimate.**

Triage projections

Triage model run projection outputs for all assessed threat scenarios at the Otago Peninsula are shown in Table 13 and Figure 22. Projected mature N is presented alongside two reference points: the base run (continuation of recent demographic rates); and $R_{\max}$, which gives the population increase under the theoretical maximum intrinsic growth rate for pinnipeds ($R_{\max} = 0.12$, $\lambda = 1.12$) (Wade 1998). Both the Setnet and Deliberate human mortality threat alleviation scenarios led to predicted λ_{2037} that slightly exceeded the theoretical maximum for pinniped species ($\lambda_{2037} = 1.15$ and 1.12, respectively). These and two other threat scenarios – Entanglement (Pollution) and Male aggression ($\lambda_{2037} = 1.11$ and 1.10, respectively) were carried forward to best-estimate projection runs.

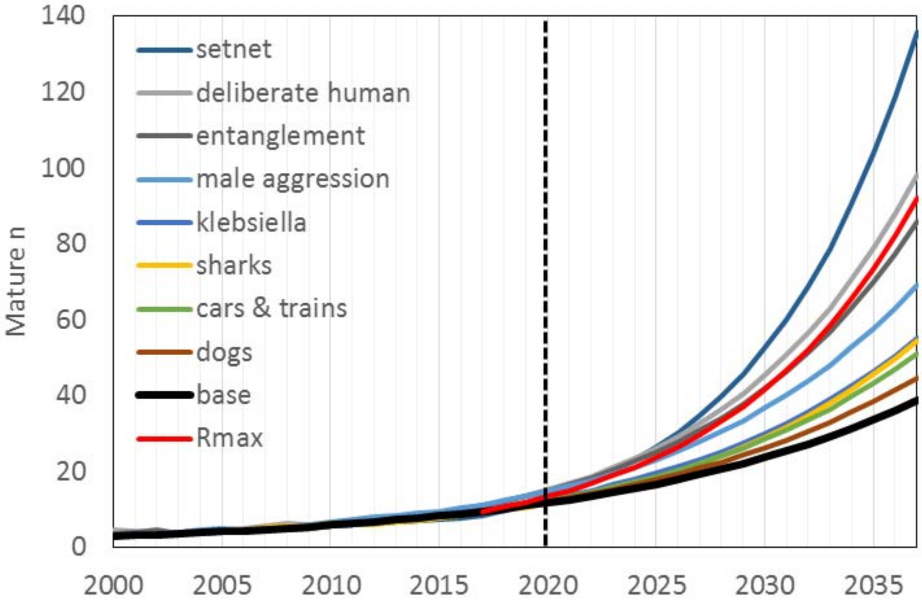


Figure 22: **Triage projections of model estimated mature n at the Otago Peninsula in the period 1990–2037, using upper values of threat mortality. Black lines are with all threats (base run); coloured lines are with threats alleviated, except that red is the population growth at R_{max} (λ = 1.12).**

Table 13: **Otago Peninsula triage model run estimates of mature female λ_{2037} and N_{2037}/N_{2017} for all threat scenarios, using upper values of threat mortality. *indicates threat scenarios carried forward to best-estimate projections.**

Threat scenario	λ_{2037}	N_{2037}
Set net*	1.15	16.31
Deliberate human mortality*	1.12	9.10
Entanglement*	1.11	7.77
Male aggression*	1.10	6.13
Shark predation	1.10	5.89
Klebsiella	1.09	5.69
Cars and trains	1.09	5.34
Dogs	1.08	4.61
Base	1.07	4.05

Best-estimate projections

Best-estimate projections of mature N for Otago Peninsula threat scenarios are presented in Table 14 and Figure 23. The predicted effects of alleviating any one of the key threats identified (male aggression, deliberate human mortality, setnet and entanglement (pollution)) produced very similar increases in mature *N* growth rate (λ ranged from 1.08 for set net to 1.09 for deliberate human mortality) relative to the base run (λ = 1.07).

Table 14: **Otago Peninsula model estimates of mature female λ_{2037} and N_{2037}/N_{2017} for all threat scenarios. Values are the median and 95% credible interval.**

Threat scenario	λ_{2037}	N_{2037}/N_{2017}
Deliberate mortality	1.093 (1.075–1.112)	5.98 (4.28–8.33)
Entanglement	1.088 (1.070–1.106)	5.41 (3.89–7.49)
Male aggression	1.087 (1.070–1.104)	5.36 (3.88–7.32)
Set net	1.082 (1.065–1.099)	4.83 (3.52–6.59)
Base	1.070 (1.053–1.087)	3.89 (2.82–5.34)

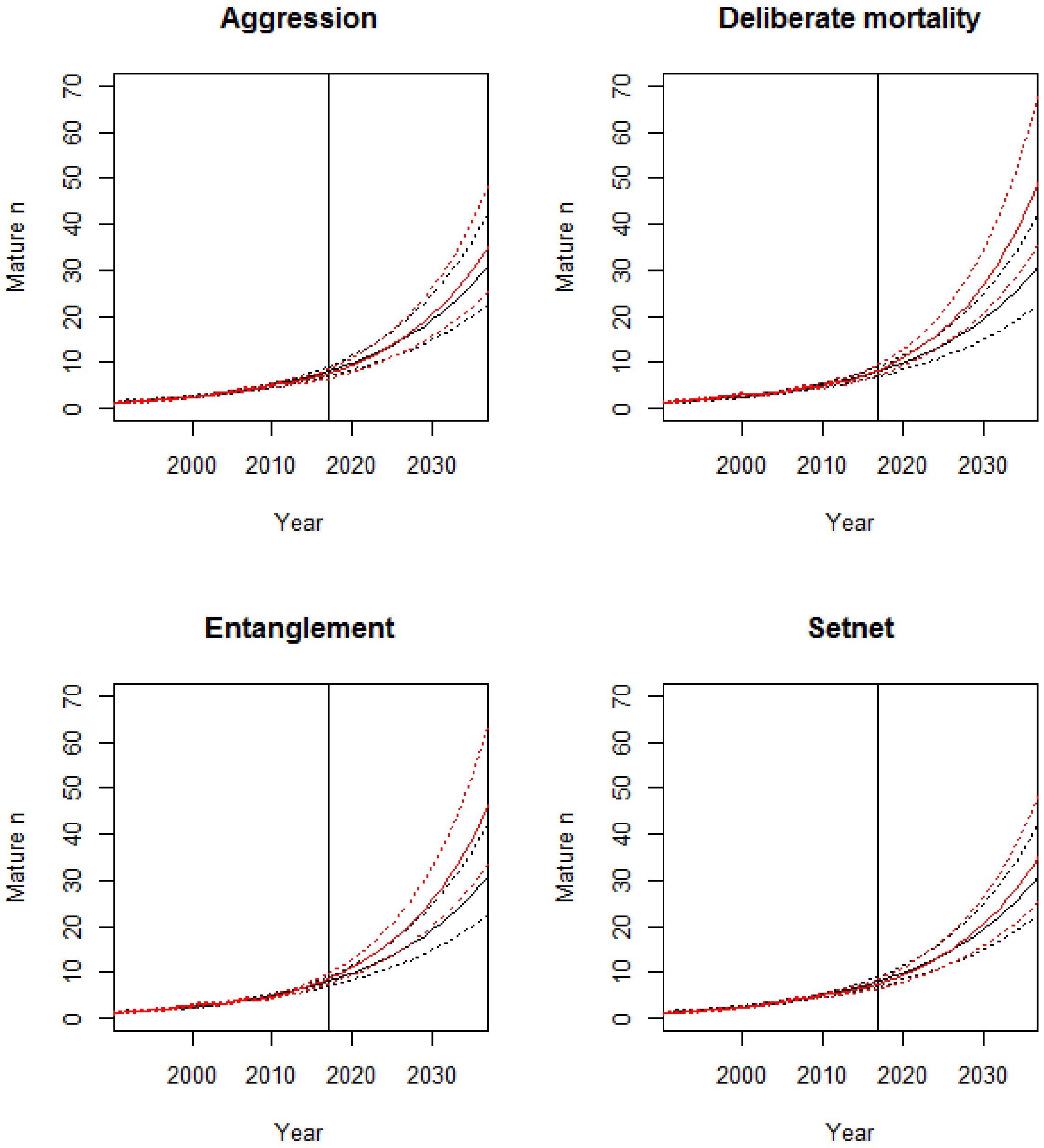


Figure 23: **Estimates of mature n at the Otago Peninsula in the period 1990–2037 for all threat scenarios. Black lines are with all threats (base run); red lines are with the threat alleviated.**

4. DISCUSSION

4.1 Comparison with previous assessments

The assessment model for the Auckland Islands population includes a number of improvements on previous modelling work completed under the DOC project POP2012-01 (Roberts et al. 2014), including a more realistic parameterisation of flipper-tag loss rate with respect to age; an alternative parameterisation of relative pupping rate at maturation ages 4–7; a longer time series of mark-recapture observations (three additional years of mark-resighting observations to 2015) and an improved use of observations based on different mark types (i.e. flipper tag, brand and chip marked individuals).

This assessment also has slightly different objectives than the previous one – the assessment undertaken by Roberts et al. (2014) was focussed on obtaining year-varying demographic rate estimates that explained population change that had already occurred; the demographic assessment described in this report was primarily designed for conducting population projections. As such it was possible to undertake some model simplification (e.g., the year-blocking of demographic rate estimates prior to 2005) that gave good fits to observations (e.g., Figure 7, Figure 8 and Figure 9) and had minimal effects on the demographic rate estimates and population *N* at age that were used to initialise projections.

Variation in population growth rate is primarily driven by temporal changes in survival-at-age. The demographic scenario analysis demonstrated the influence of pup and adult survival on population growth rate at the Auckland Islands (Figure 18). The pup survival estimates obtained here (meaning survival to age 1) approximate those obtained by Roberts et al. (2014), i.e. about 0.8 in 1990–1993 and about 0.4 since. This is considerably higher than the estimates obtained by Meyer et al. (2015) (0.185) using a similar data subset (although they did not use pups tagged in 1990–93, which in this study were estimated to have the highest survival). This could also be explained by their simple blocking of resighting probability across ages 1–3 (0.19), where we obtained a much lower resighting probability at ages 1–2 (about 0.1) than at age 3 (about 0.4) when females first show up for breeding. The estimate of adult survival at the Auckland Islands from this assessment (mean $Surv_{6\text{-}14}$ of 0.88 since 2005) approximates the values obtained by Meyer et al. (2015) (also 0.88), despite the use of a different modelling approach and different tagged population subset. MacKenzie (2012) obtained slightly higher estimates of adult survival (about 0.95 and about 0.90 for puppers and non-puppers, respectively), but this was averaged across resighting years 1999–2011 and included a period (1999–2004) when $Surv_{6\text{-}14}$ from this assessment was 0.92, between MacKenzie's (2012) estimates.

This assessment made a more complete use of brand and chip-marked individuals to reduce the confounding of survival and tag loss estimation. In addition, a novel parameterisation of annual tag loss rate was developed, with a functional form giving age effects on the probability of losing a single tag (Figure 10). High tag loss rate in the first year followed by almost no tag loss in the next year suggests that tag loss relating to tag breakage, incomplete attachment, or poor tag placement occurs almost entirely within the first year after tagging. The rapid increase in tag loss rate after age 2 indicates that tags are subsequently lost at increasing rate as individuals gain in mass and tags age, increasing the rate of breakage with sea lion age. This view is consistent with field observations and is likely to be one of the main explanations for the large proportion of adult individuals at Sandy Bay, Auckland Islands that lack tags despite nearly all pups being flipper-tagged since 1998 (Childerhouse pers. comm.). This parameterisation (in conjunction with extending the partition to age 15+ to allow senescent survival estimates) was found to give greatly improved fits to observed tag resighting of individuals missing both tags at older ages (Appendix 6), such that the confounding of survival and tag loss estimation will have been minimal.

A very different set of demographic rates were obtained for the Otago Peninsula population, with much higher pup survival (about 0.8) and higher relative pupping rate at maturation ages (4–7) (about 0.6) across all years of the assessment. This is consistent with earlier estimates of first year survival for this population of 0.77–0.83 and about 50% pupping rate at ages 4–5 (Lalas & Bradshaw 2003).

The relatively poor fits to some mark-resighting and pup census observations for the Otago Peninsula model have arisen from a conflict between the two observations types (Figure 19 and Figure 20). A simple model structure was used (i.e. all parameters constant with respect to year) and some assumptions might have been violated – e.g., 100% resighting of puppers may not have achieved in recent years when resighting effort was reduced (monthly resighting periods up until 2010, then biannual resighting after; McConkey pers. comm.). However, it was desirable to keep the number of estimated parameters low, given the small sample size of mark-recapture observations and the population model is considered to be a suitably adequate representation of the Otago Peninsula population for this risk assessment.

4.2 Demographic causes of population change

The Auckland Islands demographic assessment model produced good fits to the pup census trend through variation in the year-varying demographic rates: pup survival ($Surv_0$), adult survival ($Surv_{6\text{-}14}$) and pupping rate (Pr_P). Adult survival affects a number of age classes and so has a major effect on population growth rate (e.g., Meyer et al. 2015). In contrast to MacKenzie (2012), this assessment found evidence for a decline in adult survival since 1998, which will have contributed to the observed decline in pup production, particularly in the period since 2005. All year-varying demographic rates were particularly poor during the 2005–2009 period, when a steep decline in pup production was observed.

This assessment estimated a steep decline in pup survival after 1993 (about 0.8 prior to this and about 0.4 since). The 1994 cohort would have fully matured at around 2002, shortly after the onset of the ongoing decline in pup production. The demographic scenario assessment (Figure 18) suggested that $Surv_0$ would need to be closer to 0.6 to give stable mature population size, with all other demographic rates remaining equal. This suggests that it is likely to be the *combination* of low pup survival and low adult survival that has caused the observed decline at the Auckland Islands, i.e. if a single threat cannot adequately explain the estimated decline in all year-varying survival parameters then there may be multiple drivers of population change.

Breeding site relocations between Sandy Bay and Southeast Point rookeries (both on Enderby Island) indicate that individuals from the latter rookery relocated to Sandy Bay, as opposed to dying out (Appendix 9). Movements between these two rookeries will have dampened some of the variation in pup production at Sandy Bay, such that assessments fit to Sandy Bay mark-recapture observations should consider aggregating the census series for these two populations. The lack of consistent resighting effort precludes the estimation of pupping rate for Dundas, by some way the largest rookery at the Auckland Islands (and for the species). Roberts et al. (2014) obtained a very similar series of survival-at-age estimates for this population relative to Sandy Bay, justifying fitting to a combined Auckland Islands census in this assessment, despite using only Sandy Bay mark-recapture observations.

The Auckland Islands pup census series indicated that the decline was preceded by a period of increasing pup production. This is consistent with information from the mark-recapture observations (good pup survival in the early 1990s) and combined Sandy Bay/Dundas lactating female age distribution (the early 1990s cohorts do not stand out as particularly strong when the two rookeries are combined), in that good fits were simultaneously obtained to all three types of observation (Figure 7, Figure 8 and Figure 9). This suggests that the Auckland Islands population is capable of population growth at levels observed elsewhere (e.g., Otago Peninsula or Campbell Island) when conditions are optimal, or major threats are not adversely affecting key demographic rates. The Otago Peninsula population was founded by a female born at the Auckland Islands and this population has attained high pup survival and early maturation at low population density. This highlights the species' capacity for population growth under optimal conditions, as observed at Campbell Island where following their presumed near extirpation by commercial sealing in the nineteenth century there was limited evidence for pupping until the 1960s (Childerhouse & Gales 1998) and almost 700 pups born there in 2010 (Maloney et al. 2012).

4.3 Population consequences of threats

The models developed here ignored density-dependent effects which are likely to come into play over longer time periods (particularly if the population at the Auckland Islands continues to decline and others continue to increase). As such, the 20-year projection period is quite long and departures from predicted trends should be expected in future years, in response to changes in the relative availability of resource for NZ sea lion populations.

For the Auckland Islands population, this assessment indicated that the 20-year TMP goal of increasing mature *N* above current levels was not achievable with even the complete alleviation of a single threat (i.e. multiple threats would need to be fully alleviated to achieve this goal), though this could be achieved across the species if there was sufficient growth of other populations.

With respect to the population-specific TMP goal for the Auckland Islands, positive population growth in 2037 was only obtained with the alleviation of *Klebsiella* (λ_{2037} = 1.005, 95% CI 0.926–1.069), relative to the base run (a continuation of demographic rates since 2005) (λ_{2037} = 0.961, 95% CI 0.890–1.020). Alleviating the effects of commercial trawl related mortality when assuming the most pessimistic view of post-SLED survival (all interactions resulted in mortality and associated death of pups) still resulted in population decline (λ_{2037} = 0.977, 95% CI 0.902–1.036). The alleviation of all other individual threats had a relatively minor effect on population growth and combining all identified sources of mortality would be unlikely to lead to the maximum population growth rate estimated for the period 1990–2000 (λ_{2037} = 1.069). The estimates of threat-specific effects (e.g., mortality at age or on demographic rates) were not well-informed for some threats (particularly trophic – food limitation) and it is highly probable that all the combined sources of mortality (including natural and anthropogenic) have not been fully captured.

For the Otago Peninsula population, similar effects were estimated for the alleviation of the key identified threats – commercial setnet fishery related mortality, direct human mortality, entanglement (pollution) and male aggression related mortality – each resulting in a small increase in projected population growth rate (λ_{2037} ranged from 1.082 to 1.093 across all threats) relative to the base run (λ_{2037} = 1.070, 95% CI 1.053–1.087). Deliberate human mortality was estimated to have the greatest effect on projected population size (λ_{2037} = 1.093, 95% CI 1.075–1.112). The estimated population growth rate at the Otago Peninsula is at the lower end of the range predicted by Lalas & Bradshaw (2003) and anecdotal evidence suggests that a change in the spatial distribution of breeders has occurred in response to increasingly aggressive male harassment (McConkey pers. comm.). This could adversely affect demographic rates in a number of ways (e.g., increase exposure to new threats, increase the probability of mothers and pups becoming separated) and can also influence changes in resighting probability and the accuracy of demographic assessments. In addition, the Otago Peninsula population is small and individual stochasticity will have a greater effect here than for larger populations. This was not considered by the assessment approach here.

4.4 Future research

The lack of mark-resighting observations at Campbell Island precluded a full demographic assessment of this population. However, the analysis in Appendix 10 showed that significant increases in population growth rate might be achieved with the successful alleviation of starvation or trauma-related mortality of pups. Pups have been tagged in three recent years at Campbell Island (2008, 2010 and 2015) and five consecutive years at Stewart Island (2011–2015) and future resighting effort of these would provide the information requirements for a demographic assessment of these populations. This would be valuable not just for monitoring the causes of population change and potential effects of threats at Campbell Island and Stewart Island, but for improving our understanding of the population dynamics and key threats to NZ sea lion populations of different sizes and under alternative conditions.

Generally-speaking there is less uncertainty about the demographics of NZ sea lions than with respect to threat-specific mortality and this is true for both the Auckland Islands and Otago Peninsula populations. As a consequence, the demographic causes of population change are increasingly well-understood (Roberts et al. 2014), yet the underlying causes of changing demographic rates are not. Mortalities relating to commercial trawl fishery interactions are perhaps the best known and yet the scale of this mortality is still subject to debate, due to uncertainty with respect to the scale of potential cryptic mortality. Direct information on the causes of pup mortality is restricted to the first three months of the field season, when only a fraction of pup mortality is thought to occur. Food limitation effects are thought be influential for the Auckland Islands population, but very few adult mortalities have ever been directly linked to starvation.

There will also be biases in the probability of detecting some causes of mortality (e.g., commercial trawl captures related mortalities could easily be monitored prior to the usage of SLEDs), but shark predation mortality might not leave any evidence. The quantification of threat-specific mortality levels should be a priority activity for improving future risk assessments, particularly of more cryptic threats that could have major population consequences (e.g., food limitation or shark predation).

Food limitation can arise from climate and fishery effects on the availability of key prey, but no attempt was made to assess these separately in this assessment. At least three of the main prey species of the Auckland Islands population (hoki, red cod and southern arrow squid; Meynier et al. 2009) are subject to commercial fisheries around NZ and tentative climate drivers of recruitment or abundance have been identified for some of these (e.g., Beentjes & Renwick 2000; Hurst et al. 2012). A more comprehensive assessment of the population effects of food limitation will require significant advances in our understanding of the effects of climate and fishery effects on prey availability and follow-on effects on NZ sea lion demographics.

5. MANAGEMENT IMPLICATIONS

A number of key threats were identified for the Auckland Islands and Otago Peninsula populations, including anthropogenic (e.g., deliberate human mortality, incidental mortality in commercial trawls or resource competition with commercial fisheries) and natural threats (e.g., male aggression and climate effects on prey availability). For the Auckland Islands population, it is likely that the 20-year TMP goal would be difficult to achieve even with the complete alleviation of a single threat and natural processes affecting sea lion habitat (including prey) may make this even more difficult to attain. As such, management effort would need to address multiple threats in order to meet the goals of the TMP. This effort would ideally be complemented by the development of tools for monitoring the effects of management interventions on threat-specific mortality and influential demographic rates.

The assessment for some of the key threats was hampered by incomplete information for estimating threat-specific mortality, e.g., relating to the causes of pup mortality during the entire first year of life and of post-SLED survival. The separate assessment of fishery effects on food limitation was not attempted for any population. In addition there was a lack of demographic observations for the Campbell Island and Stewart Island populations (the second and third largest breeding populations, respectively), which precluded the development of a fully quantitative risk assessment for these populations. These are all areas that should be addressed with the aim of developing a more complete risk assessment in future years.

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APPENDIX 1 THREAT-RELATED MORTALITY BY YEAR

Table 15: Summary of threat-specific mortality, as used in Auckland Islands triage projection model runs. Threat levels are "upper bound" values provided by MPI/DOC.

	Male aggression			Entanglement			Hookworm		Tuberculosis		Shark predation		Commercial trawl - captures		Wallows
Year	Adult	Pup indirect	Pup direct	Adult	Juvenile	Pup	Pup direct	Pup health	Adult	Pup indirect	Juvenile+	Pup	Adult	Pup indirect	Pup
	5+	0	0	5+	1 to 4	0	0	0	5+	0	1+	0	3+	0	0
1990	11	4	51	1	5	0	80	33	23	8	12	4	0	0	112
1991	12	4	51	1	6	0	80	33	25	9	12	4	0	0	112
1992	13	5	51	1	6	1	80	33	27	9	12	4	0	0	112
1993	14	5	51	1	6	1	80	33	29	10	12	4	0	0	112
1994	15	5	157	2	7	1	80	102	31	11	12	4	0	0	112
1995	16	6	157	2	7	1	80	102	34	12	12	4	0	0	112
1996	18	6	167	2	8	1	85	109	37	13	13	4	121	42	119
1997	20	7	185	2	9	1	94	120	40	14	14	5	115	40	132
1998	21	7	188	2	9	1	96	122	42	15	14	5	62	22	134
1999	20	7	178	2	9	1	91	116	41	14	14	5	26	9	127
2000	19	7	178	2	9	1	91	115	39	14	14	5	67	23	127
2001	19	7	178	2	8	1	91	116	38	13	14	5	59	20	127
2002	19	7	142	2	9	1	72	92	40	14	11	4	71	25	101
2003	18	6	157	2	8	1	80	102	37	13	12	4	49	17	112
2004	18	7	156	2	8	1	80	102	38	13	12	4	194	68	112
2005	18	6	159	2	8	1	68	103	36	13	10	4	169	59	95
2006	17	6	146	2	8	1	66	95	35	12	10	3	162	57	93
2007	15	5	157	2	7	1	71	102	32	11	11	4	113	40	99
2008	15	5	131	2	7	1	69	85	31	11	10	4	256	90	97
2009	15	5	69	2	7	1	48	45	30	10	7	3	242	85	67
2010	14	5	107	1	6	1	58	70	28	10	9	3	274	96	81
2011	13	5	86	1	6	1	49	56	26	9	7	3	154	54	69
2012	12	4	98	1	5	0	53	64	24	9	8	3	116	41	75
2013	12	4	119	1	5	0	61	78	24	8	9	3	138	48	86
2014	11	4	84	1	5	0	50	55	23	8	8	3	170	60	70
2015	11	4	84	1	5	0	50	55	23	8	8	3	170	60	70
2016	11	4	84	1	5	0	50	55	23	8	8	3	170	60	70

Table 16: Summary of demographic rates used in triage projection runs for all other assessed threat scenarios for the Auckland Islands. Demographic rates provided by MPI/DOC, represent the maximum value that would be obtained with the alleviation of each respective threat.

Threat	Demographic rate	Method for deriving demographic rate	Value
Klebsiella	$Surv_0$	MPD estimate for 1990–1993 year block	0.79
Trophic – food limitation	$Surv_0$	Mean of 2009–2012 estimates	0.44
	$Surv_{6\text{-}14}$	Mean of 2009–2014 estimates	0.88
	Pr_P	Mean of 2009–2014 estimates	0.75

Table 17: **Summary of numbers of individuals killed by threat scenario, as used in Auckland Islands MCMC projection model runs. Threat levels are "best estimate" values provided by MPI/DOC.**

	Estimate of individual mortalities by threat scenario															
	Male aggression			Hook-worm	*Kleb-siella*	Wallows	Commercial trawl - captures		Commercial trawl - 82%discount		Commercial trawl - 35%discount		Commercial trawl - 20%discount		Commercial trawl - interactions	
	Adult	Pup indirect	Pup direct	Pup	Pup	Pup	Adult	Pup indirect	Adult	Pup indirect	Adult	Pup indirect	Adult	Pup indirect	Adult	Pup indirect
Year	5+	0	0	0	0	0	3+	0	3+	0	3+	0	3+	0	3+	0
1990	-	-	-	-	-	56	59	20	-	-	-	-	-	-	59	20
1991	-	-	-	-	-	56	11	4	-	-	-	-	-	-	11	4
1992	-	-	-	-	-	56	40	14	-	-	-	-	-	-	40	14
1993	-	-	-	-	-	56	9	3	-	-	-	-	-	-	9	3
1994	-	-	-	-	-	56	19	7	-	-	-	-	-	-	19	7
1995	-	-	-	-	-	56	55	19	-	-	-	-	-	-	55	19
1996	-	-	-	-	-	60	74	26	-	-	-	-	-	-	74	26
1997	-	-	-	-	-	66	77	27	-	-	-	-	-	-	77	27
1998	-	-	-	-	-	67	38	13	-	-	-	-	-	-	38	13
1999	9	3	420	105	315	64	16	6	-	-	-	-	-	-	17	6
2000	9	3	183	183	131	64	44	15	-	-	-	-	-	-	44	15
2001	8	3	315	241	56	64	31	11	-	-	-	-	-	-	42	15
2002	9	3	74	72	474	51	30	11	-	-	-	-	-	-	45	16
2003	8	3	81	74	605	56	15	5	10	3	21	7	24	9	29	10
2004	8	3	81	232	359	56	27	9	26	9	73	26	89	31	109	38
2005	8	3	83	130	371	48	23	8	23	8	62	22	75	26	92	32
2006	8	3	76	87	457	46	19	7	20	7	56	20	68	24	83	29
2007	7	3	82	94	491	49	13	5	14	5	35	12	42	15	51	18
2008	7	2	68	78	409	48	12	4	17	6	48	17	58	20	72	25
2009	7	2	35	47	260	33	9	3	16	6	43	15	51	18	63	22
2010	6	2	53	0	431	40	10	3	15	5	47	16	57	20	70	25
2011	6	2	37	19	131	34	6	2	10	4	27	9	32	11	39	14
2012	5	2	129	52	283	37	6	2	9	3	20	7	24	8	29	10
2013	5	2	62	71	373	43	6	2	9	3	23	8	27	10	33	12
2014	5	2	13	0	301	35	4	1	6	2	15	5	18	6	22	8
2015	5	2	17	9	310	35	4	1	6	2	15	5	18	6	22	8
2016	5	2	17	9	310	35	4	1	6	2	15	5	18	6	22	8

Table 18: **Summary of demographic rates used in MCMC projection runs for all other assessed threat scenarios for the Auckland Islands. Demographic rates provided by MPI/DOC, represent the best estimate value that would be obtained with the alleviation of each respective threat.**

Threat	Demographic rate	Method for deriving demographic rate
Trophic – food limitation	$Surv_0$	Sampled from 2009–2012 estimates
	$Surv_{6\text{-}14}$	Sampled from 2009–2014 estimates
	Pr_P	Sampled from 2009–2014 estimates

Table 19: **Summary of numbers killed by threat scenario, as used in Otago Peninsula triage projection model runs. Threat levels are “upper bound” values provided by MPI/DOC.**

	Estimate of individual mortalities by threat scenario																		
	Male aggression			Entanglement			Deliberate human		Commercial set net		Dogs	*Klebsiella*			Shark predation			Vehicles	
	Adult	Pup indirect	Juv.	Adult	Juv.	Pup	Adult	Pup indirect	Adult	Pup indirect	Pup	Adult	Pup direct	Pup indirect	Juv .+	Pup direct	Pup indirect	Juv .+	Pup indirect
Year	5+	0	1–4	5+	1–4	0	5+	0	5+	0	0	5+	0	0	1+	0	0	1+	0
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1993	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1994	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1997	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1998	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.4	0.4	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2002	0.0	0.0	0.0	1.0	1.0	0.4	1.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.4	0.0	1.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
2004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	0.0	0.0	0.0	1.0	1.0	0.4	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
2008	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.4	0.8	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.4	0.0	0.0
2009	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.4	0.0	1.0	0.0	0.4	1.0	0.0	0.4	0.0	0.0
2011	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.4	1.0	0.4
2012	0.0	0.0	1.0	0.0	0.0	0.0	2.0	0.7	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2013	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 20: **Summary of numbers of individuals killed, by threat scenario, as used in Otago Peninsula MCMC projection model runs. Threat levels are "best estimate" values provided by MPI/DOC.**

	Estimate of individual mortalities by threat scenario									
	Male aggression			Entanglement			Deliberate human		Commercial set net	
	Adult	Pup indirect	Juvenile	Adult	Pup indirect	Juvenile	Adult	Pup indirect	Adult	Pup indirect
Year	Age 5+	0	1–4	5+	0	1–4	5+	0	5+	0
1990	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0.5	0.2	0	0
2001	0	0	0	0	0	0	0.5	0.2	0	0
2002	0	0	0	0.5	0.2	0.5	0.5	0.2	0	0
2003	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0
2005	1	0.4	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0.1	0
2007	0	0	0	0.5	0.2	0.5	0	0	0.1	0
2008	0	0	0	0	0	0	0.5	0.2	0.1	0
2009	0	0	0	0	0	0	0.5	0.2	0.2	0.1
2010	0	0	0	0	0	0	0	0	0.2	0.1
2011	0	0	0	0	0	0	0	0	0.2	0.1
2012	0	0	1	0	0	0	1	0.4	0.2	0.1
2013	0	0	1	0	0	0	0	0	0.3	0.1
2014	0	0	0	0	0	0	0	0	0.3	0.1
2015	0	0	0	0	0	0	0	0	0.3	0.1
2016	0	0	0	0	0	0	0	0	0.3	0.1

APPENDIX 2 MCMC DIAGNOSTICS AUCKLAND ISLANDS BASE RUN USING THE 15+ MODEL CONFIGURATION

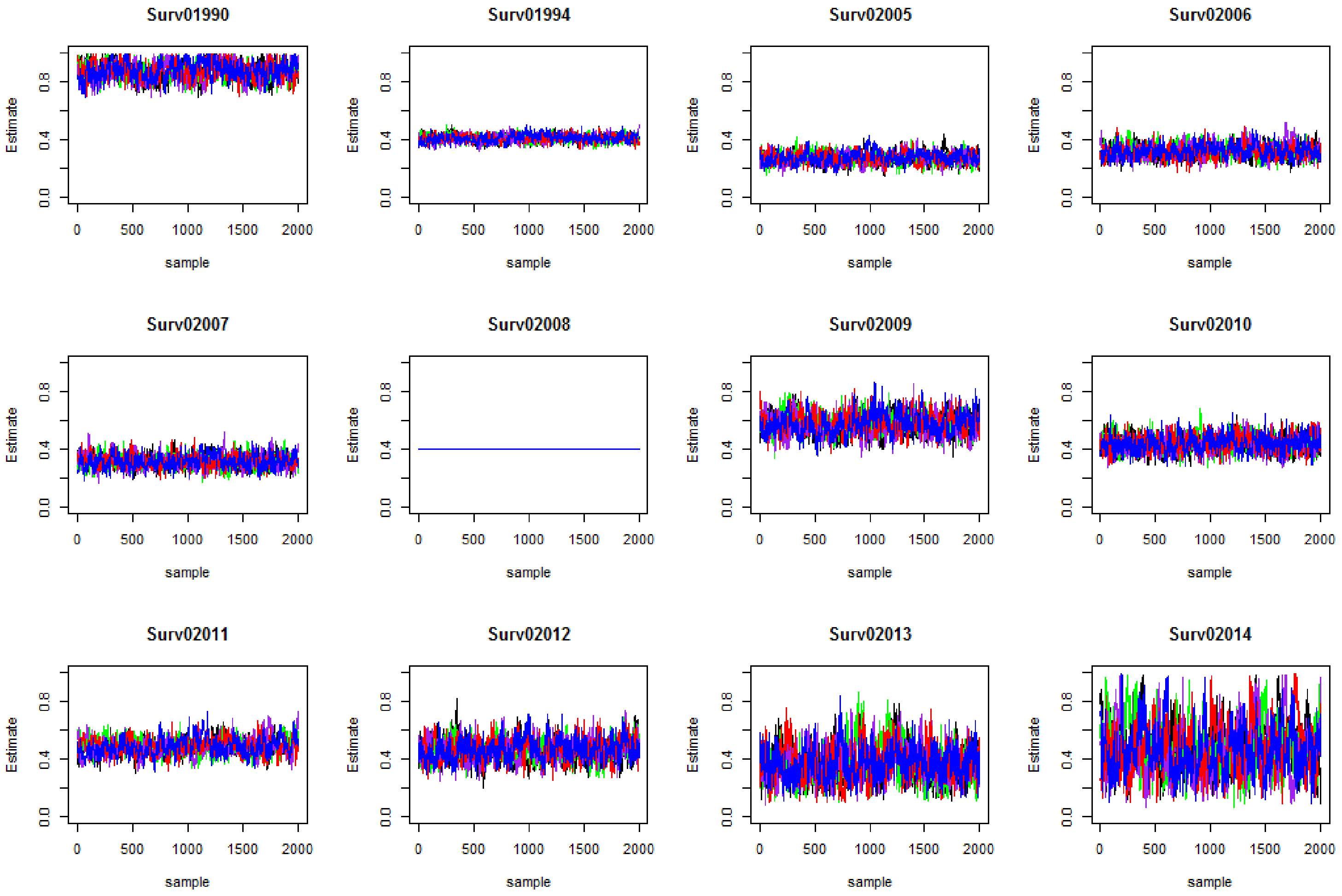


Figure 24: **Trace plots for $Surv_0$ for different year blocks (1990–1993, 1994–2004 then each year until 2014) from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.**

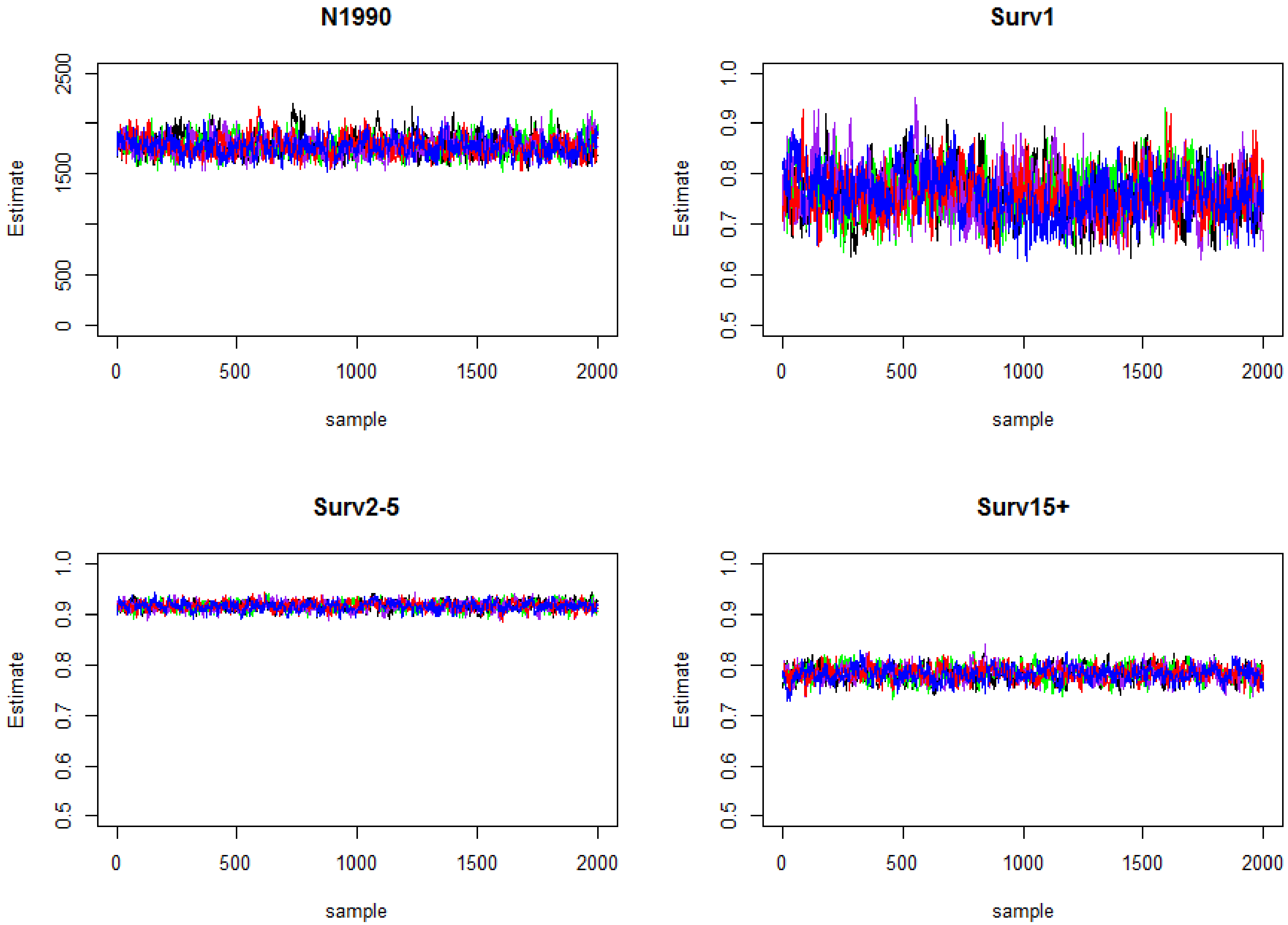


Figure 25: Trace plots for N_{1990}, $Surv_1$, $Surv_{2\text{-}5}$ and $Surv_{15+}$ from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.

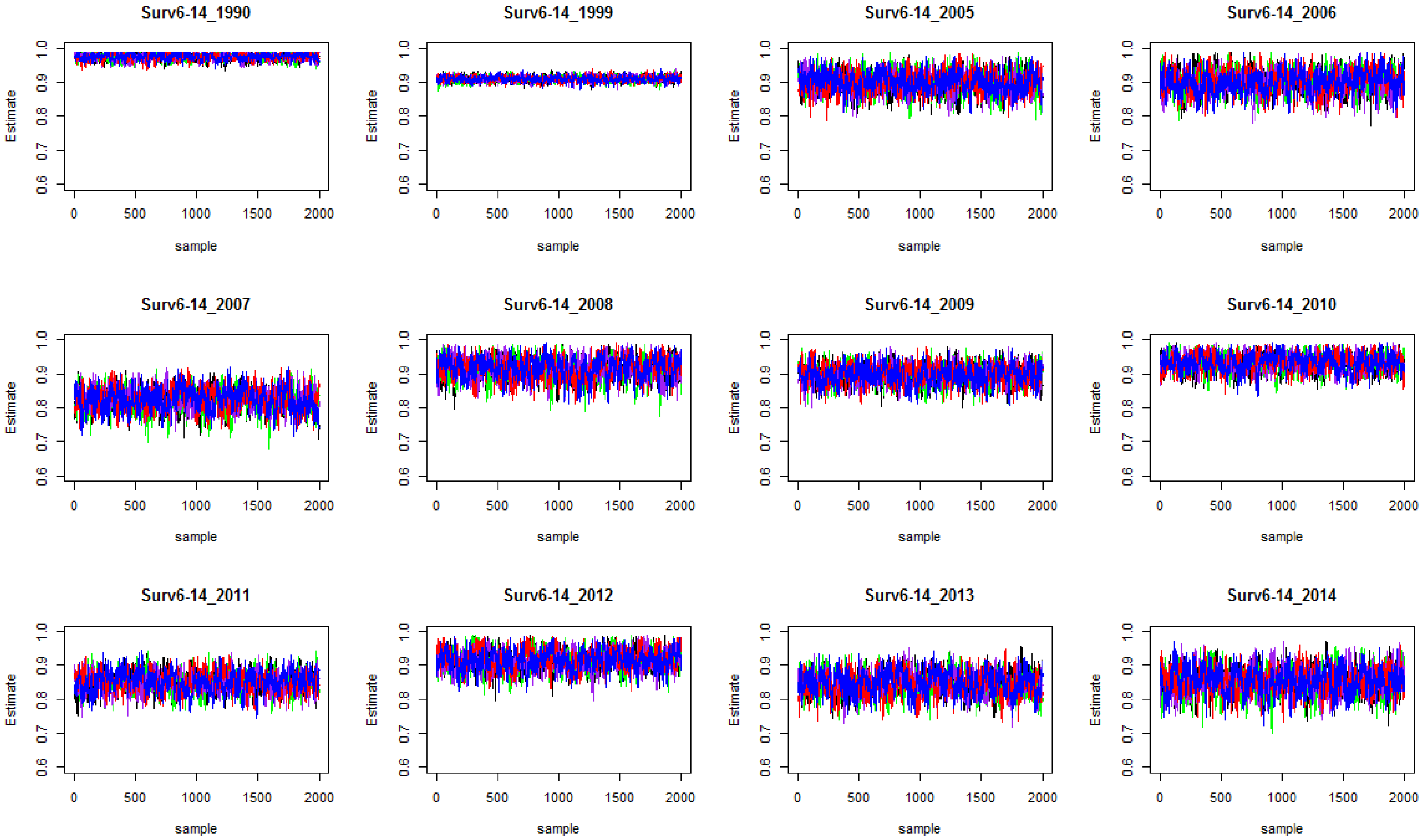


Figure 26: **Trace plots for *Surv*$_{6\text{-}14}$ for different year blocks (1990–1998, 1999–2004 then each year until 2014) from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.**

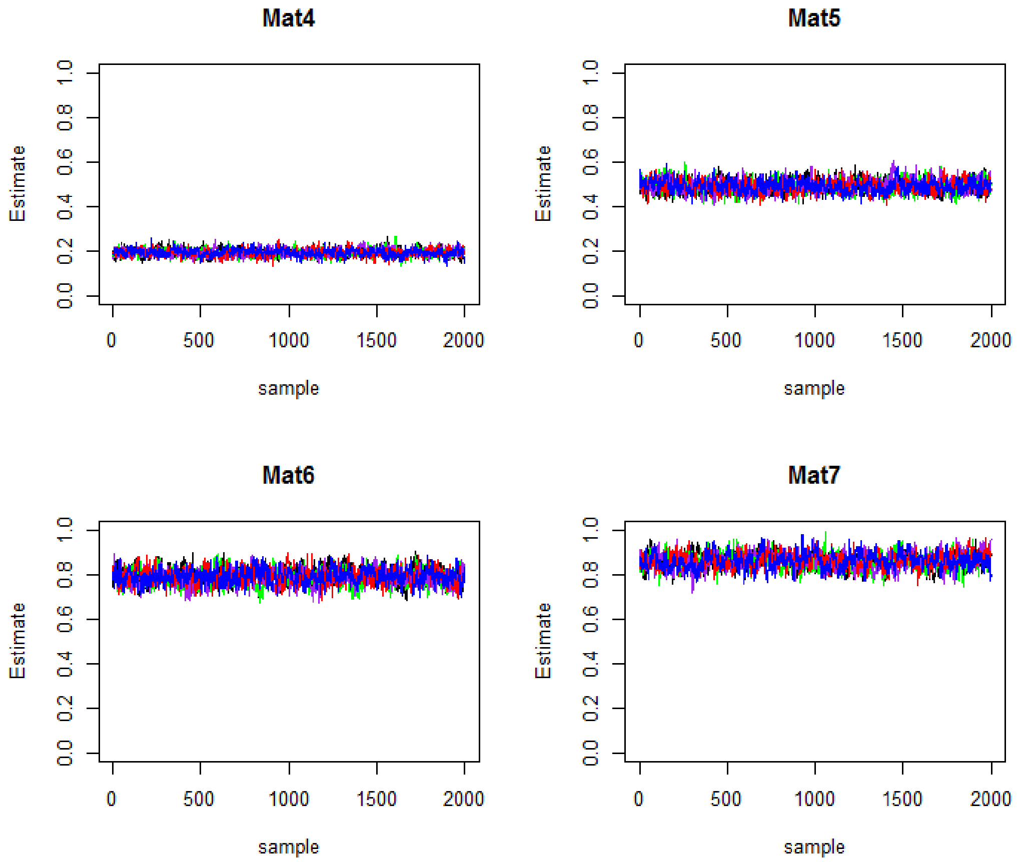


Figure 27: Trace plots for *Mat*$_4$, *Mat*$_5$, *Mat*$_6$ and *Mat*$_7$ from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.

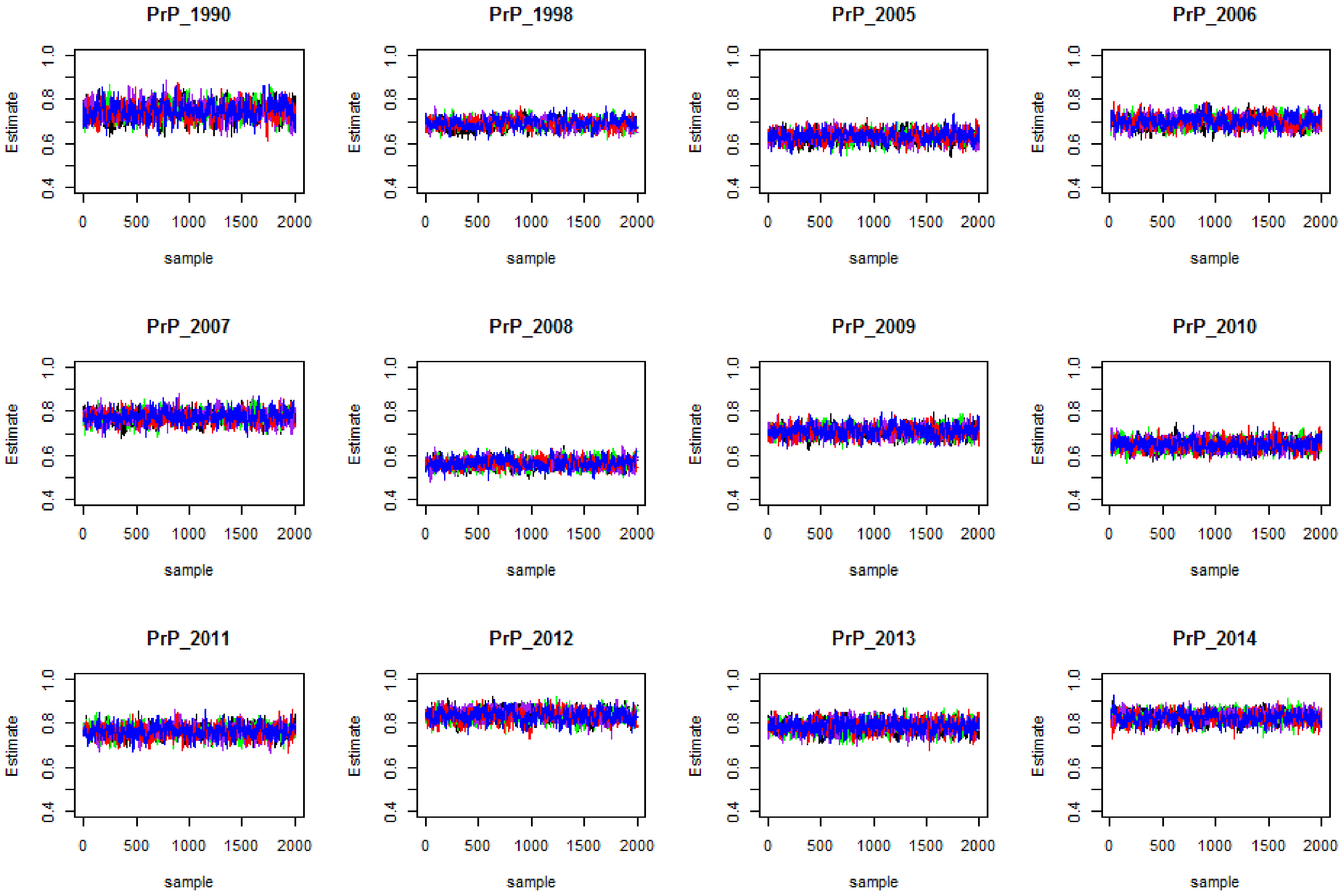


Figure 28: **Trace plots for Pr_P (the probability of breeding in year+1) for different year blocks (1990–1997, 1998–2004 then each year until 2014) from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.**

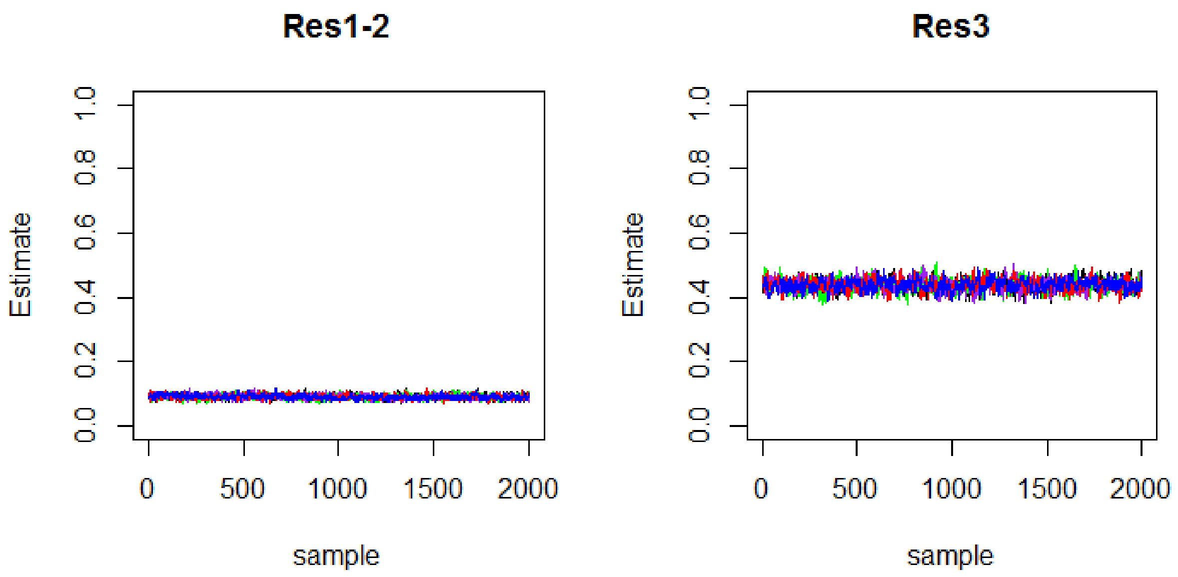


Figure 29: **Trace plots for *Res*$_{1-2}$ and *Res*$_3$ from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.**

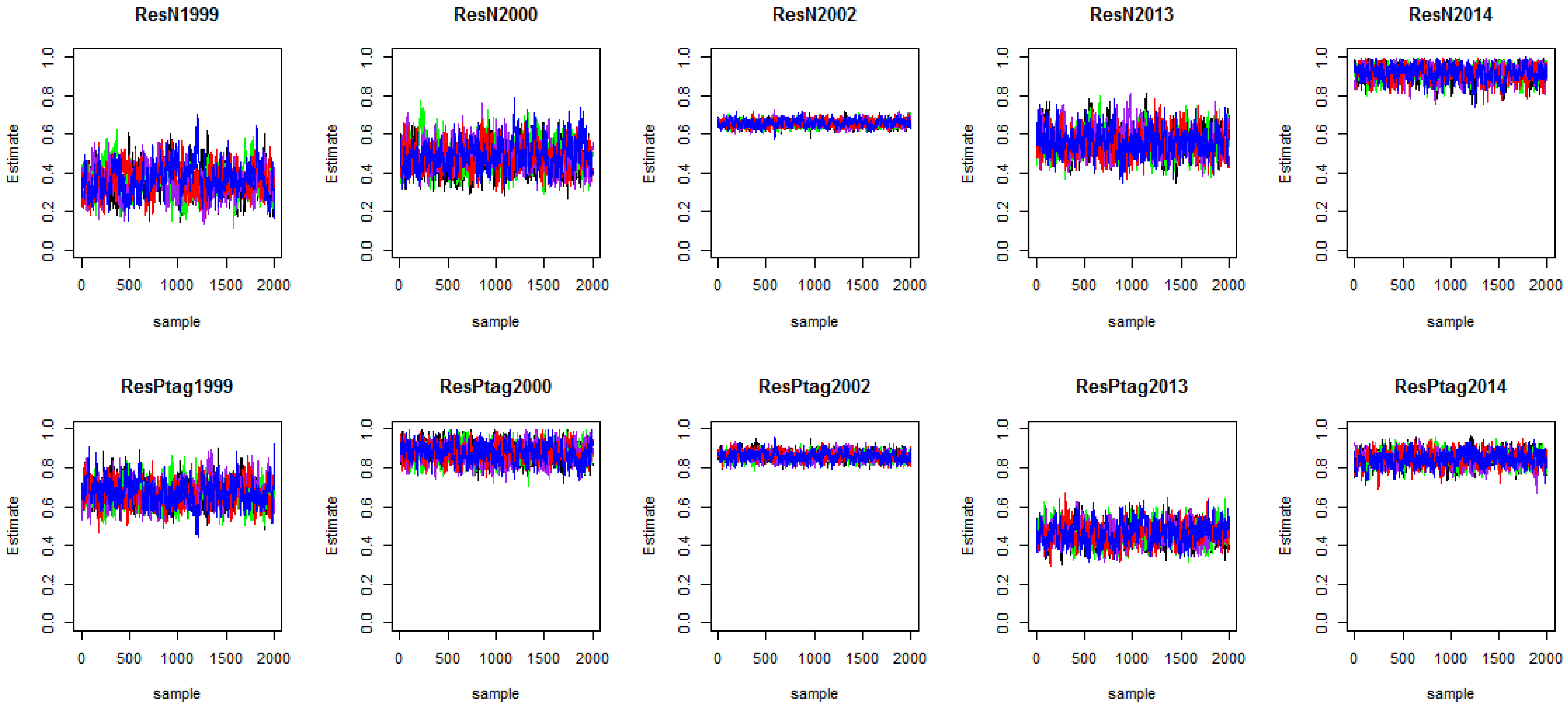


Figure 30: Trace plots for *Res*$_N$ (top row) and *Res*$_{Ptag}$ (bottom row) for different year blocks (1999, 2000–2001, 2002-2012, 2013 and 2014) from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.

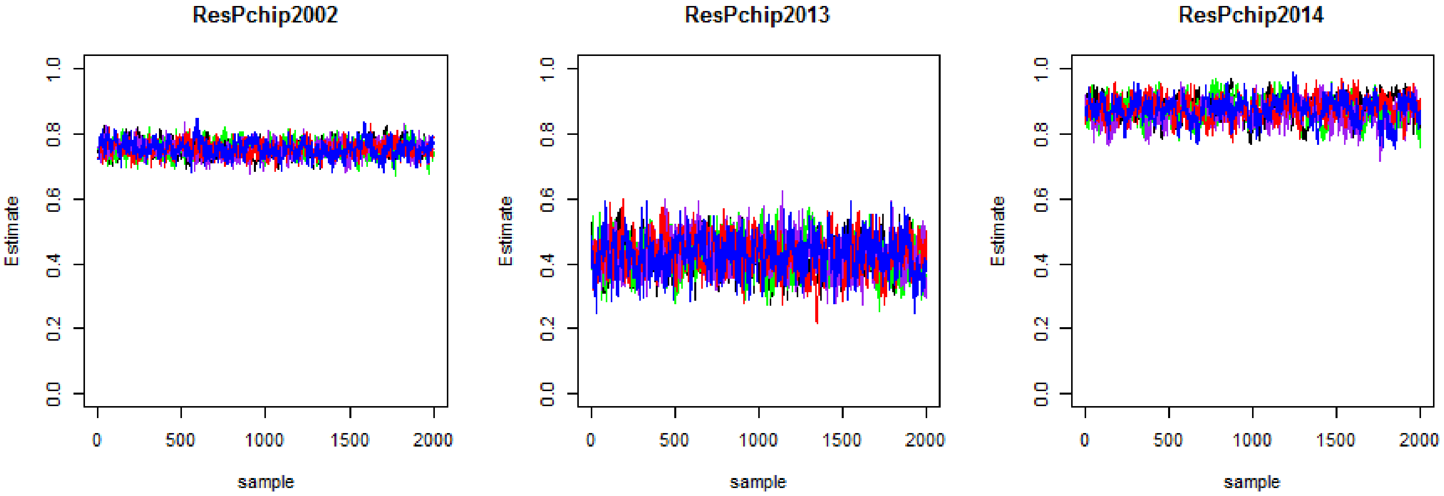


Figure 31: **Trace plots for *Res*$_{\mathbf{Pchip}}$ for different year blocks (2002–2012, 2013 and 2014) from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.**

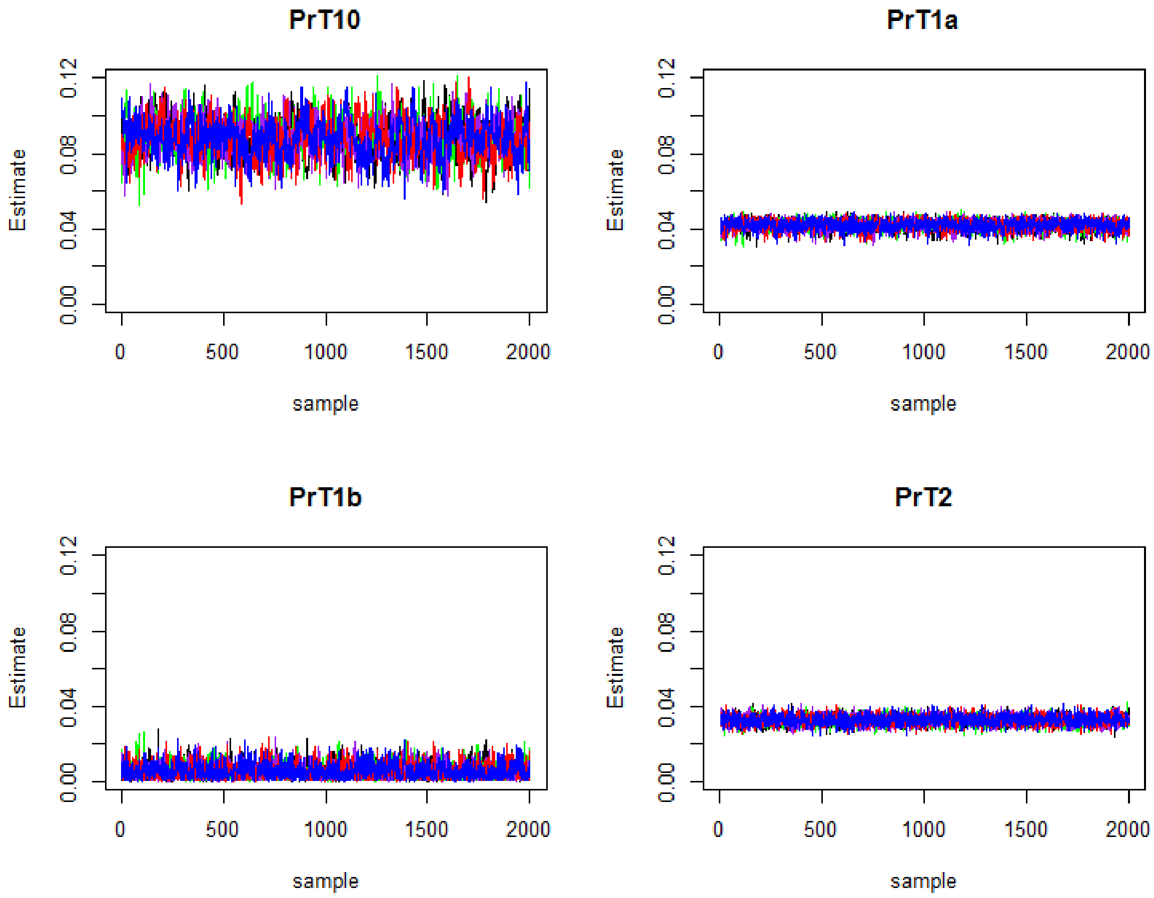


Figure 32: Trace plots for Pr_{T10}, Pr_{T1a} Pr_{T1b} and Pr_{T2} from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.

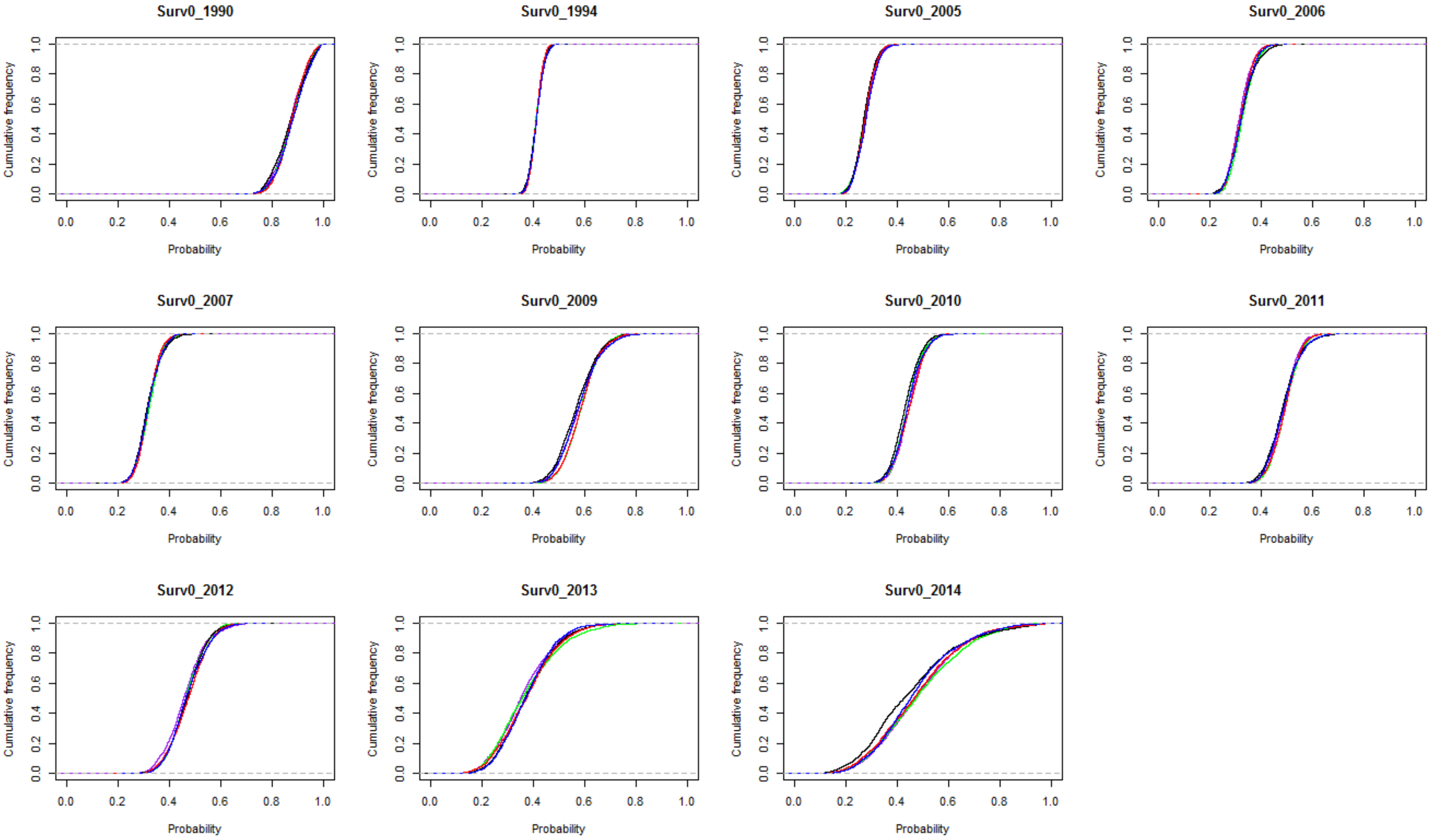


Figure 33: **Cumulative frequency plots for *Surv*$_0$ for different year blocks (1990–1993, 1994–2004 then each year until 2014) from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.**

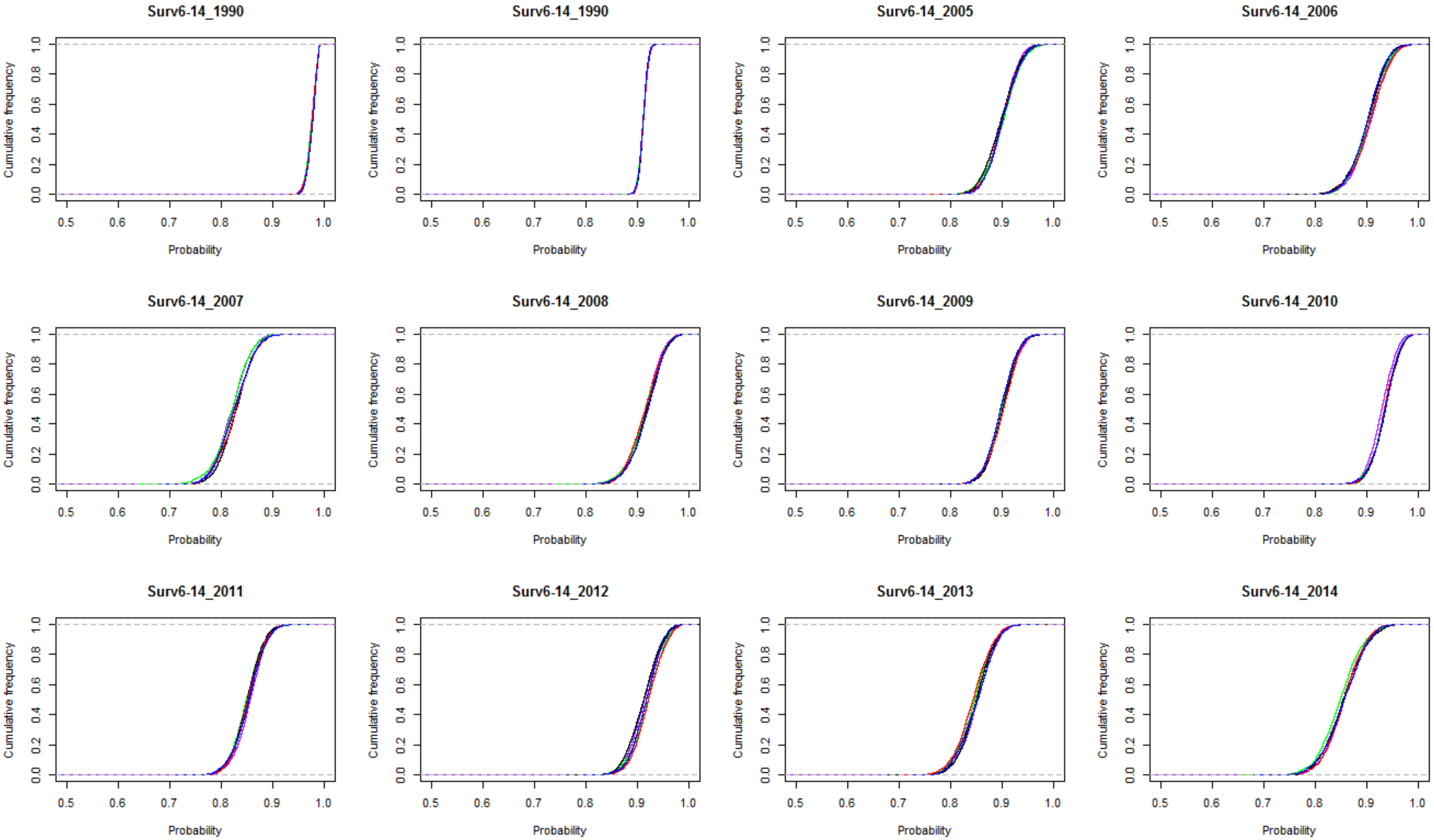


Figure 34: Cumulative frequency plots for *Surv*$_{6\text{-}14}$ for different year blocks (1990–1998, 1999–2004 then each year until 2014) from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.

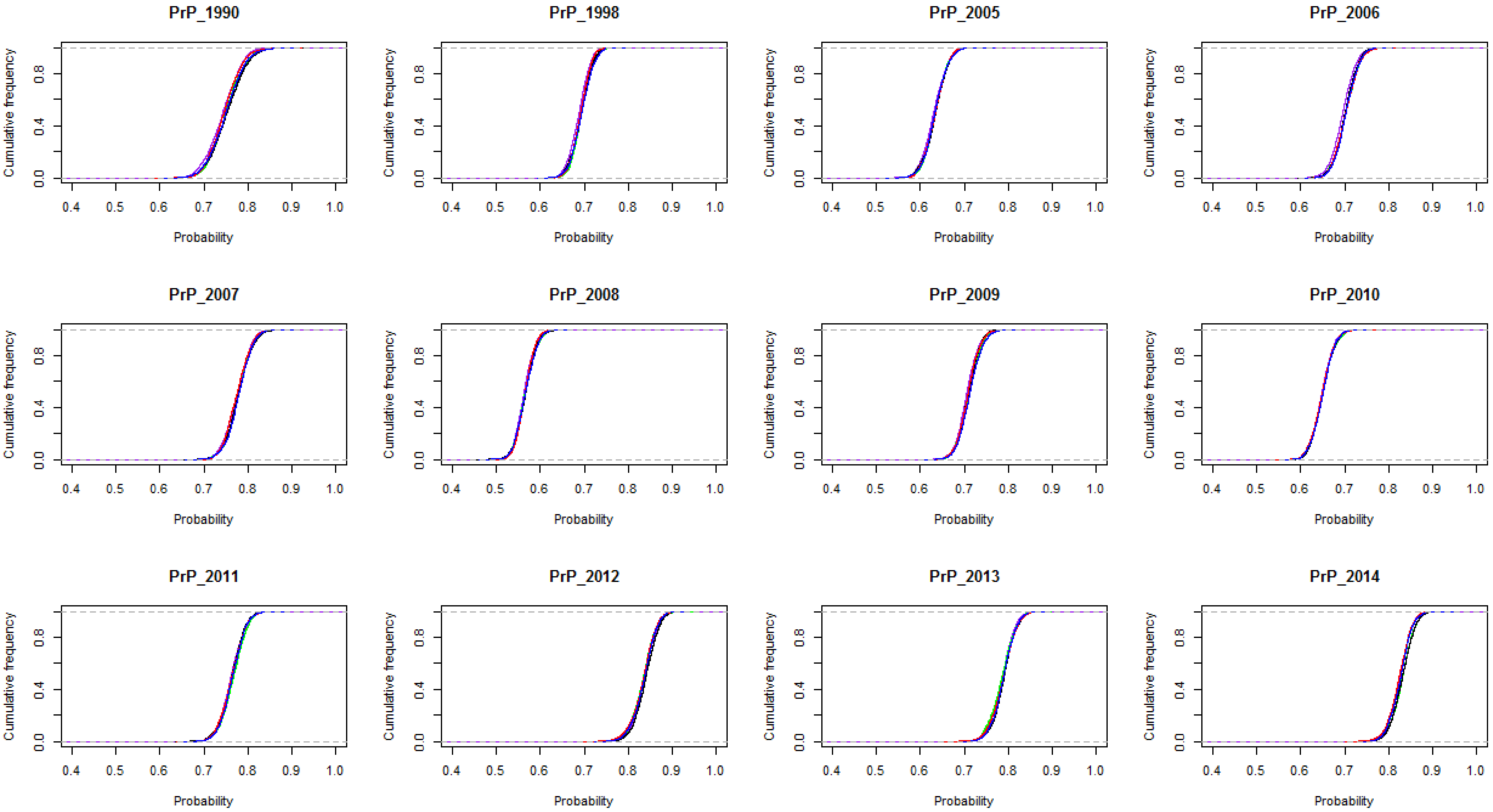


Figure 35: **Cumulative frequency plots for *Pr*P (the probability of pupping in year+1) for different year blocks (1990–1997, 1998–2004 then each year until 2014) from the Auckland Islands Base run MCMC, using the 15+ model configuration. A different colour trace is shown for each of 5 chains, comprising 2000 samples taken at intervals of 100 iterations; a total of 200 000 iterations per chain and 1 million iterations for all chains.**

Table 21: Pearson product-moment correlation coefficient between all estimates parameters for the Auckland Islands Base run MCMC, using the 15+ model configuration (all highly correlated parameter parings highlighted in grey; < -0.6 or > 0.6).

Parameter	$Surv_0$1990	$Surv_0$1994	$Surv_0$2005	$Surv_0$2006	$Surv_0$2007	$Surv_0$2009	$Surv_0$2010	$Surv_0$2011	$Surv_0$2012	$Surv_0$2013	$Surv_0$2014	$Surv_1$	$Surv_{2-5}$	$Surv_{6-14}$1990	$Surv_{6-14}$1999	$Surv_{6-14}$2005	$Surv_{6-14}$2006	$Surv_{6-14}$2007	$Surv_{6-14}$2008	$Surv_{6-14}$2009	$Surv_{6-14}$2010	$Surv_{6-14}$2011	$Surv_{6-14}$2012	$Surv_{6-14}$2013	$Surv_{6-14}$2014	$Surv_{15+}$	Mat_4	Mat_5	Mat_6	Mat_7
N_{1990}	-0.21	0.05	0.02	0.01	0.01	0.01	0.00	-0.02	0.01	-0.01	0.04	-0.01	-0.05	-0.76	0.09	-0.03	-0.02	0.03	0.01	0.02	-0.01	0.01	0.02	0.00	0.03	-0.20	0.02	0.03	0.01	-0.01
$Surv_0$1990		0.72	0.31	0.33	0.26	0.40	0.33	0.34	0.26	0.17	0.03	-0.69	-0.23	-0.01	-0.08	0.03	-0.04	0.04	-0.01	0.02	0.06	0.01	-0.02	0.02	-0.02	0.21	0.01	0.02	0.02	-0.06
$Surv_0$1994			0.31	0.39	0.34	0.41	0.38	0.38	0.30	0.15	0.07	-0.80	-0.10	-0.01	-0.09	-0.01	-0.02	0.00	-0.03	-0.01	0.03	0.00	-0.03	0.03	-0.03	-0.01	-0.08	-0.08	-0.02	-0.02
$Surv_0$2005				0.16	0.11	0.21	0.16	0.18	0.14	0.04	-0.06	-0.36	-0.03	0.00	0.03	0.03	-0.04	0.02	-0.05	-0.01	0.05	-0.04	-0.05	0.01	-0.04	-0.03	-0.01	0.03	0.03	-0.01
$Surv_0$2006					0.16	0.20	0.20	0.17	0.18	0.10	0.00	-0.42	0.00	0.00	0.00	-0.01	-0.03	0.03	-0.05	-0.01	0.02	-0.09	-0.07	0.01	-0.10	0.06	-0.03	0.01	0.00	0.01
$Surv_0$2007						0.17	0.12	0.17	0.14	0.03	0.05	-0.35	-0.03	0.03	0.02	0.02	-0.01	0.02	0.01	0.00	0.03	-0.03	-0.03	-0.03	-0.08	-0.04	-0.02	-0.04	0.01	-0.04
$Surv_0$2009							0.20	0.23	0.19	0.09	0.06	-0.46	0.00	-0.02	0.00	0.04	-0.02	-0.02	0.00	-0.02	0.06	-0.02	0.01	-0.06	-0.06	0.05	0.03	-0.01	0.04	-0.02
$Surv_0$2010								0.19	0.15	0.11	-0.03	-0.40	0.00	0.01	-0.02	0.01	0.02	0.00	-0.05	0.01	-0.01	0.04	0.01	0.00	-0.06	0.01	-0.02	-0.01	0.00	-0.03
$Surv_0$2011									0.19	0.09	0.05	-0.40	-0.01	-0.01	-0.02	0.01	0.05	-0.05	0.04	0.01	0.01	0.03	-0.04	0.01	-0.01	0.08	-0.01	-0.01	0.03	-0.06
$Surv_0$2012										0.04	0.01	-0.33	0.00	0.00	0.02	0.00	0.02	0.04	-0.01	-0.01	0.04	-0.02	-0.03	0.00	0.04	0.03	-0.02	0.02	-0.02	-0.02
$Surv_0$2013											-0.05	-0.16	-0.03	-0.02	0.00	0.02	-0.02	0.02	-0.03	-0.02	0.01	0.03	-0.06	0.03	0.00	0.04	-0.02	0.07	0.04	0.02
$Surv_0$2014												-0.03	-0.01	-0.01	0.01	-0.04	-0.01	0.05	0.05	0.02	-0.01	0.02	0.00	-0.03	-0.02	-0.02	0.00	0.03	0.00	0.02
$Surv_1$													-0.27	0.00	0.00	-0.02	0.00	0.01	0.03	-0.01	-0.03	-0.02	0.02	-0.01	0.00	-0.07	0.02	0.01	0.00	0.04
$Surv_{2-5}$														0.07	-0.11	-0.06	-0.04	-0.09	-0.09	-0.07	-0.05	-0.04	-0.01	-0.05	0.00	-0.10	-0.01	-0.02	-0.11	-0.10
$Surv_{6-14}$1990															0.12	0.05	0.05	-0.02	0.02	0.01	0.01	0.02	-0.01	0.02	-0.01	-0.19	0.00	0.04	0.10	0.16
$Surv_{6-14}$1999																-0.07	-0.01	-0.01	0.09	0.04	0.02	0.07	0.03	0.03	0.03	-0.33	0.05	0.13	0.11	0.08
$Surv_{6-14}$2005																	-0.27	-0.03	-0.01	-0.02	0.01	-0.01	-0.02	0.03	0.01	-0.08	0.06	0.00	0.03	0.02
$Surv_{6-14}$2006																		-0.29	-0.03	0.02	0.02	0.01	0.01	0.03	0.01	-0.08	-0.01	-0.01	0.00	0.03
$Surv_{6-14}$2007																			-0.22	-0.02	-0.02	-0.06	-0.02	-0.03	-0.02	-0.06	0.03	-0.01	0.01	0.02
$Surv_{6-14}$2008																				-0.25	-0.01	-0.02	-0.02	-0.01	0.00	-0.08	0.04	0.03	0.00	0.01
$Surv_{6-14}$2009																					-0.22	0.01	-0.03	0.01	-0.04	-0.09	-0.06	0.00	0.05	0.01
$Surv_{6-14}$2010																						-0.35	0.01	-0.02	-0.04	-0.01	-0.02	0.01	-0.02	0.01
$Surv_{6-14}$2011																							-0.21	-0.01	0.01	-0.07	-0.01	0.01	0.04	-0.01
$Surv_{6-14}$2012																								-0.43	0.01	-0.06	-0.01	-0.04	-0.03	0.01
$Surv_{6-14}$2013																									-0.17	-0.03	-0.03	0.02	0.03	0.00
$Surv_{6-14}$2014																										-0.05	0.00	0.00	-0.02	-0.01
$Surv_{15+}$																											-0.03	-0.04	-0.05	-0.05
Mat_4																												0.11	0.11	0.06
Mat_5																													0.13	0.08
Mat_6																														0.12
Mat_7																														

Parameter	$Pr_{\mathrm{P}}1990$	$Pr_{\mathrm{P}}1998$	$Pr_{\mathrm{P}}2005$	$Pr_{\mathrm{P}}2006$	$Pr_{\mathrm{P}}2007$	$Pr_{\mathrm{P}}2008$	$Pr_{\mathrm{P}}2009$	$Pr_{\mathrm{P}}2010$	$Pr_{\mathrm{P}}2011$	$Pr_{\mathrm{P}}2012$	$Pr_{\mathrm{P}}2013$	$Pr_{\mathrm{P}}2014$	$Res_{1\text{-}2}$	Res_3	$Res_{\mathrm{N}}1999$	$Res_{\mathrm{N}}2000$	$Res_{\mathrm{N}}2002$	$Res_{\mathrm{N}}2013$	$Res_{\mathrm{N}}2014$	$Res_{\mathrm{Ptag}}1999$	$Res_{\mathrm{Ptag}}2000$	$Res_{\mathrm{Ptag}}2002$	$Res_{\mathrm{Ptag}}2013$	$Res_{\mathrm{Ptag}}2014$	$Res_{\mathrm{Pchip}}2002$	$Res_{\mathrm{Pchip}}2013$	$Res_{\mathrm{Pchip}}2014$	Pr_{T10}	Pr_{T1a}	Pr_{T1b}	Pr_{T2}
N_{1990}	-0.63	-0.39	-0.17	-0.15	-0.11	-0.11	-0.09	-0.02	-0.04	0.02	0.06	0.02	-0.03	-0.02	-0.12	-0.19	-0.13	-0.02	0.05	0.22	0.24	0.15	0.00	-0.03	0.15	0.00	0.02	0.00	-0.03	-0.02	0.04
$Surv_0 1990$	-0.02	-0.09	-0.04	-0.03	-0.05	-0.07	-0.02	-0.06	-0.06	0.00	0.02	0.03	-0.37	0.04	-0.07	-0.06	-0.05	-0.01	0.03	-0.03	0.04	0.08	0.03	0.01	0.04	-0.01	-0.01	0.00	0.02	0.01	-0.04
$Surv_0 1994$	0.00	-0.02	-0.05	-0.06	-0.05	-0.08	-0.06	-0.10	-0.07	0.02	0.05	0.07	-0.42	0.03	-0.01	-0.04	-0.07	0.01	0.03	0.00	0.04	0.07	0.06	0.02	0.05	0.00	0.00	0.00	0.00	-0.01	0.00
$Surv_0 2005$	0.01	0.02	0.02	0.02	0.04	0.01	-0.01	-0.09	-0.07	-0.03	-0.05	-0.01	-0.17	0.05	-0.04	0.02	0.01	0.03	0.03	0.03	-0.01	-0.01	0.01	-0.01	-0.03	-0.01	-0.05	0.02	0.00	0.00	0.02
$Surv_0 2006$	0.05	0.03	-0.01	0.00	0.01	0.02	0.00	-0.08	-0.10	-0.02	-0.05	0.04	-0.23	0.00	-0.02	0.02	-0.04	-0.02	-0.01	0.00	-0.03	0.01	0.01	0.02	-0.01	0.03	-0.01	0.02	0.00	-0.02	0.04
$Surv_0 2007$	0.07	0.07	0.06	0.08	0.04	0.06	0.07	0.03	-0.06	-0.08	-0.03	0.01	-0.17	0.04	0.05	0.01	0.00	-0.03	0.00	-0.05	-0.05	-0.06	0.02	0.06	-0.02	0.01	-0.01	-0.04	-0.01	0.01	0.03
$Surv_0 2009$	0.02	0.00	-0.03	0.00	0.05	-0.03	0.02	0.01	-0.02	-0.06	-0.04	-0.12	-0.22	0.04	-0.06	0.00	-0.01	-0.07	-0.05	0.03	0.00	0.02	0.06	0.04	-0.02	-0.02	0.04	-0.04	-0.02	0.01	0.04
$Surv_0 2010$	0.05	0.06	0.04	0.02	0.01	0.03	0.02	0.03	0.02	0.04	-0.02	-0.02	-0.19	0.03	0.00	0.04	0.05	0.00	-0.02	0.02	-0.03	-0.03	-0.04	0.00	-0.02	-0.01	-0.01	-0.02	0.00	0.00	0.01
$Surv_0 2011$	0.08	0.06	0.05	0.00	0.05	-0.02	0.00	0.00	-0.02	0.00	0.02	-0.05	-0.24	0.05	0.00	0.02	0.04	0.02	-0.10	-0.05	-0.03	-0.05	0.00	0.04	-0.03	-0.04	-0.01	-0.01	0.01	-0.01	0.01
$Surv_0 2012$	0.03	0.03	0.03	0.02	-0.01	-0.04	0.02	-0.03	-0.01	-0.01	-0.01	0.04	-0.23	-0.13	0.01	0.03	0.00	-0.02	-0.01	0.02	-0.03	0.00	-0.01	0.00	0.01	0.01	-0.03	-0.01	0.00	0.00	0.02
$Surv_0 2013$	0.01	0.01	0.03	0.02	0.02	0.02	0.00	0.01	0.00	0.06	0.00	0.00	-0.27	0.05	-0.03	0.03	-0.01	0.01	-0.03	0.03	0.01	0.00	0.00	0.00	0.00	0.00	-0.06	0.01	-0.01	0.01	-0.01
$Surv_0 2014$	-0.06	-0.07	-0.04	-0.03	-0.06	-0.06	-0.03	-0.05	-0.05	-0.05	-0.05	-0.01	-0.12	-0.02	0.00	-0.03	-0.08	-0.01	-0.03	0.02	0.08	0.09	0.03	0.04	0.08	-0.03	0.02	-0.04	-0.02	0.03	0.02
$Surv_1$	-0.09	-0.04	-0.01	-0.01	-0.04	0.00	-0.01	0.02	0.03	-0.04	-0.05	-0.03	0.38	-0.12	0.02	0.00	-0.02	-0.01	-0.01	0.00	0.02	0.01	-0.02	0.02	0.02	-0.01	0.01	0.00	-0.01	0.01	0.01
$Surv_{2\text{-}5}$	0.01	-0.04	-0.03	-0.03	0.03	0.01	0.01	0.00	-0.03	-0.02	-0.05	-0.09	0.09	0.13	-0.05	-0.02	-0.04	-0.04	-0.09	0.07	0.01	0.01	0.00	0.00	0.01	0.03	0.04	0.00	-0.01	0.00	0.04
$Surv_{6\text{-}14} 1990$	0.40	0.13	0.04	0.04	0.03	0.07	0.04	0.01	0.03	0.03	-0.03	0.01	0.03	0.00	0.10	0.07	0.09	0.07	-0.01	-0.11	-0.09	-0.10	-0.03	0.03	-0.12	-0.03	0.00	0.01	0.06	0.00	-0.05
$Surv_{6\text{-}14} 1999$	-0.10	-0.35	-0.29	-0.23	-0.13	-0.10	-0.08	-0.06	-0.03	0.03	0.02	0.03	0.01	-0.04	-0.07	-0.17	-0.09	0.01	0.04	0.18	0.18	0.10	-0.01	-0.03	0.08	-0.02	-0.01	0.01	0.11	-0.05	-0.06
$Surv_{6\text{-}14} 2005$	0.04	0.09	-0.34	-0.19	-0.12	-0.06	-0.07	-0.04	-0.04	0.00	-0.01	0.00	0.00	-0.01	-0.01	-0.01	-0.04	0.03	-0.03	-0.05	-0.03	0.05	-0.02	0.04	0.03	-0.02	0.06	-0.04	0.02	0.01	-0.03
$Surv_{6\text{-}14} 2006$	0.06	0.12	0.22	-0.25	-0.08	-0.05	-0.03	-0.01	-0.01	-0.02	0.00	0.01	0.01	0.03	0.07	0.04	0.04	0.02	0.03	-0.05	-0.06	-0.05	0.00	-0.01	-0.03	0.04	-0.06	0.01	0.03	-0.02	-0.01
$Surv_{6\text{-}14} 2007$	-0.04	0.00	0.04	0.20	-0.30	-0.19	-0.14	-0.12	-0.09	-0.08	-0.02	-0.03	-0.03	0.00	0.03	0.04	-0.04	-0.07	0.01	0.02	0.01	0.09	0.01	-0.01	0.05	-0.01	0.02	-0.01	-0.03	0.03	0.00
$Surv_{6\text{-}14} 2008$	0.02	0.01	0.00	0.06	0.18	-0.27	-0.14	-0.08	-0.06	-0.08	-0.01	0.02	0.03	-0.03	0.00	0.00	0.00	-0.02	0.00	-0.02	-0.01	-0.02	0.00	-0.01	0.04	0.01	0.00	0.01	0.00	0.01	-0.02
$Surv_{6\text{-}14} 2009$	-0.01	0.04	0.06	0.07	0.08	0.25	-0.18	-0.09	-0.06	-0.02	-0.02	0.00	-0.01	0.01	0.00	0.03	0.04	0.02	0.03	-0.01	-0.03	0.01	-0.01	0.00	-0.04	0.03	0.01	-0.03	0.03	-0.01	-0.04
$Surv_{6\text{-}14} 2010$	0.00	-0.02	0.02	0.03	0.00	0.02	0.13	-0.27	-0.09	-0.09	-0.08	-0.02	-0.03	-0.04	-0.01	-0.02	-0.02	-0.05	0.00	0.02	0.00	0.02	0.05	-0.04	0.00	0.01	-0.01	-0.02	-0.01	0.01	0.03
$Surv_{6\text{-}14} 2011$	0.00	0.00	0.04	0.01	0.07	0.07	0.08	0.25	-0.19	-0.08	-0.06	-0.04	0.00	0.02	0.00	-0.03	0.03	-0.02	-0.02	-0.01	0.01	-0.02	0.01	0.03	-0.03	0.03	0.04	0.02	0.03	-0.02	-0.02
$Surv_{6\text{-}14} 2012$	-0.03	0.01	0.03	0.03	0.03	0.06	0.11	0.07	0.21	-0.29	-0.05	-0.03	0.03	0.04	-0.01	0.01	0.07	-0.15	-0.01	0.01	0.01	-0.06	-0.06	0.00	0.00	-0.09	-0.01	-0.03	0.00	0.01	-0.01
$Surv_{6\text{-}14} 2013$	0.01	0.00	-0.04	-0.01	0.03	0.00	-0.02	-0.02	0.07	0.28	-0.25	-0.15	-0.01	-0.03	0.01	-0.02	0.01	0.18	-0.18	0.00	0.03	0.00	0.07	0.04	0.00	0.05	0.06	0.03	0.01	-0.01	0.00
$Surv_{6\text{-}14} 2014$	0.01	0.01	0.04	0.03	0.04	0.03	0.08	0.07	0.12	0.07	0.20	-0.26	0.00	-0.01	-0.02	-0.01	0.04	0.01	0.07	-0.04	-0.01	-0.03	0.01	-0.21	-0.02	0.01	-0.15	-0.02	0.00	0.02	-0.02
$Surv_{15+}$	0.30	0.20	0.09	0.06	0.00	-0.03	-0.04	-0.05	-0.10	-0.10	-0.12	-0.11	-0.05	0.03	0.05	0.14	0.02	-0.07	-0.07	-0.10	-0.14	0.00	0.05	0.05	0.00	0.03	0.00	0.03	-0.08	0.01	0.01
Mat_4	-0.16	-0.14	-0.09	-0.09	-0.10	-0.08	-0.03	0.00	-0.01	0.00	-0.04	-0.05	0.02	0.02	-0.02	-0.09	0.04	0.07	-0.02	0.03	0.08	-0.05	-0.07	-0.01	-0.04	-0.05	0.00	0.00	0.01	0.00	-0.02
Mat_5	-0.23	-0.23	-0.14	-0.11	-0.10	-0.07	-0.06	-0.04	-0.05	-0.03	-0.07	-0.10	0.00	-0.02	-0.08	-0.12	0.04	0.01	-0.01	0.07	0.12	-0.04	0.02	-0.03	-0.02	-0.03	0.01	0.03	0.05	-0.05	0.00
Mat_6	-0.18	-0.18	-0.12	-0.12	-0.09	-0.09	-0.11	-0.09	-0.06	-0.05	-0.08	-0.10	-0.02	-0.01	0.01	-0.05	0.07	0.07	-0.03	-0.03	0.07	-0.03	-0.05	0.00	-0.10	-0.04	0.06	-0.03	0.00	0.02	-0.02
Mat_7	-0.09	-0.11	-0.06	-0.11	-0.10	-0.05	-0.10	-0.11	-0.05	-0.02	-0.05	-0.07	-0.01	0.01	0.05	0.03	0.12	0.08	0.05	-0.08	-0.02	-0.06	-0.05	0.05	-0.13	-0.01	-0.01	-0.01	0.01	0.00	-0.03

Parameter	Pr_{P}1990	Pr_{P}1998	Pr_{P}2005	Pr_{P}2006	Pr_{P}2007	Pr_{P}2008	Pr_{P}2009	Pr_{P}2010	Pr_{P}2011	Pr_{P}2012	Pr_{P}2013	Pr_{P}2014	$Res_{1\text{-}2}$	Res_{3}	Res_{N}1999	Res_{N}2000	Res_{N}2002	Res_{N}2013	Res_{N}2014	Res_{Ptag}1999	Res_{Ptag}2000	Res_{Ptag}2002	Res_{Ptag}2013	Res_{Ptag}2014	Res_{Pchip}2002	Res_{Pchip}2013	Res_{Pchip}2014	Pr_{T10}	Pr_{T1a}	Pr_{T1b}	Pr_{T2}
Pr_{P}1990		0.74	0.34	0.30	0.26	0.22	0.17	0.10	0.11	0.02	0.02	0.06	0.00	0.04	0.20	0.35	0.22	-0.01	-0.05	-0.26	-0.42	-0.26	0.03	-0.01	-0.21	0.02	-0.05	0.00	-0.01	0.01	-0.01
Pr_{P}1998			0.50	0.43	0.37	0.31	0.23	0.19	0.19	0.05	0.08	0.08	0.00	0.04	0.25	0.45	0.33	0.01	-0.02	-0.35	-0.54	-0.37	-0.02	-0.04	-0.29	0.05	-0.08	-0.03	-0.03	0.02	0.00
Pr_{P}2005				0.42	0.33	0.28	0.26	0.21	0.16	0.05	0.06	0.08	0.01	0.06	0.16	0.24	0.28	0.03	0.02	-0.17	-0.27	-0.29	-0.04	-0.06	-0.26	0.03	-0.08	-0.03	-0.03	0.01	0.01
Pr_{P}2006					0.38	0.34	0.27	0.23	0.21	0.08	0.09	0.06	0.01	-0.01	0.07	0.22	0.25	0.01	0.01	-0.12	-0.23	-0.30	0.00	-0.09	-0.22	0.01	-0.04	0.00	-0.04	0.02	0.02
Pr_{P}2007						0.37	0.31	0.27	0.28	0.15	0.11	0.10	0.02	0.03	0.05	0.15	0.28	0.09	0.01	-0.14	-0.20	-0.30	-0.05	-0.06	-0.26	0.01	-0.07	-0.03	0.01	-0.01	0.02
Pr_{P}2008							0.36	0.29	0.26	0.19	0.11	0.10	0.03	0.02	0.06	0.13	0.25	0.08	0.02	-0.11	-0.16	-0.28	-0.09	-0.09	-0.24	-0.02	-0.04	-0.04	-0.01	0.02	0.00
Pr_{P}2009								0.35	0.30	0.18	0.16	0.09	0.03	0.03	0.04	0.07	0.21	0.05	0.04	-0.09	-0.09	-0.27	-0.03	-0.07	-0.21	-0.06	-0.07	-0.03	-0.03	0.02	0.04
Pr_{P}2010									0.33	0.22	0.21	0.13	0.02	0.05	0.04	0.09	0.20	0.07	0.06	-0.05	-0.08	-0.24	-0.08	-0.05	-0.16	-0.03	-0.07	0.00	0.02	-0.01	0.00
Pr_{P}2011										0.29	0.23	0.15	0.02	0.01	0.05	0.11	0.26	0.11	0.07	-0.08	-0.12	-0.30	-0.10	-0.07	-0.18	-0.03	-0.09	-0.04	0.00	0.02	-0.01
Pr_{P}2012											0.26	0.16	0.00	0.01	-0.02	0.02	0.10	0.36	0.10	-0.01	-0.03	-0.09	-0.18	-0.12	-0.10	-0.05	-0.05	0.00	0.02	0.00	-0.02
Pr_{P}2013												0.29	0.00	0.03	0.03	0.03	0.06	0.10	0.36	-0.03	-0.03	-0.07	-0.05	-0.21	-0.09	-0.02	-0.20	-0.02	0.00	0.00	-0.02
Pr_{P}2014													-0.01	-0.05	0.06	0.03	0.02	0.06	0.27	-0.01	-0.06	-0.06	-0.04	-0.07	-0.03	0.01	-0.10	0.05	0.03	-0.04	-0.03
$Res_{1\text{-}2}$														0.03	-0.01	0.00	0.04	0.01	0.04	0.01	0.01	-0.02	-0.03	-0.02	-0.03	0.01	0.01	-0.02	-0.01	0.01	0.01
Res_{3}															-0.01	0.02	0.05	0.00	0.00	-0.01	-0.04	-0.01	-0.03	-0.01	-0.04	-0.02	-0.02	-0.04	-0.01	0.03	-0.01
Res_{N}1999																0.12	0.09	0.01	-0.02	-0.54	-0.12	-0.11	0.04	0.03	-0.07	0.01	-0.02	-0.01	0.00	0.00	0.00
Res_{N}2000																	0.13	0.02	-0.01	-0.18	-0.68	-0.16	-0.03	-0.01	-0.12	0.04	-0.03	-0.01	-0.01	-0.01	0.01
Res_{N}2002																		0.06	0.02	-0.17	-0.18	-0.51	-0.03	-0.04	-0.49	-0.02	-0.08	-0.02	0.00	-0.01	0.02
Res_{N}2013																			0.04	-0.03	-0.02	-0.04	-0.29	-0.05	-0.09	-0.14	-0.04	0.02	0.02	-0.02	-0.01
Res_{N}2014																				0.02	0.01	0.00	-0.01	-0.31	-0.03	0.02	-0.38	0.02	0.01	-0.01	-0.01
Res_{Ptag}1999																					0.23	0.18	0.02	-0.02	0.14	0.00	0.02	0.00	-0.01	0.02	-0.01
Res_{Ptag}2000																						0.21	0.01	0.02	0.15	-0.04	0.06	0.00	0.00	0.02	-0.01
Res_{Ptag}2002																							0.09	0.06	0.30	0.01	0.02	0.03	0.00	0.00	-0.02
Res_{Ptag}2013																								0.05	0.03	0.02	0.01	-0.02	-0.02	0.01	0.02
Res_{Ptag}2014																									0.03	0.02	0.17	-0.01	-0.01	0.00	0.03
Res_{Pchip}2002																										0.01	0.05	0.06	0.01	-0.02	-0.01
Res_{Pchip}2013																											0.01	0.01	0.02	-0.02	-0.01
Res_{Pchip}2014																												-0.04	-0.03	0.03	0.02
$Pr\mathrm{T}_{10}$																													0.28	-0.51	0.04
$Pr\mathrm{T}_{1a}$																														-0.82	-0.27
$Pr\mathrm{T}_{1b}$																															-0.11

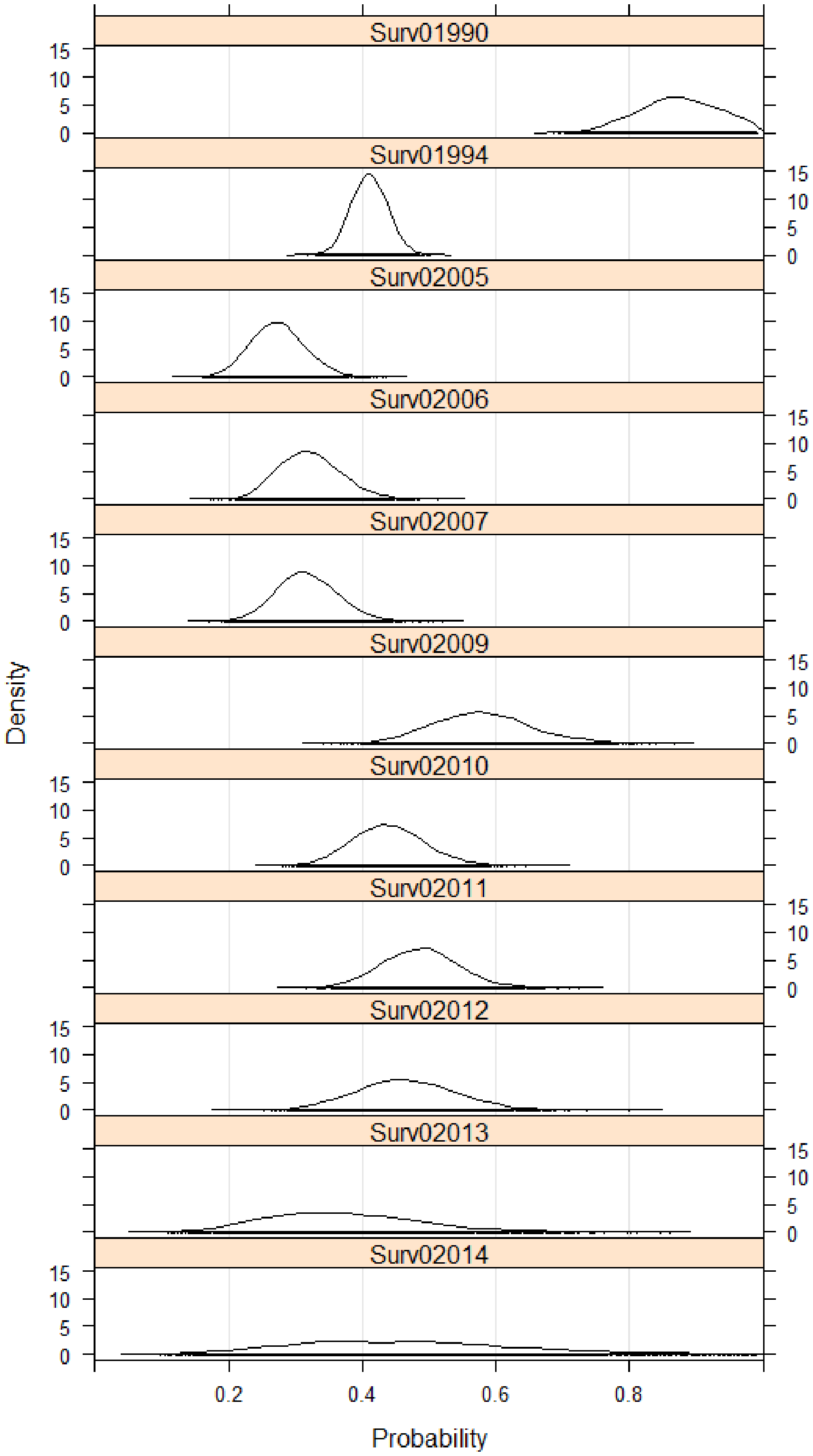


Figure 36: **Posterior densities for *Surv*$_0$ for different year blocks (1990–1993, 1994–2004 then each year from 2005 to 2014) from the Auckland Islands Base run MCMC, using the 15+ model configuration. All 10 000 samples from all 5 chains; 1 million iterations.**

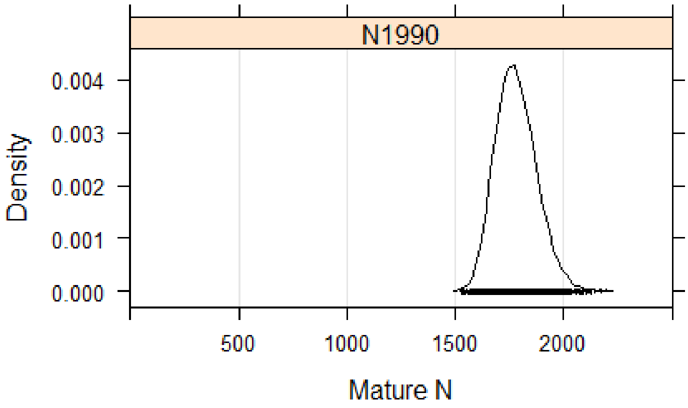


Figure 37: **Posterior density for N_{1990} from the Auckland Islands Base run MCMC, using the 15+ model configuration. All 10 000 samples from all 5 chains; 1 million iterations.**

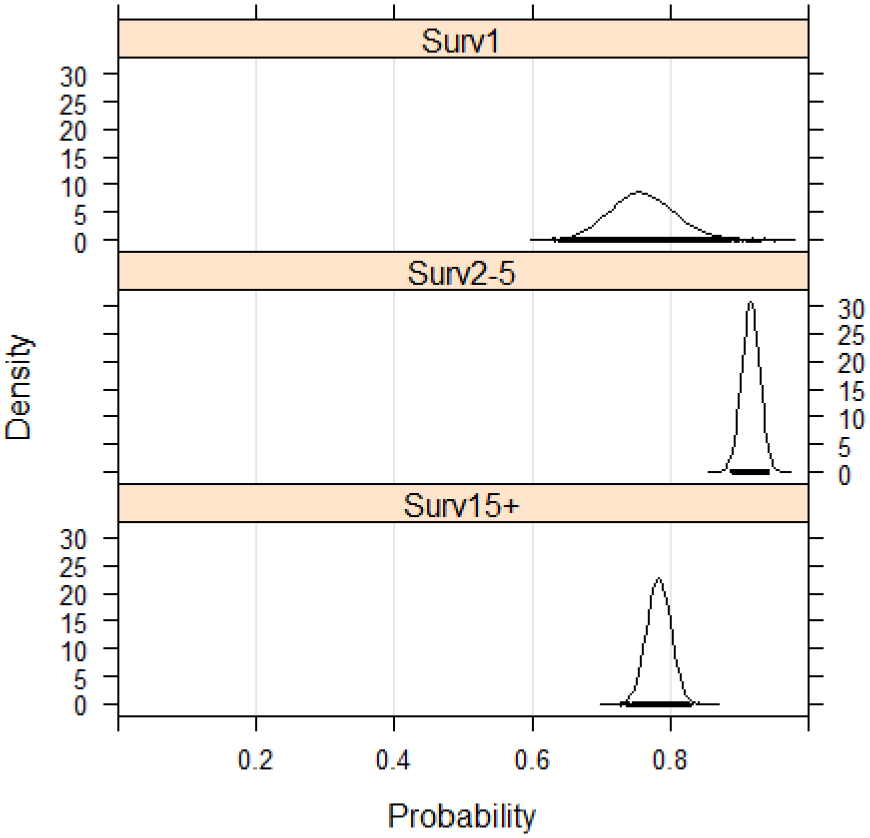


Figure 38: **Posterior densities for $Surv_{1}$, $Surv_{2\text{-}5}$ and $Surv_{15+}$ from the Auckland Islands Base run MCMC, using the 15+ model configuration. All 10 000 samples from all 5 chains; 1 million iterations.**

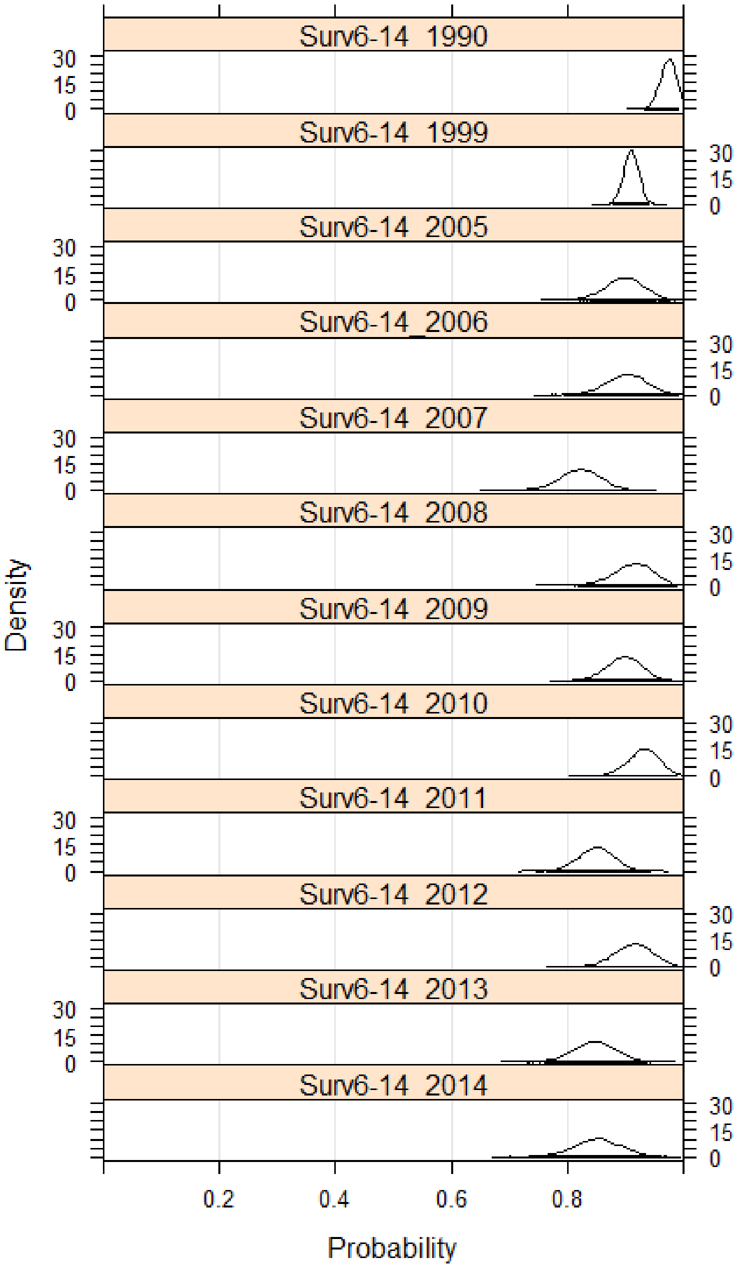


Figure 39: **Posterior densities for *Surv*$_{6\text{-}14}$ for different year blocks (1990–1998, 1999-2004 then each year from 2005 to 2014) from the Auckland Islands Base run MCMC, using the 15+ model configuration. All 10 000 samples from all 5 chains; 1 million iterations.**

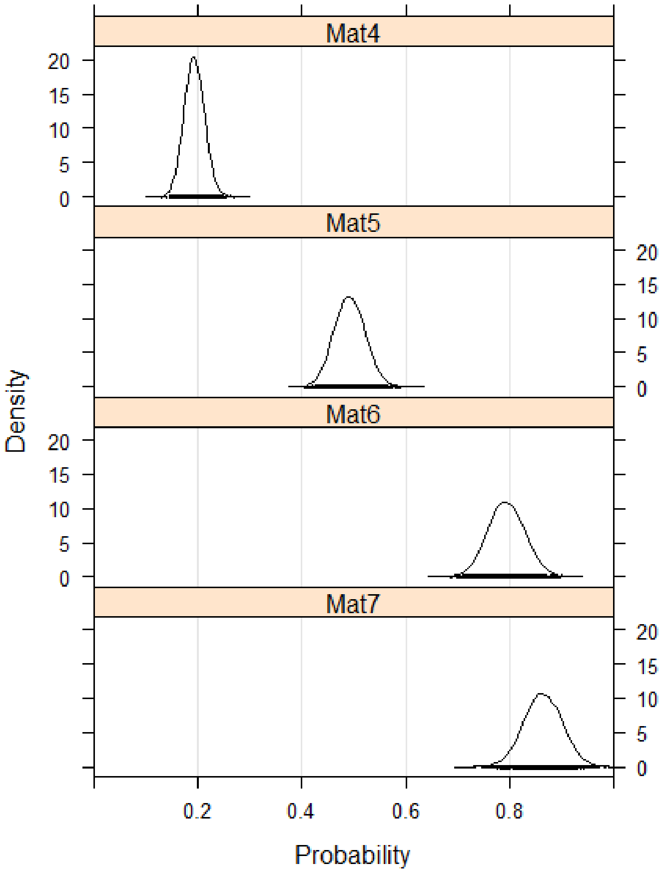


Figure 40: **Posterior densities for Mat_4, Mat_5, Mat_6 *and* Mat_7 from the Auckland Islands Base run MCMC, using the 15+ model configuration. All 10 000 samples from all 5 chains; 1 million iterations.**

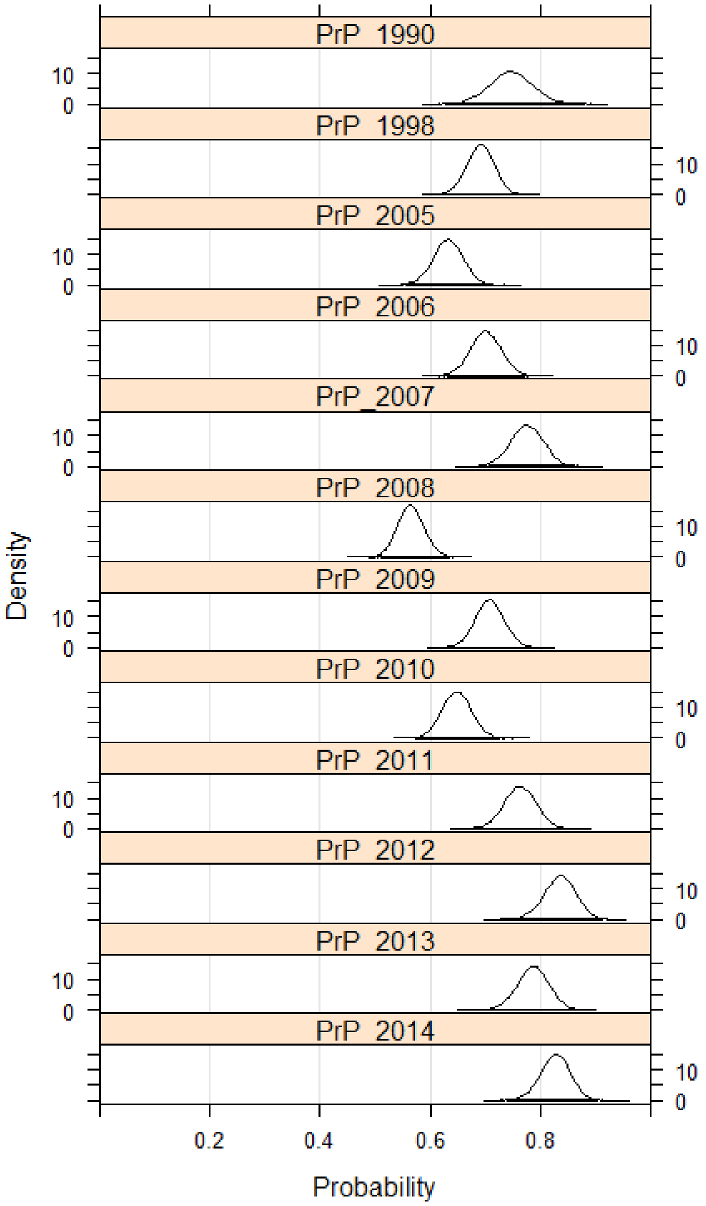


Figure 41: **Posterior densities for *Pr*P (the probability of pupping in year+1) for different year blocks (1990–1997, 1998–2004 then each year from 2005 to 2014) from the Auckland Islands Base run MCMC, using the 15+ model configuration. All 10 000 samples from all 5 chains; 1 million iterations.**

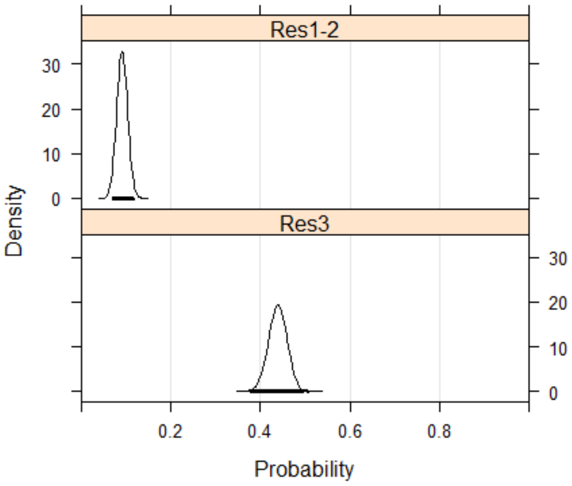


Figure 42: **Posterior densities for *Res*$_{1\text{-}2}$ (top) and *Res*$_3$ (bottom) from the Auckland Islands Base run MCMC, using the 15+ model configuration. All 10 000 samples from all 5 chains; 1 million iterations.**

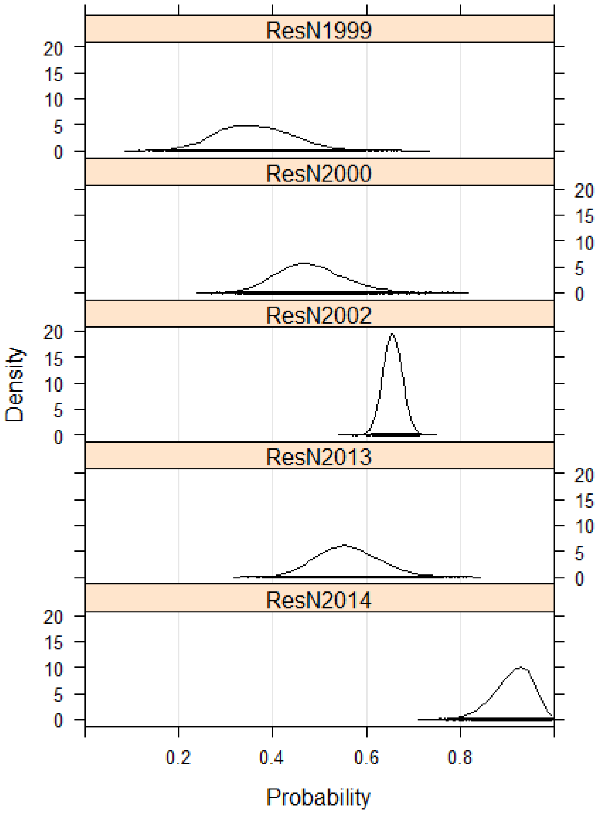


Figure 43: **Posterior densities for *Res*$_N$ for different year blocks (from top to bottom – 1999, 2000–2001, 2002–2012, 2013 and 2014–2015) from the Auckland Islands Base run MCMC, using the 15+ model configuration. All 10 000 samples from all 5 chains; 1 million iterations.**

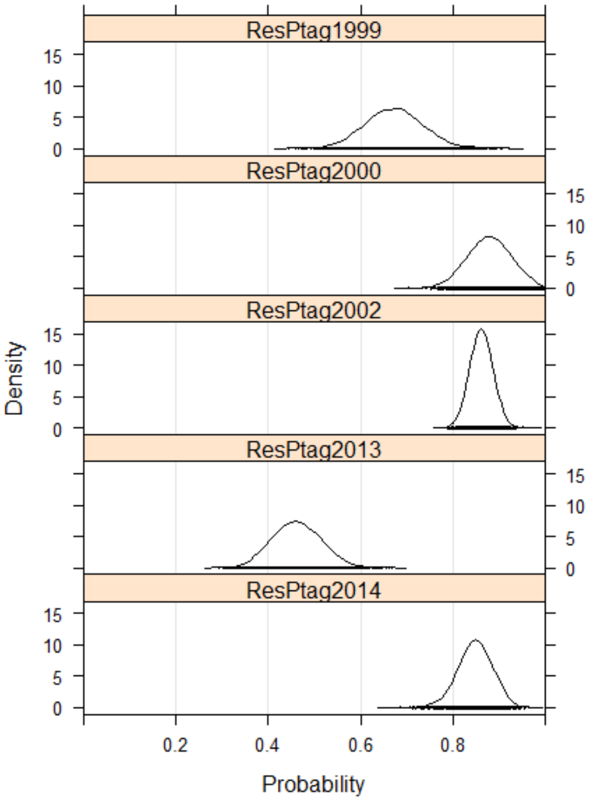


Figure 44: **Posterior densities for *Res*$_{\text{Ptag}}$ for different year blocks (from top to bottom – 1999, 2000–2001, 2002–2012, 2013 and 2014–2015) from the Auckland Islands Base run MCMC, using the 15+ model configuration. All 10 000 samples from all 5 chains; 1 million iterations.**

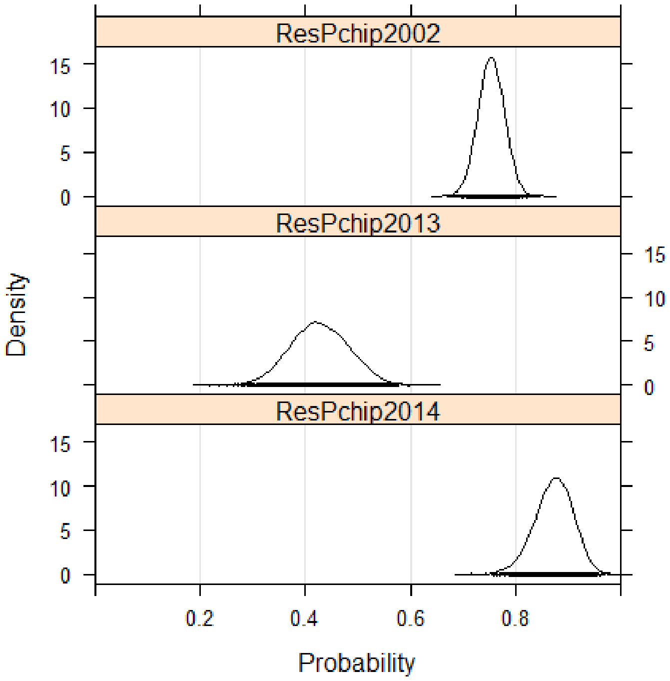


Figure 45: **MCMC posterior densities for *Res*$_{\text{Pchip}}$ for different year blocks (from top to bottom –2002–2012, 2013 and 2014–2015) from the Auckland Islands Base run MCMC, using the 15+ model configuration. All 10 000 samples from all 5 chains; 1 million iterations.**

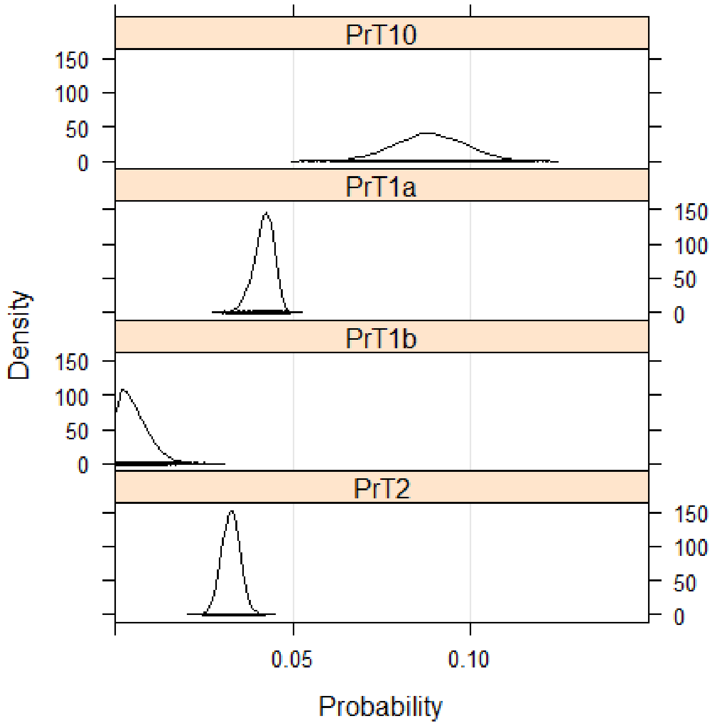


Figure 46: **Posterior densities for tag loss parameters *Pr*$_{T10}$, *Pr*$_{T1a}$ *Pr*$_{T1b}$ and *Pr*$_{T2}$ from the Auckland Islands Base run MCMC, using the 15+ model configuration. All 10 000 samples from all 5 chains; 1 million iterations.**

APPENDIX 3 PARAMETER ESTIMATES AUCKLAND ISLANDS MCMC

Table 22: Median estimates and 95% credible intervals of all estimates parameters for the Auckland Islands Base run MCMC, using the 15+ model configuration.

Parameter	Year	Estimate	95% credible interval	Parameter	Year	Estimate	95% credible interval
N_{1990}	N/A	1 774	1 612 – 1 984	Mat_4	All	0.19	0.16 – 0.23
				Mat_5	All	0.49	0.44 – 0.55
$Surv_0$	1990–1993	0.87	0.76 – 0.98	Mat_6	All	0.79	0.73 – 0.86
$Surv_0$	1994–2004	0.41	0.36 – 0.46	Mat_7	All	0.86	0.80 – 0.93
$Surv_0$	2005	0.27	0.20 – 0.35				
$Surv_0$	2006	0.32	0.24 – 0.42	Pr_{P}	1990–1997	0.75	0.68 – 0.82
$Surv_0$	2007	0.32	0.24 – 0.41	Pr_{P}	1998–2004	0.69	0.65 – 0.74
$Surv_0$	2009	0.58	0.45 – 0.73	Pr_{P}	2005	0.63	0.58 – 0.68
$Surv_0$	2010	0.44	0.34 – 0.55	Pr_{P}	2006	0.70	0.65 – 0.75
$Surv_0$	2011	0.49	0.38 – 0.61	Pr_{P}	2007	0.78	0.72 – 0.83
$Surv_0$	2012	0.46	0.33 – 0.62	Pr_{P}	2008	0.56	0.52 – 0.61
$Surv_0$	2013	0.36	0.18 – 0.63	Pr_{P}	2009	0.71	0.66 – 0.76
$Surv_0$	2014	0.46	0.19 – 0.86	Pr_{P}	2010	0.65	0.60 – 0.70
				Pr_{P}	2011	0.76	0.71 – 0.82
$Surv_1$	All	0.76	0.68 – 0.85	Pr_{P}	2012	0.84	0.78 – 0.89
$Surv_{2–5}$	All	0.92	0.90 – 0.93	Pr_{P}	2013	0.79	0.73 – 0.84
				Pr_{P}	2014	0.83	0.78 – 0.87
$Surv_{6\text{-}14}$	1990–1998	0.98	0.95 – 0.99				
$Surv_{6\text{-}14}$	1999–2004	0.91	0.89 – 0.93	$Res_{1\text{-}2}$	All	0.09	0.08 – 0.10
$Surv_{6\text{-}14}$	2005	0.90	0.84 – 0.96	Res_3	All	0.44	0.40 – 0.47
$Surv_{6\text{-}14}$	2006	0.90	0.83 – 0.96				
$Surv_{6\text{-}14}$	2007	0.82	0.76 – 0.89	Res_{N}	1999	0.36	0.22 – 0.52
$Surv_{6\text{-}14}$	2008	0.92	0.85 – 0.97	Res_{N}	2000–2001	0.48	0.36 – 0.64
$Surv_{6\text{-}14}$	2009	0.90	0.84 – 0.95	Res_{N}	2002–2012	0.66	0.62 – 0.69
$Surv_{6\text{-}14}$	2010	0.93	0.88 – 0.98	Res_{N}	2013	0.56	0.44 – 0.70
$Surv_{6\text{-}14}$	2011	0.85	0.79 – 0.91	Res_{N}	2014–2015	0.92	0.83 – 0.98
$Surv_{6\text{-}14}$	2012	0.92	0.86 – 0.97				
$Surv_{6\text{-}14}$	2013	0.85	0.78 – 0.91	Res_{Ptag}	1999	0.67	0.56 – 0.80
$Surv_{6\text{-}14}$	2014	0.85	0.78 – 0.93	Res_{Ptag}	2000–2001	0.88	0.79 – 0.97
				Res_{Ptag}	2002–2012	0.86	0.82 – 0.91
$Surv_{15+}$	All	0.78	0.76 – 0.81	Res_{Ptag}	2013	0.46	0.36 – 0.56
				Res_{Ptag}	2014–2015	0.85	0.77 – 0.92
Pr_{T10}	All	0.0880	0.0690 – 0.1078				
Pr_{T1a}	All	0.0421	0.0421 – 0.0464	Res_{Pchip}	2002–2012	0.75	0.71 – 0.80
Pr_{T1b}	All	0.0046	0.0002 – 0.0151	Res_{Pchip}	2013	0.43	0.32 – 0.53
Pr_{T2}	All	0.0326	0.0326 – 0.0374	Res_{Pchip}	2014–2015	0.88	0.80 – 0.94

Table 23: Median estimates and 95% credible intervals of all estimates parameters for the Auckland Islands Aggression run MCMC, using the 15+ model configuration.

Parameter	Year	Estimate	95% credible interval	Parameter	Year	Estimate	95% credible interval
N_{1990}	N/A	1 784	1 634 – 1992	Mat_{4}	All	0.18	0.15 – 0.22
				Mat_{5}	All	0.47	0.42 – 0.53
$Surv_{0}$	1990–1993	0.94	0.83 – 0.99	Mat_{6}	All	0.78	0.71 – 0.85
$Surv_{0}$	1994–2004	0.50	0.45 – 0.54	Mat_{7}	All	0.86	0.78 – 0.92
$Surv_{0}$	2005	0.33	0.25 – 0.43				
$Surv_{0}$	2006	0.37	0.29 – 0.47	Pr_{P}	1990–1997	0.72	0.65 – 0.79
$Surv_{0}$	2007	0.38	0.29 – 0.48	Pr_{P}	1998–2004	0.67	0.63 – 0.71
$Surv_{0}$	2009	0.63	0.5 – 0.78	Pr_{P}	2005	0.63	0.58 – 0.68
$Surv_{0}$	2010	0.50	0.4 – 0.62	Pr_{P}	2006	0.70	0.65 – 0.75
$Surv_{0}$	2011	0.53	0.42 – 0.64	Pr_{P}	2007	0.78	0.72 – 0.83
$Surv_{0}$	2012	0.59	0.45 – 0.77	Pr_{P}	2008	0.56	0.52 – 0.61
$Surv_{0}$	2013	0.41	0.22 – 0.7	Pr_{P}	2009	0.70	0.66 – 0.75
$Surv_{0}$	2014	0.47	0.2 – 0.86	Pr_{P}	2010	0.65	0.6 – 0.69
				Pr_{P}	2011	0.76	0.71 – 0.81
$Surv_{1}$	All	0.74	0.67 – 0.82	Pr_{P}	2012	0.84	0.79 – 0.89
$Surv_{2–5}$	All	0.91	0.9 – 0.93	Pr_{P}	2013	0.80	0.75 – 0.85
				Pr_{P}	2014	0.84	0.79 – 0.88
$Surv_{6-14}$	1990–1998	0.97	0.95 – 0.99				
$Surv_{6-14}$	1999–2004	0.91	0.89 – 0.92	Res_{1-2}	All	0.09	0.08 – 0.1
$Surv_{6-14}$	2005	0.90	0.84 – 0.96	Res_{3}	All	0.44	0.4 – 0.47
$Surv_{6-14}$	2006	0.91	0.84 – 0.97				
$Surv_{6-14}$	2007	0.82	0.75 – 0.89	Res_{N}	1999	0.33	0.21 – 0.49
$Surv_{6-14}$	2008	0.92	0.86 – 0.97	Res_{N}	2000–2001	0.45	0.34 – 0.59
$Surv_{6-14}$	2009	0.90	0.85 – 0.95	Res_{N}	2002–2012	0.65	0.61 – 0.68
$Surv_{6-14}$	2010	0.93	0.88 – 0.98	Res_{N}	2013	0.56	0.44 – 0.69
$Surv_{6-14}$	2011	0.86	0.8 – 0.91	Res_{N}	2014–2015	0.92	0.84 – 0.98
$Surv_{6-14}$	2012	0.92	0.86 – 0.97				
$Surv_{6-14}$	2013	0.85	0.78 – 0.92	Res_{Ptag}	1999	0.70	0.58 – 0.83
$Surv_{6-14}$	2014	0.86	0.79 – 0.93	Res_{Ptag}	2000–2001	0.90	0.81 – 0.99
				Res_{Ptag}	2002–2012	0.87	0.83 – 0.92
$Surv_{15+}$	All	0.78	0.75 – 0.81	Res_{Ptag}	2013	0.46	0.37 – 0.57
				Res_{Ptag}	2014–2015	0.84	0.77 – 0.91
Pr_{T10}	All	0.0888	0.0694 – 0.1079				
Pr_{T1a}	All	0.0420	0.0356 – 0.0463	Res_{Pchip}	2002–2012	0.76	0.72 – 0.81
Pr_{T1b}	All	0.0048	0.0002 – 0.0153	Res_{Pchip}	2013	0.43	0.32 – 0.54
Pr_{T2}	All	0.0326	0.0279 – 0.0375	Res_{Pchip}	2014–2015	0.87	0.79 – 0.93

Table 24: Median estimates and 95% credible intervals of all estimates parameters for the Auckland Islands Hookworm run MCMC, using the 15+ model configuration.

Parameter	Year	Estimate	95% credible interval	Parameter	Year	Estimate	95% credible interval
N_{1990}	N/A	1 776	1 617 – 2 012	Mat_{4}	All	0.19	0.16 – 0.22
				Mat_{5}	All	0.48	0.42 – 0.53
$Surv_{0}$	1990–1993	0.92	0.8 – 0.99	Mat_{6}	All	0.78	0.71 – 0.85
$Surv_{0}$	1994–2004	0.47	0.42 – 0.52	Mat_{7}	All	0.86	0.79 – 0.92
$Surv_{0}$	2005	0.35	0.26 – 0.44				
$Surv_{0}$	2006	0.38	0.29 – 0.48	Pr_{P}	1990–1997	0.73	0.65 – 0.8
$Surv_{0}$	2007	0.38	0.28 – 0.48	Pr_{P}	1998–2004	0.67	0.63 – 0.72
$Surv_{0}$	2009	0.63	0.5 – 0.78	Pr_{P}	2005	0.62	0.58 – 0.67
$Surv_{0}$	2010	0.45	0.35 – 0.55	Pr_{P}	2006	0.70	0.64 – 0.74
$Surv_{0}$	2011	0.50	0.39 – 0.61	Pr_{P}	2007	0.77	0.72 – 0.83
$Surv_{0}$	2012	0.51	0.37 – 0.68	Pr_{P}	2008	0.56	0.52 – 0.61
$Surv_{0}$	2013	0.40	0.22 – 0.69	Pr_{P}	2009	0.71	0.66 – 0.76
$Surv_{0}$	2014	0.48	0.2 – 0.88	Pr_{P}	2010	0.65	0.6 – 0.7
				Pr_{P}	2011	0.76	0.71 – 0.81
$Surv_{1}$	All	0.75	0.67 – 0.85	Pr_{P}	2012	0.84	0.79 – 0.89
$Surv_{2-5}$	All	0.91	0.9 – 0.93	Pr_{P}	2013	0.80	0.74 – 0.85
				Pr_{P}	2014	0.84	0.79 – 0.88
$Surv_{6-14}$	1990–1998	0.97	0.95 – 0.99				
$Surv_{6-14}$	1999–2004	0.91	0.89 – 0.92	Res_{1-2}	All	0.09	0.08 – 0.1
$Surv_{6-14}$	2005	0.90	0.83 – 0.95	Res_{3}	All	0.44	0.4 – 0.47
$Surv_{6-14}$	2006	0.90	0.84 – 0.96				
$Surv_{6-14}$	2007	0.83	0.75 – 0.89	Res_{N}	1999	0.33	0.21 – 0.49
$Surv_{6-14}$	2008	0.92	0.86 – 0.97	Res_{N}	2000–2001	0.45	0.34 – 0.6
$Surv_{6-14}$	2009	0.90	0.84 – 0.95	Res_{N}	2002–2012	0.65	0.61 – 0.68
$Surv_{6-14}$	2010	0.93	0.88 – 0.98	Res_{N}	2013	0.55	0.44 – 0.69
$Surv_{6-14}$	2011	0.85	0.79 – 0.91	Res_{N}	2014–2015	0.92	0.85 – 0.98
$Surv_{6-14}$	2012	0.92	0.86 – 0.97				
$Surv_{6-14}$	2013	0.85	0.78 – 0.91	Res_{Ptag}	1999	0.70	0.58 – 0.82
$Surv_{6-14}$	2014	0.86	0.79 – 0.93	Res_{Ptag}	2000–2001	0.90	0.81 – 0.99
				Res_{Ptag}	2002–2012	0.87	0.83 – 0.92
$Surv_{15+}$	All	0.78	0.75 – 0.81	Res_{Ptag}	2013	0.46	0.36 – 0.57
				Res_{Ptag}	2014–2015	0.84	0.77 – 0.91
Pr_{T10}	All	0.0884	0.0694 – 0.1078				
Pr_{T1a}	All	0.0420	0.0358 – 0.0464	Res_{Pchip}	2002–2012	0.76	0.72 – 0.81
Pr_{T1b}	All	0.0048	0.0002 – 0.0155	Res_{Pchip}	2013	0.42	0.32 – 0.54
Pr_{T2}	All	0.0323	0.0276 – 0.0372	Res_{Pchip}	2014–2015	0.87	0.8 – 0.93

Table 25: Median estimates and 95% credible intervals of all estimates parameters for the Auckland Islands *Klebsiella* run MCMC, using the 15+ model configuration.

Parameter	Year	Estimate	95% credible interval	Parameter	Year	Estimate	95% credible interval
N_{1990}	N/A	1 800	1 645 – 2 026	Mat_{4}	All	0.17	0.14 – 0.21
				Mat_{5}	All	0.46	0.41 – 0.51
$Surv_{0}$	1990–1993	0.97	0.91 – 0.99	Mat_{6}	All	0.77	0.7 – 0.84
$Surv_{0}$	1994–2004	0.57	0.53 – 0.62	Mat_{7}	All	0.85	0.78 – 0.92
$Surv_{0}$	2005	0.52	0.42 – 0.62				
$Surv_{0}$	2006	0.73	0.61 – 0.87	Pr_{P}	1990–1997	0.72	0.65 – 0.79
$Surv_{0}$	2007	0.72	0.61 – 0.86	Pr_{P}	1998–2004	0.67	0.62 – 0.71
$Surv_{0}$	2009	0.92	0.79 – 0.99	Pr_{P}	2005	0.60	0.55 – 0.65
$Surv_{0}$	2010	0.92	0.81 – 0.99	Pr_{P}	2006	0.67	0.63 – 0.73
$Surv_{0}$	2011	0.65	0.54 – 0.8	Pr_{P}	2007	0.77	0.71 – 0.82
$Surv_{0}$	2012	0.78	0.6 – 0.96	Pr_{P}	2008	0.57	0.52 – 0.61
$Surv_{0}$	2013	0.72	0.46 – 0.96	Pr_{P}	2009	0.71	0.66 – 0.76
$Surv_{0}$	2014	0.74	0.44 – 0.97	Pr_{P}	2010	0.66	0.61 – 0.71
				Pr_{P}	2011	0.77	0.72 – 0.82
$Surv_{1}$	All	0.70	0.64 – 0.77	Pr_{P}	2012	0.85	0.79 – 0.89
$Surv_{2\text{-}5}$	All	0.91	0.9 – 0.93	Pr_{P}	2013	0.80	0.75 – 0.85
				Pr_{P}	2014	0.84	0.8 – 0.88
$Surv_{6\text{-}14}$	1990–1998	0.98	0.95 – 0.99				
$Surv_{6\text{-}14}$	1999–2004	0.90	0.89 – 0.92	$Res_{1\text{-}2}$	All	0.09	0.08 – 0.1
$Surv_{6\text{-}14}$	2005	0.89	0.83 – 0.95	Res_{3}	All	0.44	0.41 – 0.48
$Surv_{6\text{-}14}$	2006	0.90	0.83 – 0.96				
$Surv_{6\text{-}14}$	2007	0.82	0.76 – 0.89	Res_{N}	1999	0.32	0.21 – 0.47
$Surv_{6\text{-}14}$	2008	0.93	0.86 – 0.97	Res_{N}	2000–2001	0.45	0.34 – 0.59
$Surv_{6\text{-}14}$	2009	0.91	0.85 – 0.96	Res_{N}	2002–2012	0.64	0.61 – 0.68
$Surv_{6\text{-}14}$	2010	0.93	0.88 – 0.98	Res_{N}	2013	0.56	0.44 – 0.69
$Surv_{6\text{-}14}$	2011	0.86	0.8 – 0.91	Res_{N}	2014–2015	0.92	0.84 – 0.98
$Surv_{6\text{-}14}$	2012	0.92	0.86 – 0.97				
$Surv_{6\text{-}14}$	2013	0.85	0.78 – 0.92	Res_{Ptag}	1999	0.71	0.58 – 0.83
$Surv_{6\text{-}14}$	2014	0.86	0.79 – 0.93	Res_{Ptag}	2000–2001	0.91	0.81 – 0.99
				Res_{Ptag}	2002–2012	0.88	0.84 – 0.93
$Surv_{15+}$	All	0.78	0.75 – 0.81	Res_{Ptag}	2013	0.46	0.36 – 0.57
				Res_{Ptag}	2014–2015	0.84	0.77 – 0.91
Pr_{T10}	All	0.0892	0.0701 – 0.1087				
Pr_{T1a}	All	0.0423	0.0359 – 0.0465	Res_{Pchip}	2002–2012	0.77	0.73 – 0.82
Pr_{T1b}	All	0.0046	0.0002 – 0.0154	Res_{Pchip}	2013	0.42	0.32 – 0.53
Pr_{T2}	All	0.0318	0.0271 – 0.0366	Res_{Pchip}	2014–2015	0.87	0.8 – 0.93

Table 26: Median estimates and 95% credible intervals of all estimates parameters for the Auckland Islands Wallow run MCMC, using the 15+ model configuration.

Parameter	Year	Estimate	95% credible interval	Parameter	Year	Estimate	95% credible interval
N_{1990}	N/A	1 759	1 592 – 1 993	Mat_{4}	All	0.19	0.16 – 0.23
				Mat_{5}	All	0.49	0.44 – 0.55
$Surv_{0}$	1990–1993	0.91	0.8 – 0.99	Mat_{6}	All	0.79	0.72 – 0.86
$Surv_{0}$	1994–2004	0.43	0.39 – 0.48	Mat_{7}	All	0.86	0.79 – 0.93
$Surv_{0}$	2005	0.29	0.22 – 0.38				
$Surv_{0}$	2006	0.34	0.26 – 0.43	Pr_{P}	1990–1997	0.75	0.67 – 0.82
$Surv_{0}$	2007	0.33	0.25 – 0.43	Pr_{P}	1998–2004	0.69	0.65 – 0.74
$Surv_{0}$	2009	0.59	0.47 – 0.74	Pr_{P}	2005	0.63	0.59 – 0.69
$Surv_{0}$	2010	0.46	0.36 – 0.57	Pr_{P}	2006	0.70	0.65 – 0.75
$Surv_{0}$	2011	0.50	0.4 – 0.62	Pr_{P}	2007	0.78	0.72 – 0.83
$Surv_{0}$	2012	0.48	0.35 – 0.64	Pr_{P}	2008	0.56	0.52 – 0.61
$Surv_{0}$	2013	0.38	0.2 – 0.65	Pr_{P}	2009	0.71	0.66 – 0.76
$Surv_{0}$	2014	0.51	0.23 – 0.9	Pr_{P}	2010	0.65	0.6 – 0.69
				Pr_{P}	2011	0.76	0.71 – 0.81
$Surv_{1}$	All	0.77	0.69 – 0.86	Pr_{P}	2012	0.84	0.78 – 0.88
$Surv_{2\text{-}5}$	All	0.92	0.9 – 0.93	Pr_{P}	2013	0.79	0.74 – 0.84
				Pr_{P}	2014	0.83	0.78 – 0.87
$Surv_{6\text{-}14}$	1990–1998	0.97	0.95 – 0.99				
$Surv_{6\text{-}14}$	1999–2004	0.91	0.89 – 0.93	$Res_{1\text{-}2}$	All	0.09	0.08 – 0.1
$Surv_{6\text{-}14}$	2005	0.89	0.83 – 0.96	Res_{3}	All	0.44	0.4 – 0.48
$Surv_{6\text{-}14}$	2006	0.91	0.84 – 0.97				
$Surv_{6\text{-}14}$	2007	0.82	0.75 – 0.89	Res_{N}	1999	0.35	0.22 – 0.53
$Surv_{6\text{-}14}$	2008	0.92	0.85 – 0.97	Res_{N}	2000–2001	0.48	0.36 – 0.63
$Surv_{6\text{-}14}$	2009	0.90	0.84 – 0.95	Res_{N}	2002–2012	0.66	0.62 – 0.69
$Surv_{6\text{-}14}$	2010	0.93	0.88 – 0.97	Res_{N}	2013	0.56	0.44 – 0.68
$Surv_{6\text{-}14}$	2011	0.85	0.8 – 0.9	Res_{N}	2014–2015	0.92	0.83 – 0.98
$Surv_{6\text{-}14}$	2012	0.92	0.86 – 0.97				
$Surv_{6\text{-}14}$	2013	0.85	0.78 – 0.91	Res_{Ptag}	1999	0.67	0.55 – 0.81
$Surv_{6\text{-}14}$	2014	0.86	0.78 – 0.93	Res_{Ptag}	2000–2001	0.88	0.79 – 0.97
				Res_{Ptag}	2002–2012	0.86	0.82 – 0.91
$Surv_{15+}$	All	0.79	0.76 – 0.81	Res_{Ptag}	2013	0.46	0.36 – 0.56
				Res_{Ptag}	2014–2015	0.85	0.78 – 0.91
Pr_{T10}	All	0.0881	0.0684 – 0.1066				
Pr_{T1a}	All	0.0420	0.0357 – 0.0464	Res_{Pchip}	2002–2012	0.75	0.71 – 0.8
Pr_{T1b}	All	0.0047	0.0002 – 0.0154	Res_{Pchip}	2013	0.43	0.32 – 0.54
Pr_{T2}	All	0.0326	0.028 – 0.0374	Res_{Pchip}	2014–2015	0.87	0.8 – 0.93

Table 27: Median estimates and 95% credible intervals of all estimates parameters for the Auckland Islands Trawl-captures run MCMC, using the 15+ model configuration.

Parameter	Year	Estimate	95% credible interval	Parameter	Year	Estimate	95% credible interval
N_{1990}	N/A	1 805	1 668 – 2 004	Mat_{4}	All	0.19	0.16 – 0.23
				Mat_{5}	All	0.49	0.44 – 0.55
$Surv_{0}$	1990–1993	0.89	0.77 – 0.98	Mat_{6}	All	0.79	0.72 – 0.86
$Surv_{0}$	1994–2004	0.41	0.36 – 0.46	Mat_{7}	All	0.86	0.79 – 0.93
$Surv_{0}$	2005	0.27	0.2 – 0.36				
$Surv_{0}$	2006	0.32	0.24 – 0.41	Pr_{P}	1990–1997	0.74	0.67 – 0.81
$Surv_{0}$	2007	0.31	0.23 – 0.41	Pr_{P}	1998–2004	0.69	0.65 – 0.74
$Surv_{0}$	2009	0.57	0.44 – 0.7	Pr_{P}	2005	0.64	0.59 – 0.69
$Surv_{0}$	2010	0.44	0.34 – 0.55	Pr_{P}	2006	0.70	0.65 – 0.75
$Surv_{0}$	2011	0.47	0.37 – 0.59	Pr_{P}	2007	0.78	0.72 – 0.83
$Surv_{0}$	2012	0.45	0.32 – 0.61	Pr_{P}	2008	0.56	0.52 – 0.61
$Surv_{0}$	2013	0.36	0.18 – 0.6	Pr_{P}	2009	0.71	0.66 – 0.76
$Surv_{0}$	2014	0.44	0.2 – 0.85	Pr_{P}	2010	0.65	0.6 – 0.7
				Pr_{P}	2011	0.76	0.71 – 0.82
$Surv_{1}$	All	0.77	0.68 – 0.86	Pr_{P}	2012	0.84	0.78 – 0.88
$Surv_{2\text{-}5}$	All	0.92	0.9 – 0.94	Pr_{P}	2013	0.79	0.73 – 0.83
				Pr_{P}	2014	0.83	0.78 – 0.87
$Surv_{6\text{-}14}$	1990–1998	0.98	0.96 – 0.99				
$Surv_{6\text{-}14}$	1999–2004	0.92	0.9 – 0.93	$Res_{1\text{-}2}$	All	0.09	0.08 – 0.11
$Surv_{6\text{-}14}$	2005	0.90	0.84 – 0.96	Res_{3}	All	0.44	0.4 – 0.47
$Surv_{6\text{-}14}$	2006	0.91	0.84 – 0.97				
$Surv_{6\text{-}14}$	2007	0.83	0.76 – 0.89	Res_{N}	1999	0.35	0.23 – 0.52
$Surv_{6\text{-}14}$	2008	0.92	0.86 – 0.97	Res_{N}	2000–2001	0.48	0.36 – 0.63
$Surv_{6\text{-}14}$	2009	0.90	0.84 – 0.95	Res_{N}	2002–2012	0.66	0.62 – 0.69
$Surv_{6\text{-}14}$	2010	0.93	0.88 – 0.98	Res_{N}	2013	0.56	0.44 – 0.69
$Surv_{6\text{-}14}$	2011	0.85	0.79 – 0.9	Res_{N}	2014–2015	0.92	0.83 – 0.97
$Surv_{6\text{-}14}$	2012	0.92	0.85 – 0.97				
$Surv_{6\text{-}14}$	2013	0.85	0.78 – 0.91	Res_{Ptag}	1999	0.68	0.56 – 0.8
$Surv_{6\text{-}14}$	2014	0.85	0.78 – 0.92	Res_{Ptag}	2000–2001	0.88	0.79 – 0.97
				Res_{Ptag}	2002–2012	0.86	0.82 – 0.91
$Surv_{15+}$	All	0.79	0.76 – 0.82	Res_{Ptag}	2013	0.46	0.36 – 0.57
				Res_{Ptag}	2014–2015	0.85	0.77 – 0.92
Pr_{T10}	All	0.0882	0.0686 – 0.1075				
Pr_{T1a}	All	0.0420	0.0357 – 0.0463	Res_{Pchip}	2002–2012	0.75	0.71 – 0.8
Pr_{T1b}	All	0.0047	0.0002 – 0.0152	Res_{Pchip}	2013	0.43	0.32 – 0.53
Pr_{T2}	All	0.0326	0.0279 – 0.0374	Res_{Pchip}	2014–2015	0.87	0.8 – 0.94

Table 28: Median estimates and 95% credible intervals of all estimates parameters for the Auckland Islands Trawl-82%discount run MCMC, using the 15+ model configuration.

Parameter	Year	Estimate	95% credible interval	Parameter	Year	Estimate	95% credible interval
N_{1990}	N/A	1 769	1 615 – 1 982	Mat_{4}	All	0.19	0.16 – 0.23
				Mat_{5}	All	0.49	0.44 – 0.55
$Surv_{0}$	1990–1993	0.86	0.74 – 0.98	Mat_{6}	All	0.79	0.72 – 0.86
$Surv_{0}$	1994–2004	0.41	0.36 – 0.46	Mat_{7}	All	0.86	0.79 – 0.94
$Surv_{0}$	2005	0.28	0.2 – 0.36				
$Surv_{0}$	2006	0.32	0.24 – 0.42	Pr_{P}	1990–1997	0.75	0.68 – 0.82
$Surv_{0}$	2007	0.32	0.24 – 0.41	Pr_{P}	1998–2004	0.69	0.65 – 0.73
$Surv_{0}$	2009	0.58	0.45 – 0.73	Pr_{P}	2005	0.63	0.59 – 0.69
$Surv_{0}$	2010	0.44	0.34 – 0.55	Pr_{P}	2006	0.70	0.65 – 0.75
$Surv_{0}$	2011	0.48	0.38 – 0.6	Pr_{P}	2007	0.78	0.72 – 0.83
$Surv_{0}$	2012	0.46	0.32 – 0.62	Pr_{P}	2008	0.57	0.52 – 0.61
$Surv_{0}$	2013	0.36	0.18 – 0.67	Pr_{P}	2009	0.71	0.66 – 0.76
$Surv_{0}$	2014	0.44	0.19 – 0.84	Pr_{P}	2010	0.65	0.6 – 0.7
				Pr_{P}	2011	0.77	0.72 – 0.82
$Surv_{1}$	All	0.76	0.68 – 0.86	Pr_{P}	2012	0.84	0.79 – 0.89
$Surv_{2\text{-}5}$	All	0.92	0.9 – 0.94	Pr_{P}	2013	0.79	0.74 – 0.84
				Pr_{P}	2014	0.83	0.78 – 0.88
$Surv_{6\text{-}14}$	1990–1998	0.98	0.95 – 0.99				
$Surv_{6\text{-}14}$	1999–2004	0.91	0.89 – 0.93	$Res_{1\text{-}2}$	All	0.09	0.08 – 0.11
$Surv_{6\text{-}14}$	2005	0.90	0.84 – 0.96	Res_{3}	All	0.44	0.4 – 0.48
$Surv_{6\text{-}14}$	2006	0.91	0.84 – 0.97				
$Surv_{6\text{-}14}$	2007	0.82	0.76 – 0.89	Res_{N}	1999	0.34	0.21 – 0.51
$Surv_{6\text{-}14}$	2008	0.92	0.86 – 0.97	Res_{N}	2000–2001	0.48	0.35 – 0.63
$Surv_{6\text{-}14}$	2009	0.91	0.85 – 0.96	Res_{N}	2002–2012	0.66	0.62 – 0.69
$Surv_{6\text{-}14}$	2010	0.94	0.88 – 0.98	Res_{N}	2013	0.56	0.44 – 0.69
$Surv_{6\text{-}14}$	2011	0.85	0.8 – 0.91	Res_{N}	2014–2015	0.92	0.84 – 0.98
$Surv_{6\text{-}14}$	2012	0.92	0.86 – 0.97				
$Surv_{6\text{-}14}$	2013	0.85	0.78 – 0.92	Res_{Ptag}	1999	0.68	0.56 – 0.81
$Surv_{6\text{-}14}$	2014	0.86	0.78 – 0.93	Res_{Ptag}	2000–2001	0.88	0.79 – 0.98
				Res_{Ptag}	2002–2012	0.86	0.82 – 0.91
$Surv_{15+}$	All	0.79	0.76 – 0.81	Res_{Ptag}	2013	0.46	0.36 – 0.56
				Res_{Ptag}	2014–2015	0.84	0.77 – 0.91
Pr_{T10}	All	0.0887	0.069 – 0.1072				
Pr_{T1a}	All	0.0420	0.0357 – 0.0464	Res_{Pchip}	2002–2012	0.75	0.71 – 0.8
Pr_{T1b}	All	0.0048	0.0002 – 0.0154	Res_{Pchip}	2013	0.42	0.32 – 0.54
Pr_{T2}	All	0.0325	0.0279 – 0.0373	Res_{Pchip}	2014–2015	0.87	0.8 – 0.93

Table 29: Median estimates and 95% credible intervals of all estimates parameters for the Auckland Islands Trawl-35% discount run MCMC, using the 15+ model configuration.

Parameter	Year	Estimate	95% credible interval	Parameter	Year	Estimate	95% credible interval
N_{1990}	N/A	1 761	1 605 – 1995	Mat_4	All	0.19	0.16 – 0.23
				Mat_5	All	0.49	0.44 – 0.55
$Surv_0$	1990–1993	0.85	0.73 – 0.97	Mat_6	All	0.79	0.72 – 0.86
$Surv_0$	1994–2004	0.41	0.36 – 0.47	Mat_7	All	0.86	0.79 – 0.93
$Surv_0$	2005	0.29	0.21 – 0.38				
$Surv_0$	2006	0.33	0.25 – 0.44	Pr_P	1990–1997	0.75	0.68 – 0.82
$Surv_0$	2007	0.32	0.24 – 0.43	Pr_P	1998–2004	0.69	0.65 – 0.73
$Surv_0$	2009	0.59	0.46 – 0.73	Pr_P	2005	0.64	0.59 – 0.68
$Surv_0$	2010	0.45	0.35 – 0.57	Pr_P	2006	0.70	0.66 – 0.76
$Surv_0$	2011	0.49	0.38 – 0.61	Pr_P	2007	0.78	0.72 – 0.83
$Surv_0$	2012	0.48	0.34 – 0.64	Pr_P	2008	0.57	0.52 – 0.61
$Surv_0$	2013	0.37	0.18 – 0.66	Pr_P	2009	0.71	0.66 – 0.76
$Surv_0$	2014	0.46	0.2 – 0.86	Pr_P	2010	0.65	0.61 – 0.7
				Pr_P	2011	0.77	0.72 – 0.82
$Surv_1$	All	0.75	0.66 – 0.85	Pr_P	2012	0.84	0.79 – 0.89
$Surv_{2\text{-}5}$	All	0.93	0.91 – 0.94	Pr_P	2013	0.79	0.74 – 0.84
				Pr_P	2014	0.83	0.78 – 0.87
$Surv_{6\text{-}14}$	1990–1998	0.98	0.95 – 0.99				
$Surv_{6\text{-}14}$	1999–2004	0.91	0.89 – 0.93	$Res_{1\text{-}2}$	All	0.09	0.08 – 0.1
$Surv_{6\text{-}14}$	2005	0.92	0.86 – 0.97	Res_3	All	0.44	0.4 – 0.47
$Surv_{6\text{-}14}$	2006	0.92	0.85 – 0.98				
$Surv_{6\text{-}14}$	2007	0.84	0.77 – 0.9	Res_N	1999	0.35	0.22 – 0.51
$Surv_{6\text{-}14}$	2008	0.93	0.86 – 0.98	Res_N	2000–2001	0.47	0.35 – 0.63
$Surv_{6\text{-}14}$	2009	0.92	0.86 – 0.97	Res_N	2002–2012	0.66	0.62 – 0.69
$Surv_{6\text{-}14}$	2010	0.95	0.89 – 0.98	Res_N	2013	0.55	0.43 – 0.68
$Surv_{6\text{-}14}$	2011	0.86	0.8 – 0.92	Res_N	2014–2015	0.92	0.84 – 0.98
$Surv_{6\text{-}14}$	2012	0.93	0.86 – 0.98				
$Surv_{6\text{-}14}$	2013	0.86	0.79 – 0.92	Res_{Ptag}	1999	0.68	0.57 – 0.8
$Surv_{6\text{-}14}$	2014	0.86	0.79 – 0.94	Res_{Ptag}	2000–2001	0.89	0.79 – 0.97
				Res_{Ptag}	2002–2012	0.86	0.82 – 0.91
$Surv_{15+}$	All	0.79	0.76 – 0.82	Res_{Ptag}	2013	0.46	0.36 – 0.57
				Res_{Ptag}	2014–2015	0.84	0.76 – 0.91
Pr_{T10}	All	0.0891	0.0681 – 0.1082				
Pr_{T1a}	All	0.0419	0.0357 – 0.0462	Res_{Pchip}	2002–2012	0.75	0.71 – 0.8
Pr_{T1b}	All	0.0048	0.0002 – 0.0154	Res_{Pchip}	2013	0.43	0.32 – 0.55
Pr_{T2}	All	0.0325	0.0279 – 0.0373	Res_{Pchip}	2014–2015	0.87	0.8 – 0.93

Table 30: Median estimates and 95% credible intervals of all estimates parameters for the Auckland Islands Trawl-20%discount run MCMC, using the 15+ model configuration.

Parameter	Year	Estimate	95% credible interval	Parameter	Year	Estimate	95% credible interval
N_{1990}	N/A	1 766	1 617 – 1 978	Mat_{4}	All	0.19	0.16 – 0.23
				Mat_{5}	All	0.49	0.44 – 0.55
$Surv_{0}$	1990–1993	0.85	0.73 – 0.96	Mat_{6}	All	0.79	0.72 – 0.86
$Surv_{0}$	1994–2004	0.41	0.36 – 0.46	Mat_{7}	All	0.87	0.79 – 0.94
$Surv_{0}$	2005	0.28	0.21 – 0.37				
$Surv_{0}$	2006	0.33	0.25 – 0.44	Pr_{P}	1990–1997	0.74	0.68 – 0.82
$Surv_{0}$	2007	0.32	0.24 – 0.42	Pr_{P}	1998–2004	0.68	0.64 – 0.73
$Surv_{0}$	2009	0.59	0.46 – 0.73	Pr_{P}	2005	0.63	0.58 – 0.68
$Surv_{0}$	2010	0.46	0.36 – 0.57	Pr_{P}	2006	0.70	0.65 – 0.75
$Surv_{0}$	2011	0.49	0.38 – 0.6	Pr_{P}	2007	0.78	0.73 – 0.83
$Surv_{0}$	2012	0.46	0.33 – 0.63	Pr_{P}	2008	0.57	0.52 – 0.61
$Surv_{0}$	2013	0.36	0.17 – 0.64	Pr_{P}	2009	0.71	0.66 – 0.76
$Surv_{0}$	2014	0.46	0.19 – 0.86	Pr_{P}	2010	0.65	0.61 – 0.7
				Pr_{P}	2011	0.77	0.71 – 0.82
$Surv_{1}$	All	0.76	0.67 – 0.85	Pr_{P}	2012	0.84	0.79 – 0.89
$Surv_{2\text{-}5}$	All	0.93	0.91 – 0.94	Pr_{P}	2013	0.79	0.74 – 0.84
				Pr_{P}	2014	0.83	0.78 – 0.87
$Surv_{6\text{-}14}$	1990–1998	0.98	0.95 – 0.99				
$Surv_{6\text{-}14}$	1999–2004	0.91	0.89 – 0.93	$Res_{1\text{-}2}$	All	0.09	0.08 – 0.11
$Surv_{6\text{-}14}$	2005	0.92	0.86 – 0.97	Res_{3}	All	0.44	0.4 – 0.47
$Surv_{6\text{-}14}$	2006	0.92	0.85 – 0.98				
$Surv_{6\text{-}14}$	2007	0.84	0.77 – 0.9	Res_{N}	1999	0.34	0.22 – 0.49
$Surv_{6\text{-}14}$	2008	0.94	0.87 – 0.98	Res_{N}	2000–2001	0.47	0.35 – 0.62
$Surv_{6\text{-}14}$	2009	0.92	0.86 – 0.97	Res_{N}	2002–2012	0.66	0.62 – 0.69
$Surv_{6\text{-}14}$	2010	0.95	0.89 – 0.99	Res_{N}	2013	0.56	0.43 – 0.69
$Surv_{6\text{-}14}$	2011	0.86	0.8 – 0.92	Res_{N}	2014–2015	0.92	0.84 – 0.98
$Surv_{6\text{-}14}$	2012	0.93	0.86 – 0.98				
$Surv_{6\text{-}14}$	2013	0.86	0.79 – 0.92	Res_{Ptag}	1999	0.68	0.57 – 0.8
$Surv_{6\text{-}14}$	2014	0.86	0.78 – 0.93	Res_{Ptag}	2000–2001	0.89	0.8 – 0.98
				Res_{Ptag}	2002–2012	0.86	0.82 – 0.91
$Surv_{15+}$	All	0.79	0.76 – 0.82	Res_{Ptag}	2013	0.46	0.36 – 0.56
				Res_{Ptag}	2014–2015	0.85	0.77 – 0.91
Pr_{T10}	All	0.0881	0.0685 – 0.1077				
Pr_{T1a}	All	0.0419	0.0355 – 0.0463	Res_{Pchip}	2002–2012	0.76	0.71 – 0.8
Pr_{T1b}	All	0.0049	0.0002 – 0.0157	Res_{Pchip}	2013	0.43	0.32 – 0.54
Pr_{T2}	All	0.0325	0.0278 – 0.0373	Res_{Pchip}	2014–2015	0.87	0.8 – 0.93

Table 31: Median estimates and 95% credible intervals of all estimates parameters for the Auckland Islands Trawl-interactions run MCMC, using the 15+ model configuration.

Parameter	Year	Estimate	95% credible interval	Parameter	Year	Estimate	95% credible interval
N_{1990}	N/A	1 788	1 657 – 1 989	Mat_4	All	0.19	0.16 – 0.23
				Mat_5	All	0.49	0.44 – 0.55
$Surv_0$	1990–1993	0.87	0.76 – 0.98	Mat_6	All	0.79	0.72 – 0.85
$Surv_0$	1994–2004	0.41	0.36 – 0.46	Mat_7	All	0.86	0.79 – 0.93
$Surv_0$	2005	0.29	0.21 – 0.38				
$Surv_0$	2006	0.34	0.25 – 0.43	Pr_{P}	1990–1997	0.74	0.67 – 0.81
$Surv_0$	2007	0.32	0.24 – 0.42	Pr_{P}	1998–2004	0.69	0.64 – 0.73
$Surv_0$	2009	0.59	0.46 – 0.72	Pr_{P}	2005	0.63	0.59 – 0.69
$Surv_0$	2010	0.45	0.35 – 0.57	Pr_{P}	2006	0.70	0.65 – 0.76
$Surv_0$	2011	0.49	0.38 – 0.6	Pr_{P}	2007	0.78	0.72 – 0.83
$Surv_0$	2012	0.46	0.34 – 0.63	Pr_{P}	2008	0.57	0.53 – 0.61
$Surv_0$	2013	0.37	0.18 – 0.63	Pr_{P}	2009	0.71	0.66 – 0.76
$Surv_0$	2014	0.46	0.19 – 0.86	Pr_{P}	2010	0.65	0.61 – 0.7
				Pr_{P}	2011	0.76	0.71 – 0.82
$Surv_1$	All	0.76	0.67 – 0.85	Pr_{P}	2012	0.84	0.79 – 0.89
$Surv_{2\text{-}5}$	All	0.93	0.91 – 0.95	Pr_{P}	2013	0.79	0.74 – 0.84
				Pr_{P}	2014	0.83	0.78 – 0.88
$Surv_{6\text{-}14}$	1990–1998	0.98	0.96 – 0.99				
$Surv_{6\text{-}14}$	1999–2004	0.92	0.9 – 0.93	$Res_{1\text{-}2}$	All	0.09	0.08 – 0.11
$Surv_{6\text{-}14}$	2005	0.92	0.86 – 0.98	Res_3	All	0.44	0.4 – 0.47
$Surv_{6\text{-}14}$	2006	0.92	0.86 – 0.98				
$Surv_{6\text{-}14}$	2007	0.84	0.77 – 0.9	Res_{N}	1999	0.35	0.22 – 0.5
$Surv_{6\text{-}14}$	2008	0.94	0.87 – 0.98	Res_{N}	2000–2001	0.47	0.35 – 0.63
$Surv_{6\text{-}14}$	2009	0.92	0.86 – 0.97	Res_{N}	2002–2012	0.65	0.62 – 0.69
$Surv_{6\text{-}14}$	2010	0.95	0.9 – 0.99	Res_{N}	2013	0.55	0.44 – 0.68
$Surv_{6\text{-}14}$	2011	0.87	0.81 – 0.92	Res_{N}	2014–2015	0.92	0.84 – 0.98
$Surv_{6\text{-}14}$	2012	0.93	0.86 – 0.98				
$Surv_{6\text{-}14}$	2013	0.86	0.79 – 0.92	Res_{Ptag}	1999	0.68	0.56 – 0.81
$Surv_{6\text{-}14}$	2014	0.86	0.78 – 0.93	Res_{Ptag}	2000–2001	0.88	0.79 – 0.98
				Res_{Ptag}	2002–2012	0.86	0.82 – 0.91
$Surv_{15+}$	All	0.80	0.77 – 0.82	Res_{Ptag}	2013	0.46	0.36 – 0.57
				Res_{Ptag}	2014–2015	0.84	0.77 – 0.91
Pr_{T10}	All	0.0888	0.0697 – 0.1083				
Pr_{T1a}	All	0.0419	0.0357 – 0.0462	Res_{Pchip}	2002–2012	0.76	0.71 – 0.8
Pr_{T1b}	All	0.0047	0.0002 – 0.0152	Res_{Pchip}	2013	0.43	0.33 – 0.54
Pr_{T2}	All	0.0325	0.0279 – 0.0374	Res_{Pchip}	2014–2015	0.87	0.79 – 0.93

Table 32: Median estimates and 95% credible intervals of all estimates parameters for the Auckland Islands Base run MCMC, using the 8+ model configuration.

Parameter	Year	Estimate	95% credible interval	Parameter	Year	Estimate	95% credible interval
N_{1990}	N/A	1 613	1 421 – 1847	Mat_{4}	All	0.19	0.16 – 0.23
				Mat_{5}	All	0.50	0.44 – 0.55
$Surv_{0}$	1990–1993	0.89	0.75 – 0.98	Mat_{6}	All	0.79	0.73 – 0.86
$Surv_{0}$	1994–2004	0.41	0.36 – 0.46	Mat_{7}	All	0.89	0.81 – 0.97
$Surv_{0}$	2005	0.27	0.2 – 0.34				
$Surv_{0}$	2006	0.31	0.23 – 0.42	Pr_{P}	1990–1997	0.80	0.72 – 0.88
$Surv_{0}$	2007	0.30	0.22 – 0.4	Pr_{P}	1998–2004	0.70	0.66 – 0.74
$Surv_{0}$	2009	0.56	0.44 – 0.7	Pr_{P}	2005	0.62	0.57 – 0.68
$Surv_{0}$	2010	0.44	0.34 – 0.55	Pr_{P}	2006	0.69	0.63 – 0.74
$Surv_{0}$	2011	0.47	0.37 – 0.61	Pr_{P}	2007	0.77	0.71 – 0.83
$Surv_{0}$	2012	0.45	0.32 – 0.61	Pr_{P}	2008	0.58	0.53 – 0.63
$Surv_{0}$	2013	0.36	0.18 – 0.62	Pr_{P}	2009	0.72	0.66 – 0.77
$Surv_{0}$	2014	0.18	0.04 – 0.5	Pr_{P}	2010	0.64	0.59 – 0.7
				Pr_{P}	2011	0.76	0.71 – 0.82
$Surv_{1}$	All	0.76	0.68 – 0.86	Pr_{P}	2012	0.82	0.76 – 0.88
$Surv_{2-5}$	All	0.92	0.9 – 0.93	Pr_{P}	2013	0.78	0.72 – 0.83
				Pr_{P}	2014	0.82	0.76 – 0.87
$Surv_{6-14}$	1990–1998	0.96	0.93 – 0.98				
$Surv_{6-14}$	1999–2004	0.88	0.87 – 0.89	Res_{1-2}	All	0.09	0.08 – 0.11
$Surv_{6-14}$	2005	0.89	0.83 – 0.94	Res_{3}	All	0.44	0.4 – 0.48
$Surv_{6-14}$	2006	0.88	0.81 – 0.94				
$Surv_{6-14}$	2007	0.80	0.73 – 0.86	Res_{N}	1999	0.35	0.22 – 0.51
$Surv_{6-14}$	2008	0.82	0.75 – 0.89	Res_{N}	2000–2001	0.51	0.37 – 0.67
$Surv_{6-14}$	2009	0.88	0.82 – 0.94	Res_{N}	2002–2012	0.66	0.62 – 0.69
$Surv_{6-14}$	2010	0.91	0.85 – 0.97	Res_{N}	2013	0.55	0.43 – 0.68
$Surv_{6-14}$	2011	0.82	0.77 – 0.88	Res_{N}	2014–2015	0.91	0.83 – 0.98
$Surv_{6-14}$	2012	0.90	0.84 – 0.96				
$Surv_{6-14}$	2013	0.82	0.75 – 0.89	Res_{Ptag}	1999	0.66	0.54 – 0.78
$Surv_{6-14}$	2014	0.83	0.77 – 0.9	Res_{Ptag}	2000–2001	0.86	0.77 – 0.96
				Res_{Ptag}	2002–2012	0.86	0.82 – 0.91
$Surv_{15+}$	N/A	N/A	N/A	Res_{Ptag}	2013	0.46	0.36 – 0.57
				Res_{Ptag}	2014–2015	0.85	0.78 – 0.92
Pr_{T10}	All	0.0895	0.066 – 0.1105				
Pr_{T1a}	All	0.0357	0.0263 – 0.0425	Res_{Pchip}	2002–2012	0.75	0.7 – 0.8
Pr_{T1b}	All	0.0094	0.0006 – 0.024	Res_{Pchip}	2013	0.43	0.32 – 0.55
Pr_{T2}	All	0.0300	0.025 – 0.0351	Res_{Pchip}	2014–2015	0.88	0.81 – 0.94

APPENDIX 4 MCMC DIAGNOSTICS OTAGO PENINSULA BASE RUN MCMC

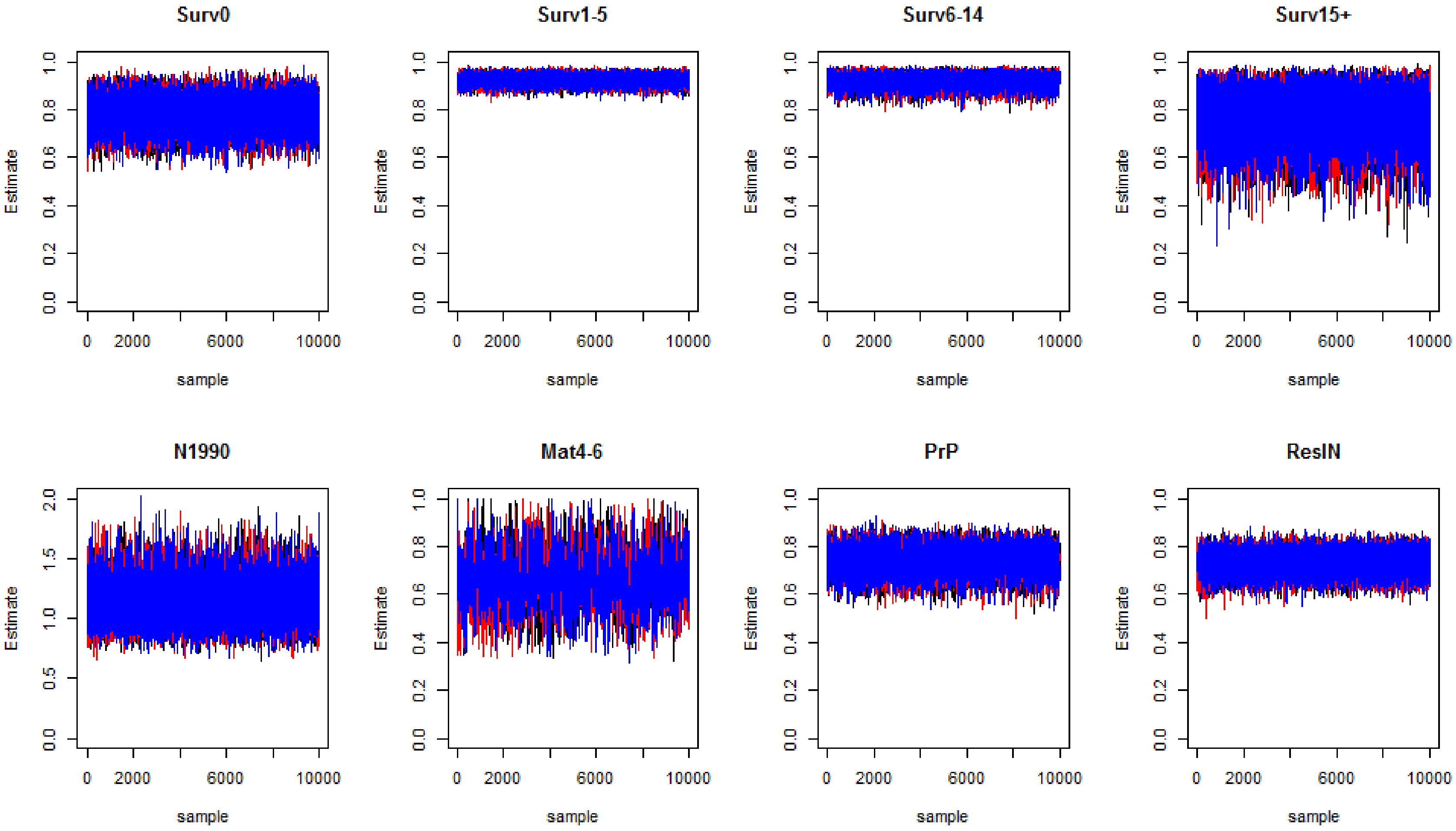


Figure 47: Trace plots for all estimated parameters from the Otago Peninsula Base run MCMC. A different colour trace is shown for each of 3 chains, comprising 10 000 samples taken at intervals of 100 iterations; a total of 1 000 000 iterations per chain and 3 million iterations for all chains.

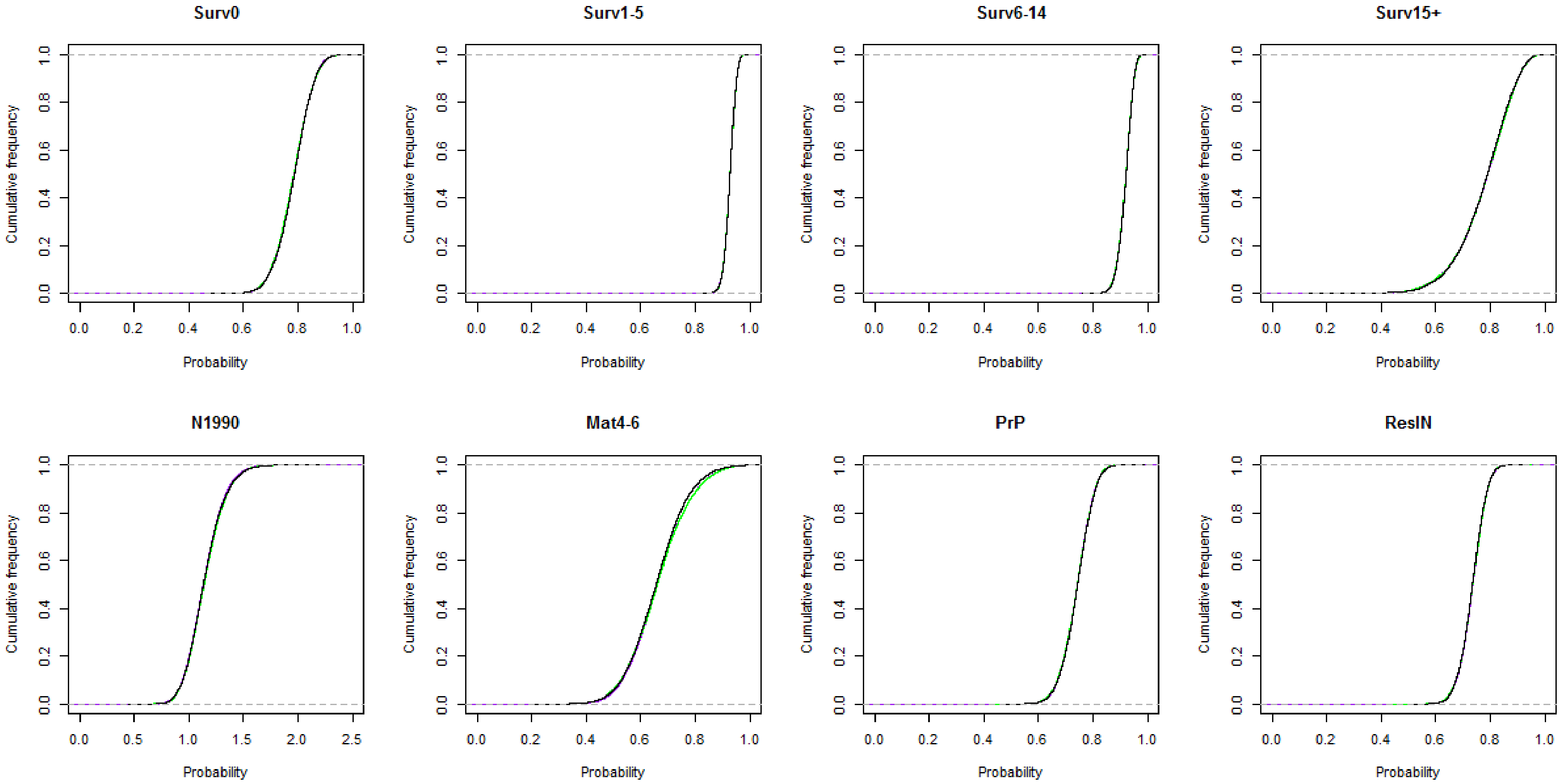


Figure 48: Cumulative frequency plots for all estimated parameters from the Otago Peninsula Base run MCMC. A different colour trace is shown for each of 3 chains, comprising 10 000 samples taken at intervals of 100 iterations; a total of 1 000 000 iterations per chain and 3 million iterations for all chains.

Table 33: **Pearson product-moment correlation coefficient between all estimates parameters for the Otago Peninsula Base run MCMC.**

	$Surv_{0}$	$Surv_{1-5}$	$Surv_{6-14}$	$Surv_{15+}$	Mat_{4-6}	Pr_{P}	Res_{IN}
N_{0}	-0.18	-0.30	-0.13	-0.10	0.03	-0.14	0.02
$Surv_{0}$		-0.28	-0.24	-0.13	-0.02	-0.10	-0.18
$Surv_{1-5}$			-0.38	-0.17	-0.04	-0.14	0.01
$Surv_{6-14}$				-0.07	-0.03	-0.15	0.06
$Surv_{15+}$					-0.05	-0.06	0.02
Mat_{4-6}						-0.49	0.03
Pr_{P}							0.06

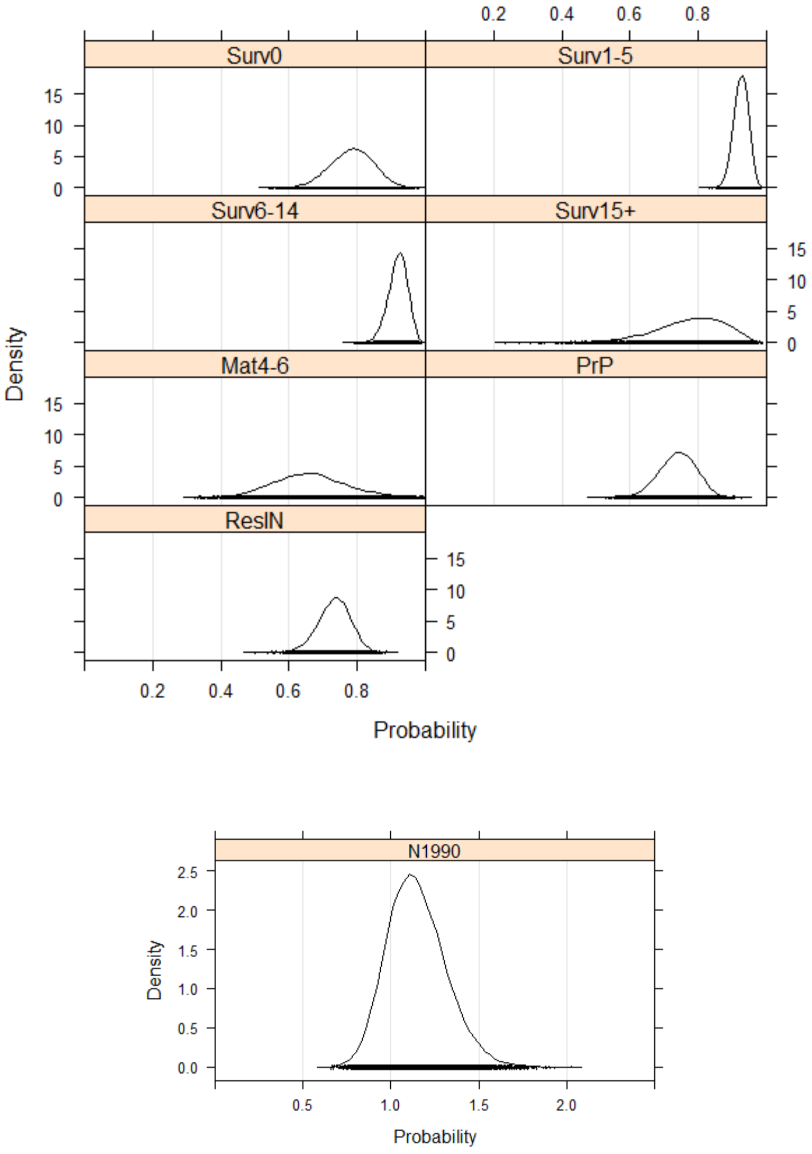


Figure 49: **Posterior densities for all estimated parameters from the Otago Peninsula Base run MCMC. All 30 000 samples from all 3 chains; 3 million iterations.**

APPENDIX 5 PARAMETER ESTIMATES OTAGO PENINSULA MCMC

Table 34: Median estimates and 95% credible intervals of all estimates parameters for the Otago Peninsula Base run MCMC.

Parameter	Estimate	95% credible interval
N_{1990}	1.13	0.86 – 1.51
$Surv_{0}$	0.79	0.66 – 0.90
$Surv_{1\text{-}5}$	0.93	0.88 – 0.96
$Surv_{6\text{-}14}$	0.92	0.86 – 0.96
$Surv_{15+}$	0.79	0.54 – 0.94
$Mat_{4\text{-}6}$	0.66	0.47 – 0.88
Pr_{P}	0.74	0.63 – 0.84
Res_{IN}	0.73	0.64 – 0.82

Table 35: Median estimates and 95% credible intervals of all estimates parameters for the Otago Peninsula Aggression run MCMC.

Parameter	Estimate	95% credible interval
N_{1990}	0.98	0.74 – 1.3
$Surv_{0}$	0.82	0.7 – 0.93
$Surv_{1\text{-}5}$	0.94	0.9 – 0.97
$Surv_{6\text{-}14}$	0.93	0.87 – 0.97
$Surv_{15+}$	0.79	0.54 – 0.94
$Mat_{4\text{-}6}$	0.68	0.48 – 0.91
Pr_{P}	0.73	0.62 – 0.83
Res_{IN}	0.73	0.63 – 0.81

Table 36: Median estimates and 95% credible intervals of all estimates parameters for the Otago Peninsula Deliberate run MCMC.

Parameter	Estimate	95% credible interval
N_{1990}	1.09	0.84 – 1.44
$Surv_{0}$	0.83	0.71 – 0.94
$Surv_{1\text{-}5}$	0.94	0.9 – 0.97
$Surv_{6\text{-}14}$	0.94	0.89 – 0.98
$Surv_{15+}$	0.84	0.6 – 0.97
$Mat_{4\text{-}6}$	0.68	0.47 – 0.91
Pr_{P}	0.72	0.6 – 0.82
Res_{IN}	0.73	0.63 – 0.81

Table 37: Median estimates and 95% credible intervals of all estimates parameters for the Otago Peninsula Entanglement run MCMC.

Parameter	Estimate	95% credible interval
N_{1990}	1.05	0.8 – 1.39
$Surv_0$	0.82	0.71 – 0.92
$Surv_{1\text{-}5}$	0.94	0.9 – 0.97
$Surv_{6\text{-}14}$	0.93	0.88 – 0.97
$Surv_{15+}$	0.81	0.56 – 0.95
$Mat_{4\text{-}6}$	0.65	0.46 – 0.88
Pr_{P}	0.74	0.62 – 0.84
Res_{IN}	0.73	0.63 – 0.81

Table 38: Median estimates and 95% credible intervals of all estimates parameters for the Otago Peninsula Setnet run MCMC.

Parameter	Estimate	95% credible interval
N_{1990}	1.00	0.75 – 1.33
$Surv_0$	0.79	0.66 – 0.91
$Surv_{1\text{-}5}$	0.93	0.88 – 0.96
$Surv_{6\text{-}14}$	0.94	0.88 – 0.98
$Surv_{15+}$	0.81	0.56 – 0.97
$Mat_{4\text{-}6}$	0.66	0.47 – 0.89
Pr_{P}	0.75	0.63 – 0.84
Res_{IN}	0.74	0.64 – 0.82

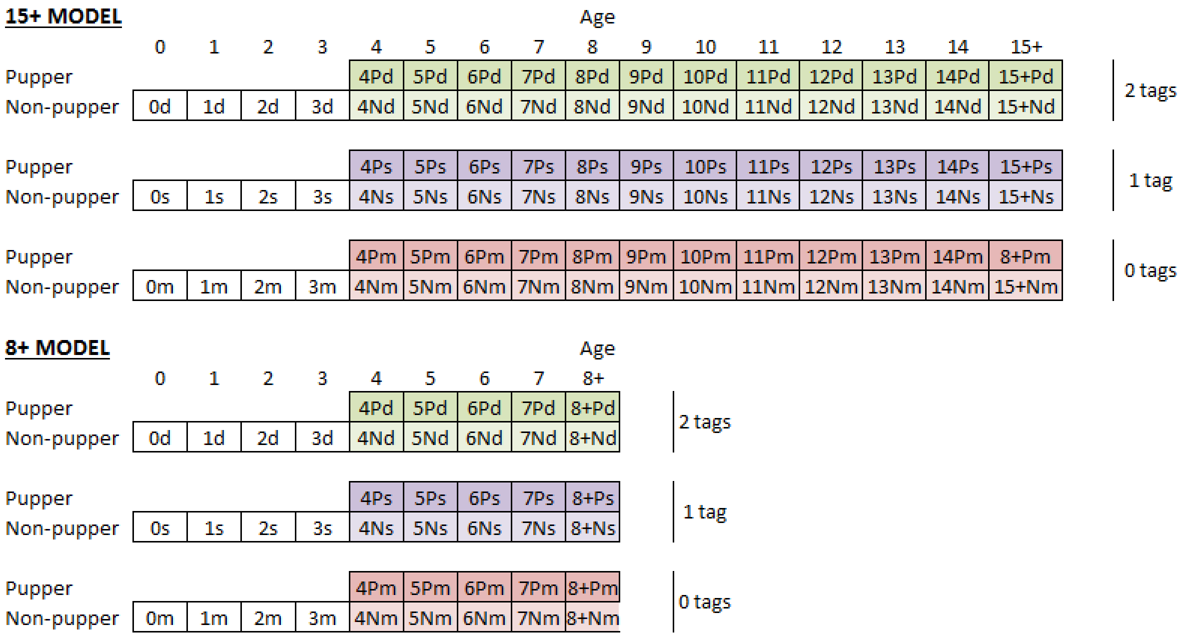
APPENDIX 6 AUCKLAND ISLANDS DEMOGRAPHIC ASSESSMENT DEVELOPMENT

Model development followed a sequential process, with alterations made subsequent to review at TMP workshops and DOC/MPI working group meetings. As such the model development process is different from the typical series of sensitivity analyses compared to a reference model, meaning that not all models were directly comparable by AIC, but AIC was used to compare models that used the same observations.

Initial model development

The initial model structure was loosely based on the optimal model structure developed by Roberts et al. (2014, model run 7 from that assessment), although with an alternative parameterisation of tag loss and pupping rate (both described in more detail below). Also a longer time series of observations was used and different mark types were differentiated to minimise the confounding of tag loss and survival estimation (e.g., flipper-tagged only vs. chip or brand marked).

At the time of the initial phase of model development, field observations (pup census and mark-resighting) were available up to and including the 2013/14 field season. Mark-resighting observations included all tagged at Sandy Bay from 1990–2013 and all resighted from 1999–2014. Census observation period was from 1966–2014 at Sandy Bay and 1995–2014 for all other Auckland Islands rookeries. Mark-resighting observations were differentiated in the SeaBird input files to allow the estimation of mark-type specific resighting probability (with zero probability of resighting individuals that had lost flipper tags and were not chip or brand-marked).



15+ MODEL

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	
Pupper					4Pd	5Pd	6Pd	7Pd	8Pd	9Pd	10Pd	11Pd	12Pd	13Pd	14Pd	15+Pd	2 tags
Non-pupper	0d	1d	2d	3d	4Nd	5Nd	6Nd	7Nd	8Nd	9Nd	10Nd	11Nd	12Nd	13Nd	14Nd	15+Nd	
Pupper					4Ps	5Ps	6Ps	7Ps	8Ps	9Ps	10Ps	11Ps	12Ps	13Ps	14Ps	15+Ps	1 tag
Non-pupper	0s	1s	2s	3s	4Ns	5Ns	6Ns	7Ns	8Ns	9Ns	10Ns	11Ns	12Ns	13Ns	14Ns	15+Ns	
Pupper					4Pm	5Pm	6Pm	7Pm	8Pm	9Pm	10Pm	11Pm	12Pm	13Pm	14Pm	8+Pm	0 tags
Non-pupper	0m	1m	2m	3m	4Nm	5Nm	6Nm	7Nm	8Nm	9Nm	10Nm	11Nm	12Nm	13Nm	14Nm	15+Nm	

8+ MODEL

Age	0	1	2	3	4	5	6	7	8+	
Pupper					4Pd	5Pd	6Pd	7Pd	8+Pd	2 tags
Non-pupper	0d	1d	2d	3d	4Nd	5Nd	6Nd	7Nd	8+Nd	
Pupper					4Ps	5Ps	6Ps	7Ps	8+Ps	1 tag
Non-pupper	0s	1s	2s	3s	4Ns	5Ns	6Ns	7Ns	8+Ns	
Pupper					4Pm	5Pm	6Pm	7Pm	8+Pm	0 tags
Non-pupper	0m	1m	2m	3m	4Nm	5Nm	6Nm	7Nm	8+Nm	

Figure 50 **15+ (top) and 8+ Partitioning (bottom) for demographic assessment models documented in this report. Cell notation is <age><breeding status><number of tag code>, where breeding status is N (did not pup in year+1), and P (pupped in year+1, and the number of tags is given by the "d" = double (2 tags); "s" = single (1 tag); "m" = missing (0 tags). Transitions were permitted to any class of age+1 (or from and to the age plus group), except where the number of tags increased post-transition.**

The initial (reference) model period ran from 1960–2014, adopted the 8+ partitioning (Figure 50) and was parameterised as follows (uniform priors for all parameters):

Initial population size:

- N_{1960} Mature female N in 1960

Year-varying rates:

$Surv_0$	Annual survival age 0 (1960–1989, 1990, 1991, 1991, 1993, 1994–1997, then all from 2009 to 2013)
$Surv_{6+}$	Annual survival age 6+ (1960–1998, then all to 2013)
Pr_P	Annual probability of pupping age 8+ (1960–1997, then all to 2013)

Year-constant rates:

$Surv_1$	Survival from age 1 to age 2
$Surv_{2-5}$	Survival at ages 2–5
Mat_4	Relative probability of pupping at age 4 (multiplier of Pr_P)
Mat_5	Relative probability of pupping at age 5 (multiplier of Pr_P)
Mat_6	Relative probability of pupping at age 6 (multiplier of Pr_P)
Mat_7	Relative probability of pupping at age 7 (multiplier of Pr_P)
$Res_{1\text{-}2\text{tag}}$	Annual resighting probability of flipper-tagged age 1–2
$Res_{1\text{-}2\text{chip}}$	Annual resighting probability of chip-marked age 1–2
$Res_{1\text{-}2\text{brand}}$	Annual resighting probability of brand-marked age 1–2
$Res_{3\text{tag}}$	Annual resighting probability of flipper-tagged age 3
$Res_{3\text{chip}}$	Annual resighting probability of chip-marked age 3
$Res_{3\text{brand}}$	Annual resighting probability of brand-marked age 3
Res_{Ptag}	Annual resighting probability of tag-marked puppers
Res_{Pchip}	Annual resighting probability of chip-marked puppers
Res_{Pbrand}	Annual resighting probability of brand-marked puppers (fixed to 1)
Res_{Ntag}	Annual resighting probability of tag-marked non-puppers
Res_{Nchip}	Annual resighting probability of chip-marked non-puppers
Res_{Nbrand}	Annual resighting probability of brand-marked non-puppers
Pr_{T1}	Probability of losing 1 tag in a year
Pr_{T2}	Probability of losing 2 tags in a year

The 2008 cohort was marked with flipper-tags that had a high pull-out rate (DOC unpublished data). As such, the 2008 value of $Surv_0$ was fixed to 0.4 – approximates to the mean of 2007 and 2008 values.

A number of alternative parameterisations were trialled with respect to tag loss rate, resighting probability, survival at age 1, survival at ages 2–5 and the annual probability of pupping (Table 39). All but one of the alternative configurations led to increased AIC (indicative of a less favourable model fit). The exception to this was making the resighting probability of puppers and non-puppers year varying (-220 AIC units relative to the reference model) and this parameterisation was retained in subsequent runs (the working base model).

Table 39: Comparison of models trialled in the initial phase of model development. $Surv_0$ and $Surv_{6-14}$ were the only parameters that were year-varying in all runs. "Annual" = year-varying, "Constant" = constant with respect to year.

Run name	Pr_P	$Surv_1$	$Surv_{2-5}$	Resighting of puppers and non-puppers	Tag loss parameters	Estimated parameter N	-Log-likelihood	δ-AIC
Resighting	Annual	Constant	Constant	Annual	2	124	17 867	-220
Reference	Annual	Constant	Constant	Constant	2	70	18 031	0
Tagloss4	Annual	Constant	Constant	Constant	4	72	18 030	3
Juvenile	Annual	Constant	Annual	Constant	2	83	18 022	8
Yearling	Annual	Annual	Constant	Constant	2	90	18 020	19
Pupping	Constant	Constant	Constant	Constant	2	54	18,058	23
Tagloss1	Annual	Constant	Constant	Constant	1	69	18,061	59

The reference run above was fit to alternative census series and compared in terms to fits to mark-resighting observations. There was almost no effect of fitting to a combined Enderby Island (Sandy Bay

+ Southeast Point) census (Appendix 9 demonstrated the evidence for extensive breeding site relocations between these closely situated rookeries) and a minor decrease in likelihood when fitting to the combined Auckland Islands trend (Table 40). Even so, the model fitting to Sandy Bay census was retained as the working model structure because of the longer time series of observations for this colony alone (since 1966, compared with since 1995 for Southeast Point).

Table 40: The effect of fitting to alternative census series on fits to mark-resighting observations.

Run name	Census rookery	-Log-likelihood Flipper tag	-Log-likelihood Chip	-Log-likelihood Brand	Relative -Log-likelihood All
Reference – SB	Sandy Bay	12 745	4 832	527	0
Reference – EN	Enderby (Sandy Bay + Southeast Point)	12 741	4 836	527	0
Reference – AI	Auckland Islands	12 747	4 835	527	5

Inclusion of latest year of field observations

The 2014/15 mark-recapture and census observations were included at this point of the model development process, such that the total AIC of subsequent models was not directly comparable with runs above.

Extension of partition to age 15+

The previous phase of model development used the 8+ model partitioning and had 6+ and 8+ age groups for adult survival and pupping rate, respectively. This configuration does not account for known senescence of NZ sea lions at age 15+ (Breen 2012; Childerhouse 2010a; MacKenzie 2012) and cannot make best use of lactating female age distribution estimates in 1998–2001 (i.e. for informing survival-at-age in early assessment years). The 15+ model partitioning (Figure 50) was trialled with additional parameters for survival and pupping rate at age 15+ ($Surv_{15+}$), both constant with respect to year.

This gave $Surv_{15+}$ and Pr_{P15+} estimates of 0.70 and 0.97, respectively when fitting to Sandy Bay census and mark-resighting observations. When fitting to mark-recapture only the demographic rate estimates for plus group were very slightly different ($Surv_{15+} = 0.70$ and $Pr_P = 0.93$), such that fitting to census did not produce unrealistic estimates for these less well-informed parameters.

This parameterisation with respect to the 15+ age group was retained as the working model structure.

Parameterisation of tag loss

Previous models had tag loss parameters that were constant with respect to age. These model runs tended to underestimate numbers missing both flipper tags at older age and there was likely to be an associated bias in survival estimates. Alternative parameterisations with respect to tag loss were explored, and compared in terms of log-likelihood and AIC:

- Tag loss model 1 – Probability of losing either 1 or 2 tags constant with respect to age 0–15
- Tag loss model 2 – Separate estimate for probability of losing either 1 or 2 tags for all ages 0–15
- Tag loss model 3 – Separate estimate for probability of losing 1 tag for all ages 0–15 and age-constant probability of losing 2 tags
- Tag loss model 4 – Separate estimate for the probability of losing a single tag at age 0 and logarithmic functional form for ages 1–15

$$\text{tag loss} = Pr_{\text{T1a}} + Pr_{\text{T1b}} \ln(\text{age})$$

where Pr_{T1a} and Pr_{T1b} are the estimated parameters. Year-constant probability of losing 2 tags.

Annual estimates (tag loss model 2) indicated a much higher probability of losing 1 tag in the first year after tagging as a pup (0.16) than in the second year (0.01), then a curvilinear increase approaching an asymptote at age 15. When taking this configuration and making the probability of losing 2 tags age constant (tag loss model 3) gave an improved AIC relative to the age-constant parameterisation (tag loss model 1) but required 14 additional estimated parameters (Figure 51). A clear improvement in AIC (about 14 units) was obtained when using the functional form and this parameterisation was adopted in the working model (Figure 51).

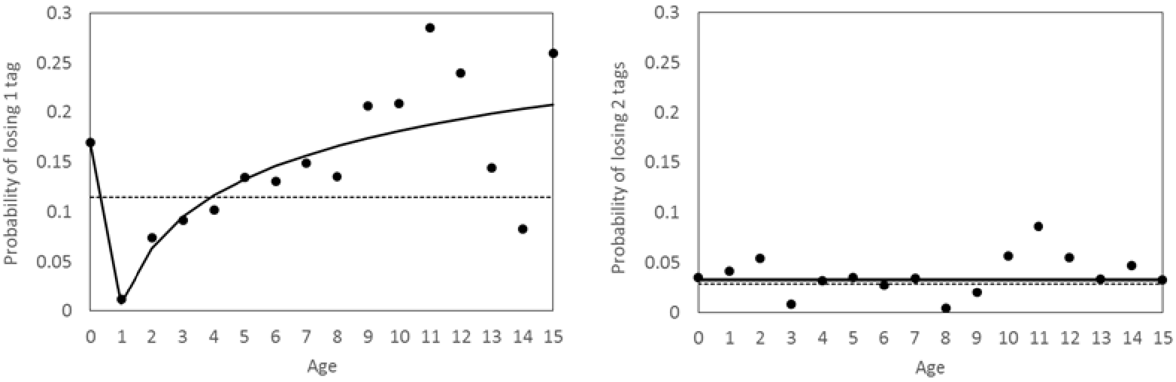


Figure 51: **Age effects on the annual probability of losing a single flipper-tag (left) and both tags (right) given alternative parameterisation of tag loss. The dashed line is the age constant model (tag loss model 1); points are estimates from age varying model (Tag loss model 2); the solid line is the functional form model (tag loss model 4).**

Table 41: **Comparison of models with alternative parameterisation of tag loss with respect to age**

Parameterisation of tag loss	-Log-likelihood	Parameters	δ-AIC
Functional form (model 4)	19 288	79	0
Annual varying (model 3)	19 283	91	14
Age-constant (model 1)	19 320	77	59

Effects of fitting to alternative observation types on demographic rate estimates

The effects of fitting to alternative combinations of observation types on demographic rate estimates was explored (e.g., mark-resighting, census, age distribution and different combinations of these). The age distribution of lactating females at Sandy Bay from 1998–2001 (Childerhouse 2010b) was used to inform the estimation of survival-at-age in early assessment years when there was not consistent resighting effort of marked individuals (1990–1998) and, so, $Surv_0$ was allowed to be year-varying 1994–1997.

Models were fit to:

- Sandy Bay mark-recapture only
- Sandy Bay mark-recapture and age distribution
- Sandy Bay mark-recapture and census
- Sandy Bay mark-recapture, age distribution and census

Estimates of $Surv_0$, $Surv_{6\text{-}14}$ or Pr_P were generally insensitive to the combination of observations that were fitted to, except that fitting age produced lower estimates of $Surv_0$ and increased $Surv_{6\text{-}14}$ and Pr_P in the period prior to 1990 (Figure 52). The estimation of these parameters was likely to be confounded by a lack of resighting effort prior to 1999, such that this does not necessarily indicate a conflict in the information from different observation types. $Surv_0$ estimates in the 1994–97 period (informed by age distribution and to a lesser extent by census) were similar to the period from 1998 on, indicating that an abrupt decline in $Surv_0$ occurred in 1994 that has continued until 2015 (Figure 52).

Other estimated parameters were highly insensitive to the set of observation types used, except that the relative pupping rate at age 15+ reached the upper bound (1), suggesting a lack of reproductive senescence. The model using Sandy Bay mark recapture, age distribution and census and with a pupping rate plus group at age 8+ (as opposed to 15+) was retained as the working model.

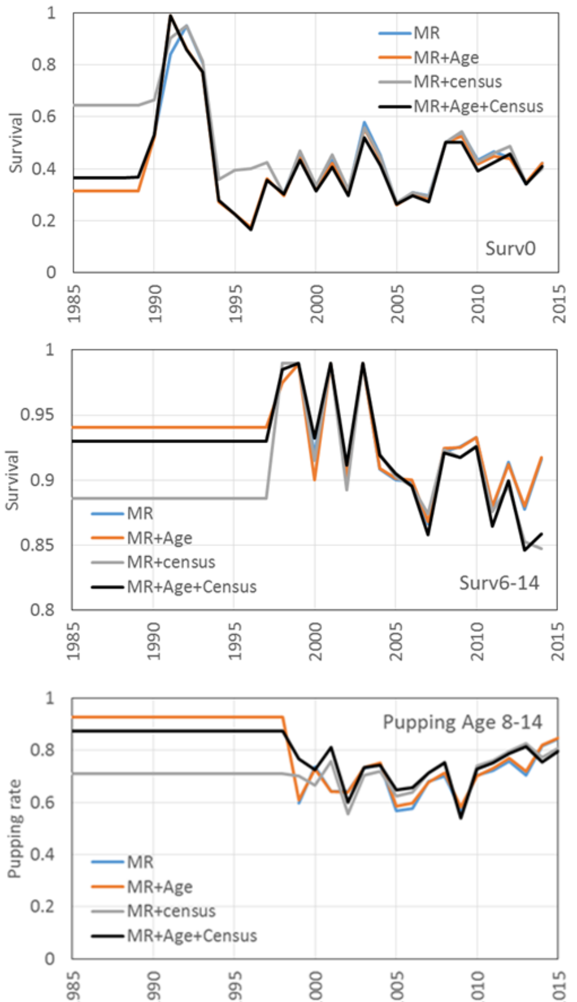


Figure 52: Effect of fitting to alternative observation types (all Sandy Bay, "MR" = mark-recapture) on year-varying demographic rate estimates (*$Surv_0$*, *$Surv_{6\text{-}14}$* and *Pr_P*).

Fitting to Auckland Islands age distribution and census

Previous runs were fit to Sandy Bay census and age composition of lactating females (puppers). MPI/DOC opted to change the main census series to Auckland Islands for the assessment of threats.

Childerhouse's (2010b) ageing study of lactating females indicated a very different age composition at Dundas and Sandy Bay in 1998–2001. These age distributions were combined (weighted to relative pup production at each rookery). Fitting to the combined age distribution had a tiny effect on all parameters except $Surv_0$ in 1990–1989 (increased from 0.37 to 0.70) as a consequence of using the combined Sandy Bay + Dundas age distribution, which had a much longer tail than Sandy Bay only. Also the relative pupping rate at age 4 (Mat_4) increased from 0.15 to 0.22 to fit to the increased proportion of individuals at age 4 in the combined Sandy Bay + Dundas age distribution of lactating females.

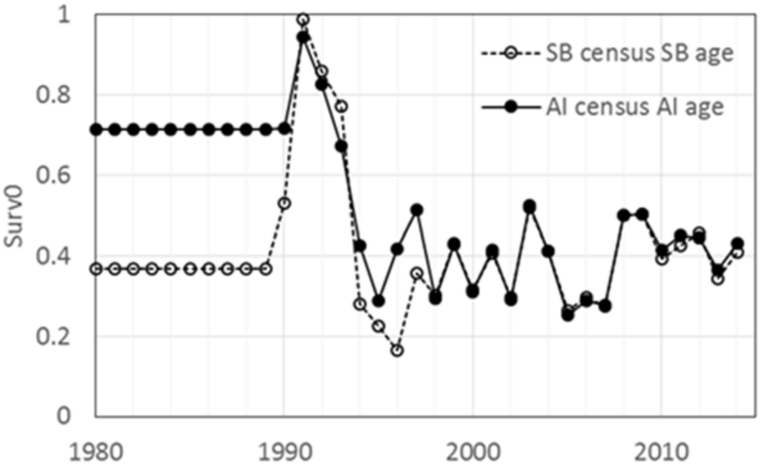


Figure 53: The effect of fitting to Sandy Bay census and age distribution versus Auckland Islands census and age (actually Sandy Bay and Dundas) on estimates of $Surv_0$.

The model fit to Auckland Islands census and Sandy Bay+Dundas age was retained as the working model. The Auckland Islands census series began later (1995) than the Sandy Bay series (1966) and the model start was changed from 1960 to 1990 in all subsequent runs.

Parameterisation of resighting probability

Year-blocking

Noting large between-year differences in resighting effort at Sandy Bay (Figure 51), AEWG recommended the base model configuration should have year-varying resighting probability. However, this greatly increased the number of estimated parameters, many of which were likely to be strongly correlated.

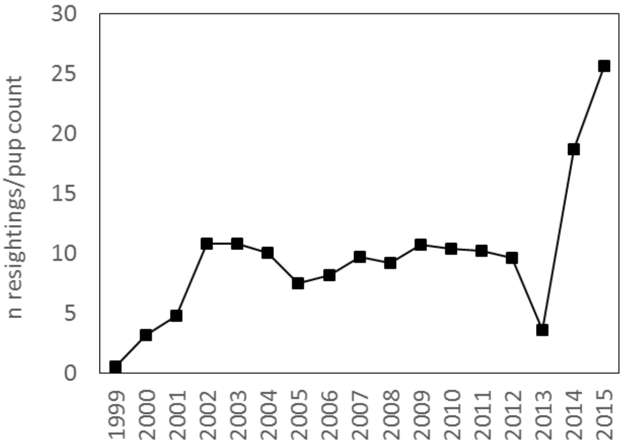


Figure 54: Variation in the annual count of female individual resightings at Sandy Bay (i.e. an individual could be counted multiple times) scaled to the total pup count – a simple index of comparative resighting effort per breeder.

An alternative parameterisation of resighting effort was trialled in which resighting parameters were year-blocked, such that there were separate estimates for 1999, 2000–2001, 2002–2012, 2013 and 2014–2015. The MPD estimates for each parameter (Figure 55) were consistent with an index of annual resighting effort and so this parameterisation was retained (Figure 54).

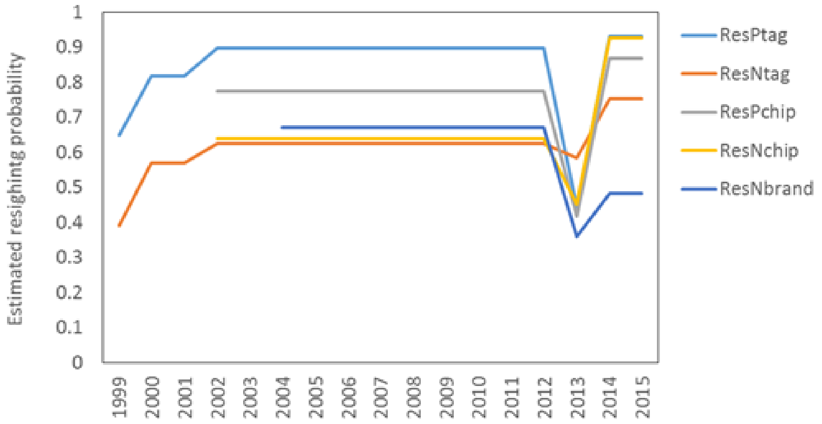


Figure 55: MPD estimates of year-blocked resighting parameters.

Combining non-puppers

The MPD run above produced very similar estimates of resighting probability for non-puppers (in the well-estimated 2002–2012 period) and juveniles for each mark type, i.e. chip, brand or flipper-tagged only (e.g., comparing $Res_{3\text{tag}}$, $Res_{3\text{chip}}$ and $Res_{3\text{brand}}$) (Figure 56). An alternative parameterisation was trialled in which mark type was ignored for non-puppers and ages 1–3. This saved 10 parameters and resulted in a marginally worse AIC (0.2 units), so this simpler parameterisation was retained as the working model.

Figure 56: Comparison of preliminary MCMC run estimates (with 95% credible intervals) for year-blocked estimates of resighting parameters of non-breeders by mark type. Parameter estimates for non-puppers in the period 2002–2012 are highlighted by blue ovals.

Model simplification

Noting that projections will only use current age distribution and demographic rate estimates from 2005–2014, year-blocks were trialled for year-varying demographic rates prior to 2005:

- $Surv_0$ – 1990–1993, 1994–2004
- $Surv_{6\text{-}14}$ – 1990–1998, 1999–2004
- Pr_P – 1990–1998, 1999–2004

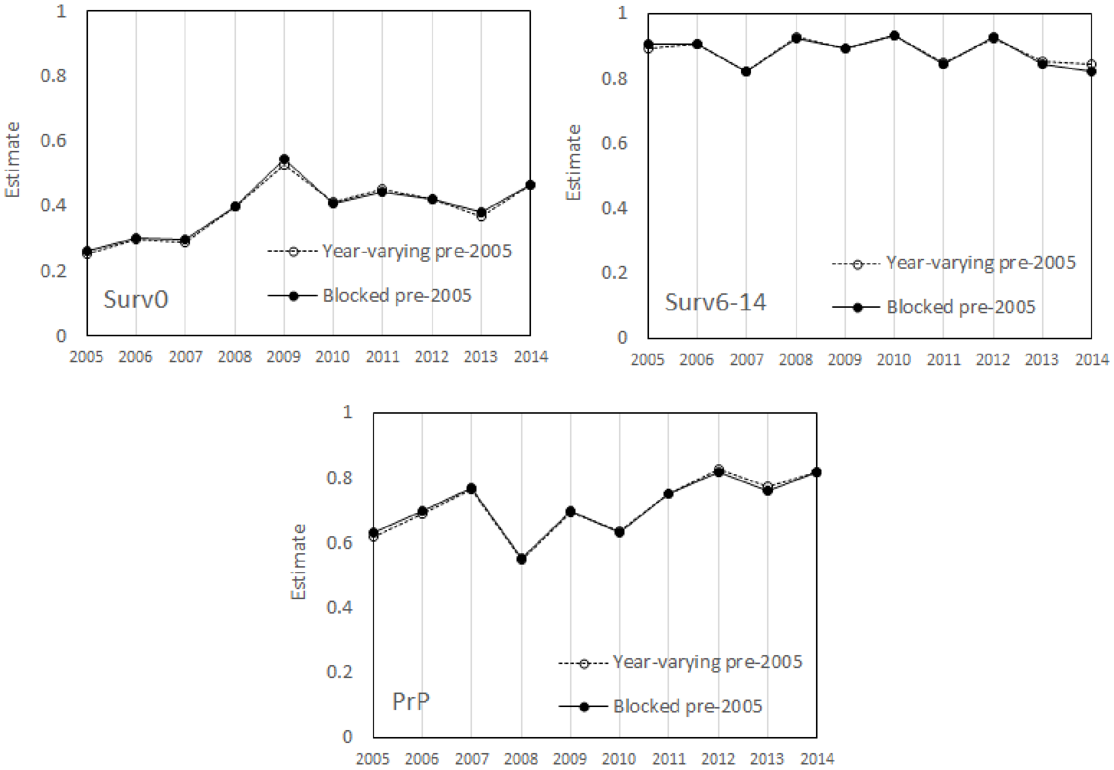


Figure 57: MPD estimates of $Surv_0$ (left), $Surv_{6\text{-}14}$ (centre) and Pr_P (right) from the 15+ model with year-varying estimates (broken line) and year-blocked prior to 2005 (solid line).

Each of these demographic rates remained year-varying from 2005–2014. Year-blocking in the 1990–2004 period had the effect of greatly increasing model AIC (70 units) but had almost no effect on year-varying estimates or on age distribution in the 2005–2014 period (Figure 64 and Figure 65). As such, there would be almost no difference in the projections obtained with these two alternative parameterisations and this model structure was retained as the base model configuration.

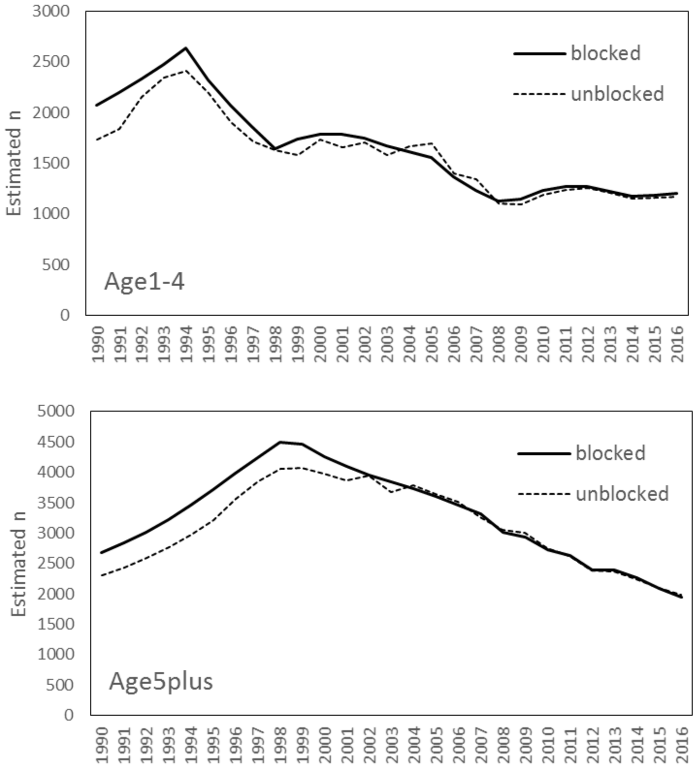


Figure 58: Estimated mature *N* by year from the 15+ model with year-varying estimates of *Surv*$_0$, *Surv*$_{6\text{-}14}$ and *Pr*$_P$ (solid line) and year-blocked prior to 2005 (broken line).

Auckland Islands base model

The Auckland Islands base model developed for the risk assessment used the following observations:

- Sandy Bay mark-recapture (1990–2015) with the "strict" definition of pupping status
- Auckland Islands census (1995–2015) with CV of 3%
- Combined Sandy Bay and Dundas age distribution of lactating females (1998–2001)

The 15+ Partition was used and the final parameterisation was as follows:

Initial population size:

N_{1990}	Mature female *N* in 1990

Year-varying rates:

$Surv_0$	Annual survival age 0 (1990–1993, 1994–2004, then all to 2014)
$Surv_{6\text{-}14}$	Annual survival age 6-14 (1990–1998, 1999–2004, then all to 2014)
Pr_P	Annual probability of pupping age 8+ (1990–1997, 1998–2004, then all to 2014)
Res_N	Annual resighting probability of non-puppers (1999, 2000–2001, 2002–2012, 2013, 2014–2015)
Res_{Ptag}	Annual resighting probability of tag marked puppers (1999, 2000–2001, 2002–2012, 2013, 2014–2015)
Res_{Pchip}	Annual resighting probability of chip-marked puppers (1999, 2000–2001, 2002–2012, 2013, 2014–2015)

Constant with respect to year:

$Surv_1$	Annual survival age 1
$Surv_{2\text{-}5}$	Annual survival age 2–5
$Surv_{15+}$	Annual survival age 15+
Mat_4	Probability of pupping at age 4 (relative to Pr_P)

Mat_5	Probability of pupping at age 5 (relative to Pr_{P})
Mat_6	Probability of pupping at age 6 (relative to Pr_{P})
Mat_7	Probability of pupping at age 7 (relative to Pr_{P})
$Res_{1\text{-}2}$	Annual resighting probability at age 1–2
Res_3	Annual resighting probability at age 3
Res_{Pbrand}	Annual resighting probability of branded puppers (fixed to 1)
Pr_{T10}	Annual probability of losing a single tag in the first year
Pr_{T1a}	Functional form parameter that gives the probability of losing 1 tag in a year (1)
Pr_{T1b}	Functional form parameter that gives the probability of losing 1 tag in a year (2)
Pr_{T2}	Annual probability of losing 2 tags in a year

Uniform priors were used for all estimated parameters, which were bounded between 0 and 1, with the exception of Survival parameters (0 and 0.99) and N_{1990} (100 and 4000). The 2008 cohort was marked with flipper-tags that had a high pull-out rate (DOC unpublished data). As such, the 2008 value of $Surv_0$ was fixed to 0.4 – approximates to the mean of 2007 and 2008 values.

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APPENDIX 7 OTAGO PENINSULA DEMOGRAPHIC ASSESSMENT DEVELOPMENT

Alternative model configurations were compared with respect to fits to observations, model AIC and estimates of key parameters. Previous studies have indicated that the relative pupping rate at maturation ages (4–7) is quite different at the Otago Peninsula compared with the Auckland Islands (Augé 2010; Lalas & Bradshaw, 2003). In addition, the increase in pup production at the Otago Peninsula appeared to slow after 2005. A reference model configuration was developed adopting the 15+ Partitioning. The parameterisation was a simplification of that used for the base model for the Auckland Islands population, with 8 estimated parameters (all constant with respect to year):

– N_{1990}	Number of breeders in 1990
– $Surv_0$	Survival to age 1
– $Surv_{1\text{-}5}$	Survival age 1 to age 6
– $Surv_{6\text{-}14}$	Survival age 6 to age 15
– $Surv_{15+}$	Survival age 15+
– Pup_{7+}	Pupping rates age 7+
– $Mat_{4\text{-}6}$	Pupping rate ages 4–6 relative to Pr_P, the pupping rate at age 7+
– Res_{ImNP}	Annual resighting probability immature and non-puppers

Three alternative model configurations were compared with the aim of finding an optimal model configuration for the assessment of threat effects:

1. Reference run (as above)
2. Maturation run (as above, except that there were separate parameters for pupping rate at ages 4,5,6 and 7 relative to Pr_P, the pupping rate at age 8+)
3. Year-varying run (as reference run, except with separate estimates of Surv0, Surv6-14 and PrP for 1990–2004 and 2005–2014)

The Maturation model run had the highest AIC, so the reference configuration of pupping rate was retained in the optimal configuration (Table 42). The Year-varying run produced a much lower AIC, but the fit to the latest census estimate was poor relative to the reference model (Figure 59). The reference model parameterisation (described above) was adopted for the Otago Peninsula base model, as although it had higher AIC than the year-varying configuration, the fit to the latest census estimate was improved and it had fewer potentially correlated parameters.

The parameter estimates using the year-varying parameterisation suggests that since 2005 there has been a decline in pup survival ($Surv_0$, 0.97 before 2005 and 0.65 since), adult survival ($Surv_{6\text{-}14}$, 0.99 before 2005 and 0.86 since) and pupping rate (Pr_P, 0.79 before 2005 and 0.74 since) (Figure 60).

Table 42: Comparison of model structures for the Otago Peninsula population with respect to model configuration, number of parameters estimated and AIC.

Model run	Pupping parameterisation	Year-blocking	Parameters	Log-likelihood	δ AIC
Year-varying	Mat4-Mat6, PrP at 7+	Surv0, Surv6-14, PrP - 1990-2004, 2005-2014	11	195.6	0.0
Reference	Mat4-Mat6, PrP at 7+	None	8	206.4	15.5
Maturation	Mat4, Mat5, Mat6, Mat7, PrP at 8+	None	11	206.0	20.7

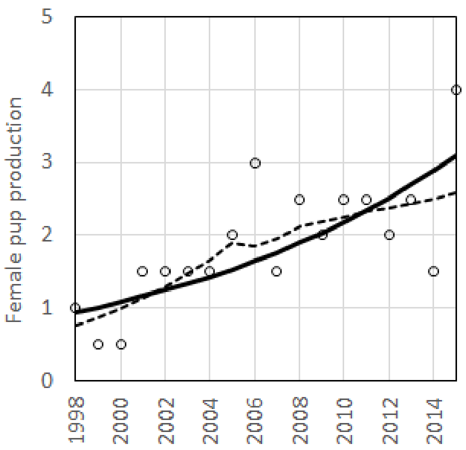


Figure 59: **Model fits to pup census estimates for the Otago Peninsula. Open points are pup census estimates, the solid line is the fit with the reference model parameterisation, the broken line is the fit with the Year-varying parameterisation.**

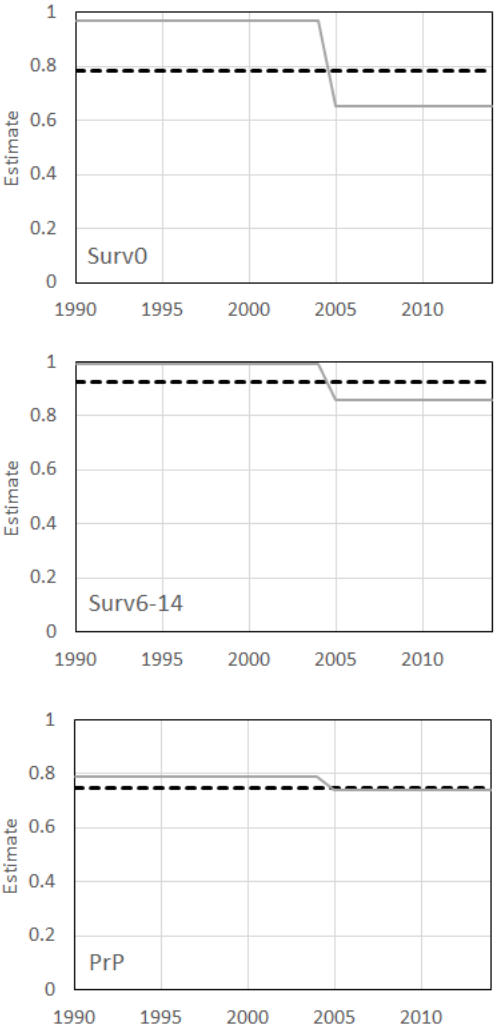


Figure 60: **Model estimated of *Surv*$_{0}$, *Surv*$_{6\text{-}14}$ and *Pr*$_{P}$ for the reference and year-varying model runs.**

APPENDIX 8 AUCKLAND ISLANDS RETROSPECTIVE ANALYSIS

Introduction

There has been about a 50% decline in pup production at the Auckland Islands since the late 1990s and we would like to know how much of the decline can be explained by the effects of a particular threat. A retrospective analysis was conducted in which demographic rate estimates obtained from the best-estimate MCMC run were used to project forwards from the year 2000 with threat-specific mortality reset to zero (or optimal demographic rates used in the case of trophic food limitation).

The following threats were assessed (all passed through the Triage stage):

- Trophic (food limitation)
- Commercial trawl – interactions
- *Klebsiella pneumoniae* mortality of pups
- Hookworm mortality of pups

Note that the timing of the effect of each threat on mature numbers varied because a different time series of mortality effect was used for each threat (e.g., trophic prey directly affected demographic rates from 2005–2008, whereas all other effects affected N at age from 2000–2015) and because threats affected different age groups:

- Trophic food limitation affected $Surv_0$, $Surv_{6\text{-}14}$ and Pr_P
- Commercial trawl interactions affected ages 3+ and 0 (indirect effect)
- *Klebsiella* and hookworm – both affected age 0

As such it was not a fair comparison of the effects of each threat with respect to the mature N in 2015, although it does give an indication of the effect on the growth rate of mature N during the time period that the threat was effective on that demographic.

Results

None of the threats assessed were sufficient alone to explain the observed decline in pup production at the Auckland Islands (Figure 61 and Table 43). The alleviation of *Klebsiella pneumoniae* mortality of pups had the greatest effect on population growth rate (λ_{2015} = 0.98, 95% CI = 0.94-1.01) relative to the base run (λ_{2015} = 0.94, 95% CI = 0.91–0.98) (in which the threat effect was still applied).

Discussion

Three things are apparent from this analysis:

1. That even with the most-pessimistic view of cryptic mortality and of associated loss of pups, commercial trawl-related mortality does not appear sufficient alone to explain the observed decline in pup production at the Auckland Islands.
2. That disease-related mortality of pups could have a major effect on population growth rate if the best-estimates of annual mortality are realistic, but it would need to have commenced some years prior to the start of the decline in pup production to be the main cause of the decline (given the delay to maturation).
3. The combination of these four threats is unlikely to be sufficient to explain the decline relative to the estimated period of population increase that preceded it.

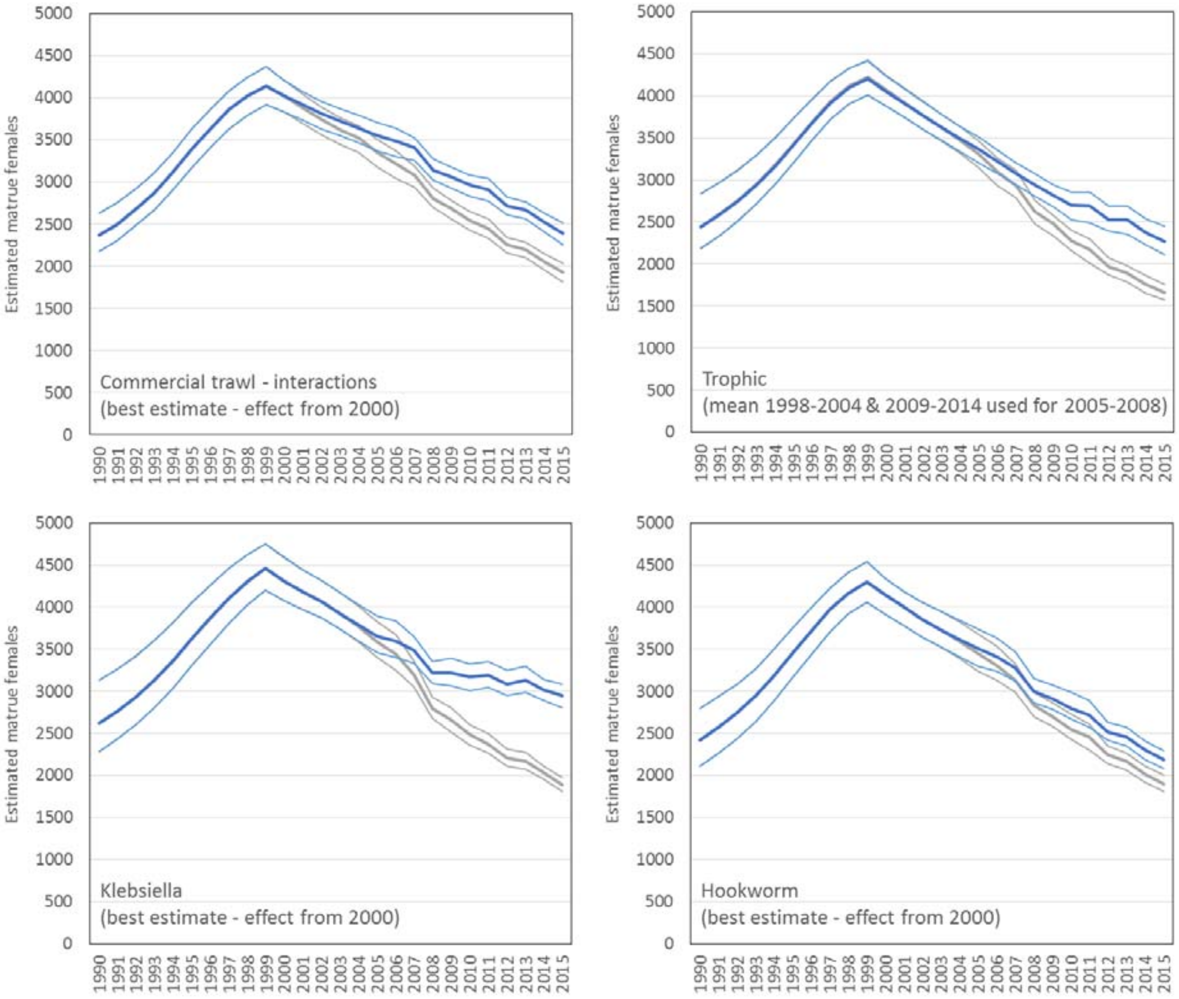


Figure 61: **Predicted mature N by year comparing the base run – mature N with threat affecting population (grey lines) and run with the threat alleviated (blue lines). Heavy lines are median estimates and light lines are credible intervals.**

Table 43: **Projected growth rate of mature N (λ_{2015}) and population status in 2015 N_{2015}/N_{2000} (%).**

Threat	λ_{2015}	N_{2015}/N_{2000} (%)
Klebsiella	0.98 (0.94–1.01)	68 (63–73)
Trophic (prey)	0.96 (0.92–1.00)	56 (52–61)
Hookworm	0.95 (0.92–0.98)	53 (49–57)
Commercial trawl – Interactions	0.94 (0.91–0.97)	59 (55–64)
Base run	0.94 (0.91–0.98)	47 (44–51)

APPENDIX 9 AUCKLAND ISLANDS BREEDING SITE RELOCATION ASSESSMENT

Introduction

The pup production trends are quite different comparing the breeding rookeries of the Auckland Islands: Sandy Bay, Dundas, Southeast Point and Figure of Eight (Figure 62). A brief demographic assessment was undertaken in SeaBird to assess the rate of breeding site relocations of females between rookeries at the Auckland Islands.

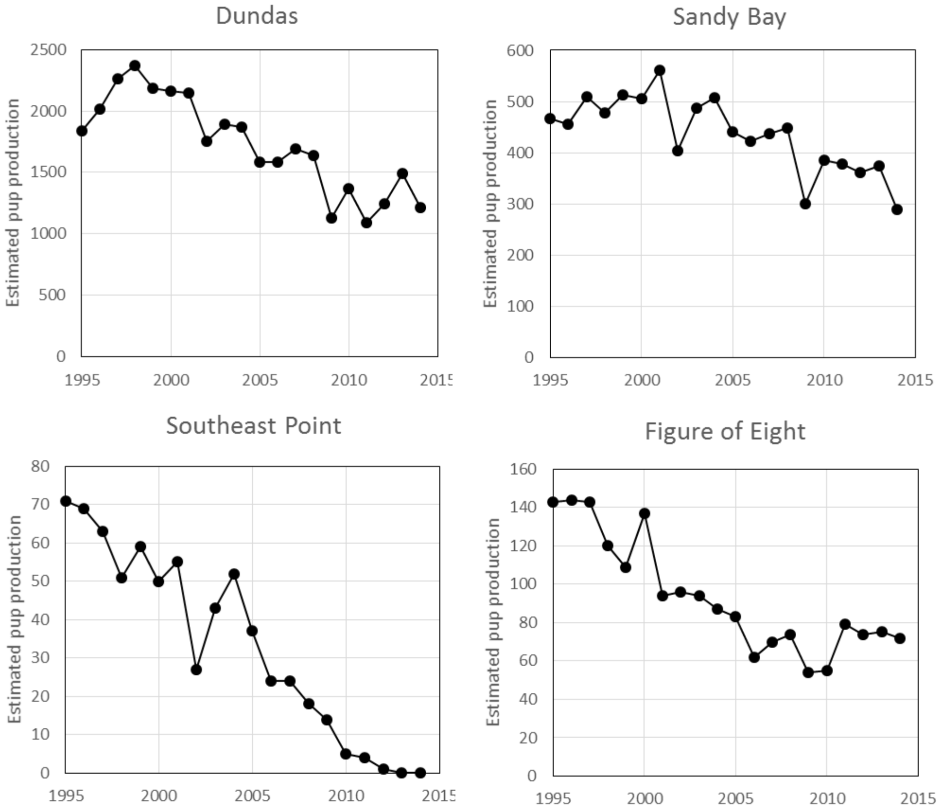
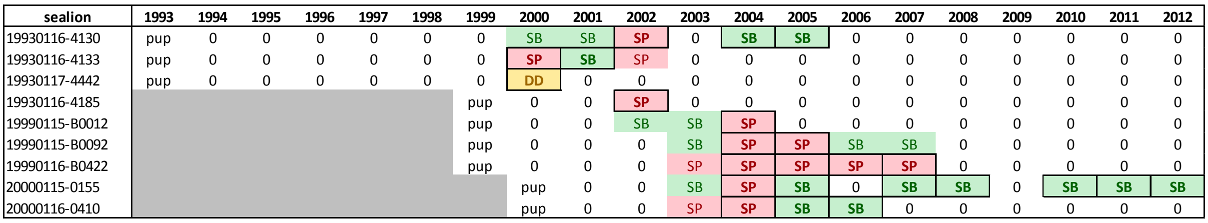


Figure 62: Annual pup census estimates of Auckland Islands rookeries of NZ sea lions (Childerhouse et al. 2015).

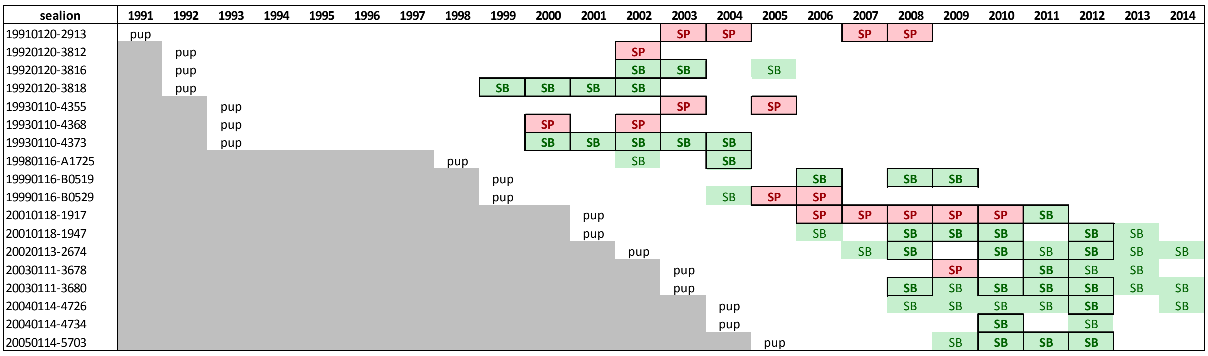
Observed breeding site relocations

A strict definition of pupping status was used (as MacKenzie 2012). Eight females tagged as pups at Sandy Bay were attributed confirmed pupping status when observed at Southeast Point in the years 2000–2007, including 4 individuals that were subsequently observed pupping at Sandy Bay in following years (Figure 63). Of females tagged as pups at Southeast Point, 18 were observed pupping at any rookery, including 13 individuals that were observed pupping at Sandy Bay. Any that were observed pupping at Sandy Bay were not observed pupping back at Southeast Point in subsequent years, suggesting that these were permanent breeding site relocations (Figure 64). Considering the relatively large size of the Dundas rookery and the number of individuals that have been tagged there, comparatively few individuals tagged at Dundas have been observed pupping elsewhere (Figure 65).



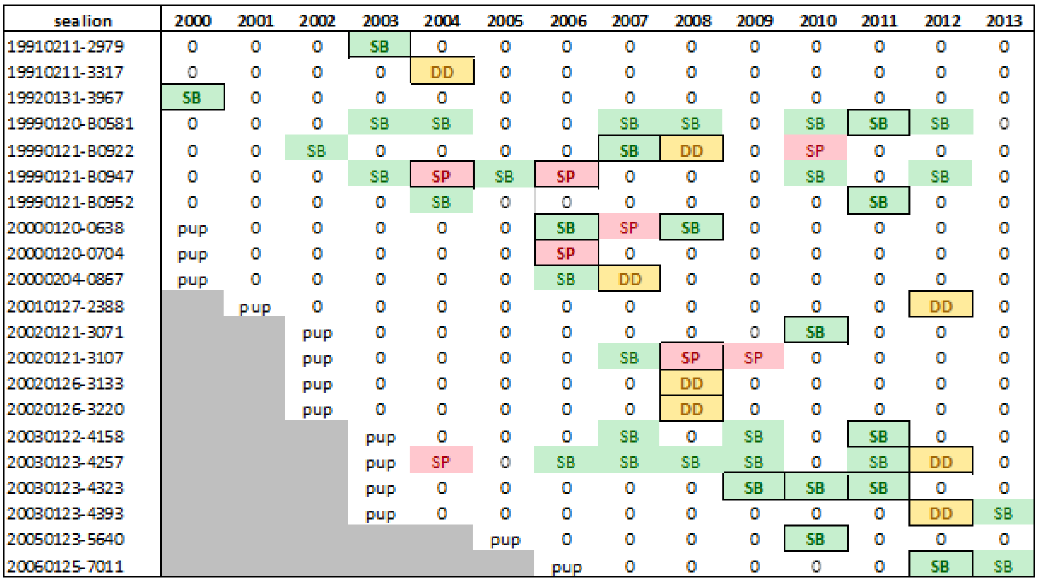
sealion	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
19930116-4130	pup	0	0	0	0	0	0	SB	SB	SP	0	SB	SB	0	0	0	0	0	0	0
19930116-4133	pup	0	0	0	0	0	0	SP	SB	SP	0	0	0	0	0	0	0	0	0	0
19930117-4442	pup	0	0	0	0	0	0	DD	0	0	0	0	0	0	0	0	0	0	0	0
19930116-4185							pup	0	0	SP	0	0	0	0	0	0	0	0	0	0
19990115-B0012							pup	0	0	SB	SB	SP	0	0	0	0	0	0	0	0
19990115-B0092							pup	0	0	0	SB	SP	SP	SB	SB	0	0	0	0	0
19990116-B0422							pup	0	0	0	SP	SP	SP	SP	SP	0	0	0	0	0
20000115-0155								pup	0	0	SB	SP	SB	0	SB	SB	0	SB	SB	SB
20000116-0410								pup	0	0	SP	SP	SB	SB	0	0	0	0	0	0

Figure 63: Annual observations of females tagged as pups at Sandy Bay and confirmed pupped at either Southeast Point or Dundas in a subsequent season. “pup” = year in which individual was tagged as pup; “SB”, ”SP” or “DD” in highlighted text with a black outline indicates female observed pupping at Sandy Bay, Southeast Point or Dundas; or observed but unknown pupping status if not highlighted, “0” = not observed. “sealion” is the individual ID in the mark-recapture database maintained by Dragonfly.



sealion	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
19910120-2913	pup												SP	SP			SP	SP						
19920120-3812		pup										SP												
19920120-3816		pup										SB	SB		SB									
19920120-3818		pup							SB	SB	SB	SB												
19930110-4355			pup										SP		SP									
19930110-4368			pup							SP		SP												
19930110-4373			pup							SB	SB	SB	SB	SB										
19980116-A1725								pup				SB		SB										
19990116-B0519									pup							SB		SB	SB					
19990116-B0529									pup					SB	SP	SP								
20010118-1917											pup					SP	SP	SP	SP	SP	SB			
20010118-1947											pup					SB		SB	SB	SB		SB	SB	
20020113-2674												pup					SB	SB		SB	SB	SB	SB	SB
20030111-3678													pup						SP		SB	SB	SB	
20030111-3680													pup					SB	SB	SB	SB	SB	SB	SB
20040114-4726														pup				SB	SB	SB	SB	SB		SB
20040114-4734														pup						SB		SB		
20050114-5703															pup				SB	SB	SB	SB		

Figure 64: Annual observations of females tagged as pups at Southeast Point and confirmed pupped at any rookery in a subsequent season. “pup” = year in which individual was tagged as pup; “SB”, ”SP” or “DD” in highlighted text with a black outline indicates female observed pupping at Sandy Bay, Southeast Point or Dundas; or observed but unknown pupping status if not highlighted, “0” = not observed. “sealion” is the individual ID in the mark-recapture database maintained by Dragonfly.



sealion	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
19910211-2979	0	0	0	SB	0	0	0	0	0	0	0	0	0	0
19910211-3317	0	0	0	0	DD	0	0	0	0	0	0	0	0	0
19920131-3967	SB	0	0	0	0	0	0	0	0	0	0	0	0	0
19990120-B0581	0	0	0	SB	SB	0	0	SB	SB	0	SB	SB	SB	0
19990121-B0922	0	0	SB	0	0	0	0	SB	DD	0	SP	0	0	0
19990121-B0947	0	0	0	SB	SP	SB	SP	0	0	0	SB	0	SB	0
19990121-B0952	0	0	0	0	SB	0	0	0	0	0	0	SB	0	0
20000120-0638	pup	0	0	0	0	0	SB	SP	SB	0	0	0	0	0
20000120-0704	pup	0	0	0	0	0	SP	0	0	0	0	0	0	0
20000204-0867	pup	0	0	0	0	0	SB	DD	0	0	0	0	0	0
20010127-2388		pup	0	0	0	0	0	0	0	0	0	0	DD	0
20020121-3071			pup	0	0	0	0	0	0	0	SB	0	0	0
20020121-3107			pup	0	0	0	0	SB	SP	SP	0	0	0	0
20020126-3133			pup	0	0	0	0	0	DD	0	0	0	0	0
20020126-3220			pup	0	0	0	0	0	DD	0	0	0	0	0
20030122-4158				pup	0	0	0	SB	0	SB	0	SB	0	0
20030123-4257				pup	SP	0	SB	SB	SB	SB	0	SB	DD	0
20030123-4323				pup	0	0	0	0	0	SB	SB	SB	0	0
20030123-4393				pup	0	0	0	0	0	0	0	0	DD	SB
20050123-5640						pup	0	0	0	0	SB	0	0	0
20060125-7011							pup	0	0	0	0	0	SB	SB

Figure 65: Annual observations of females tagged as pups at Dundas and confirmed pupped at any rookery in a subsequent season. “pup” = year in which individual was tagged as pup; “SB”, ”SP” or “DD” in highlighted text with a black outline indicates female observed pupping at Sandy Bay, Southeast Point or Dundas; or observed but unknown pupping status if not highlighted, “0” = not observed. “sealion” is the individual ID in the mark-recapture database maintained by Dragonfly.

There was only a single example of a tagged individual moving between Figure of Eight and any other colony (resighted at immature age) and breeding site relocations between this and other rookeries were assumed to be close to zero and omitted from multi-area modelling assessment.

Multi-area demographic assessment model configuration

The SeaBird demographic modelling software was used to develop a simple multi-area model fit to mark-resighting observations of females that were flipper tagged as pups at Sandy Bay, Southeast Point or Dundas from 1990–2011 and resighted at any of these rookeries from 1999–2012. Only observations made from 1–20th January were used, as mothers are known to relocate with pups within-season after this date (Chilvers pers. comm.).

In order to minimise the number of possible classes an observation could take a simple model structure was used with a plus group at age-4. A simple model partitioning was used, making use of observations of age, area, pupping status and number of flipper tags for each individual sighted in a year (Figure 66).

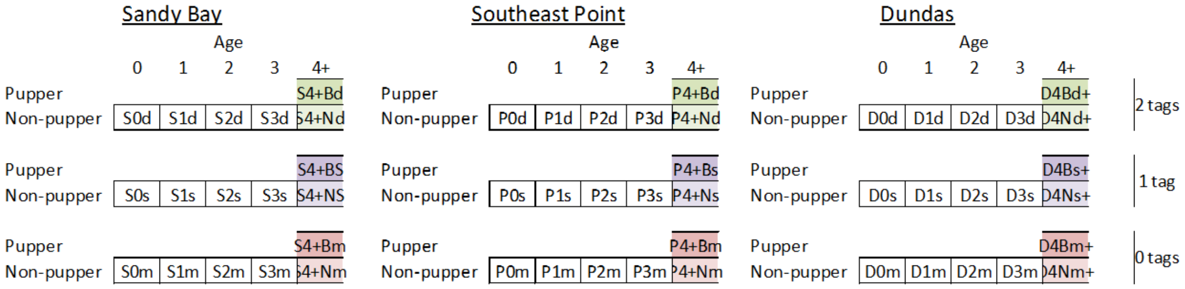


Figure 66: **Multi-area model Partitioning. Cell notation is <rookery><age><breeding status><number of tag code>, where rookery is S (Sandy Bay), P (Southeast Point) or D (Dundas), breeding status is N (did not pup in year+1), and P (pupped in year+1, and the number of tags is given by the "d" = double (2 tags); "s" = single (1 tag); "m" = missing (0 tags). All transitions to a state of age+1 are possible (or from 4+ to 4+).**

All demographic rates were year-invariant. Survival, pupping rate and tag loss parameters were fixed to values obtained from a preliminary run using on Sandy Bay mark-resighting observations:

- Annual survival at age 0 (0.46), age 1 (0.61), age 2–3 (0.91) and age 4+ ($Surv_{4+} = 0.92$);
- Annual pupping rate probability for ages 4+ (0.38);
- Tag loss parameters for the annual probability of losing 1 tag at age 0 (0.082) or at age 1+ (0.130); or of losing 2 tags at age 0 (0.030) or at age 1+ (0.019)

Only resighting probabilities and annual relocation rates were estimated:

- Annual resighting probability for chip/brand or just flipper-tag marked individuals at each rookery at ages 1–2 ($Res_{\text{1-2chip}}$), 3 (Res_{3chip}), and puppers/non-puppers at age 4+ (Res_{Pchip} and Res_{Nchip}). There was a separate set of parameters for each of the three rookeries. Note that the Resighting probability of puppers at Sandy Bay was fixed to 1 for all mark types (e.g., flipper-tag, chip or brand-marked individuals);
- Annual relocation rate – 4 parameters giving the rate of relocation between each pair of colonies (3 pairings in all, or 12 parameters): 2 parameters gave the relocation rate of immature and non-puppers and another 2 parameters gave the relocation of breeders at one rookery to breeders at another rookery in the following year.

Multi-area model estimates

Relocation rate estimates were much greater for immature/non-puppers, particularly from Sandy Bay to Southeast Point (0.187) and in the opposite direction (0.314). Breeding site relocations of puppers (i.e. pupped at one rookery in year and at another rookery in year+1) were very low (<0.01) for all rookery pairings, except from Southeast Point to Sandy Bay (0.087) (Figure 67). All parameter estimates are tabulated below (Table 44 and Table 45).

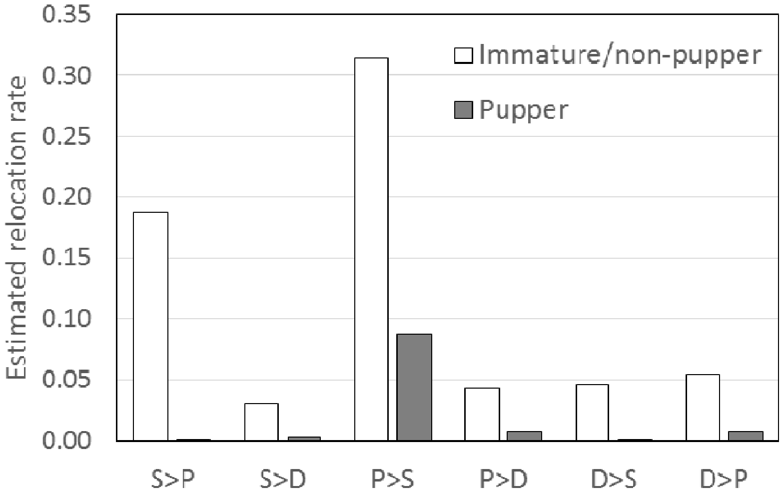


Figure 67: **Estimated breeding site relocation rates of females between Auckland Islands rookeries. Labels denote rookeries (“S” = Sandy Bay; “D” = Dundas; “P” = Southeast Point) and direction of relocation (e.g., “S>D” denotes relocations from Sandy Bay and Dundas).**

Table 44: **Resighting parameter estimates from the multi-area model.**

Mark-type as pup	Parameter	MPD estimate		
		Sandy Bay	Southeast Point	Dundas
Flipper-tagged only	Res1-2tag	0.032	0.005	0.047
	Res3tag	0.336	0.025	0.091
	ResPtag	1.000*	0.011	0.046
	ResNtag	0.735	0.104	0.084
Chip-marked (not branded)	Res1-2chip	0.028	0.003	0.045
	Res3chip	0.249	0.005	0.092
	ResPchip	1.000*	0.022	0.059
	ResNchip	0.624	0.077	0.036
Branded	Res1-2brand	0.040	0.000*	0.000*
	Res3brand	0.156	0.000*	0.000*
	ResPbrand	1.000*	0.000*	0.000*
	ResNbrand	0.792	0.000*	0.000*

*fixed values

Table 45: Relocation parameter estimates from the multi-area model.

		Sandy Bay	Southeast Point	Dundas
		Rookery yr+1		
Rookery in yr	Sandy Bay		0.187	0.031
	Southeast Point	0.314		0.043
	Dundas	0.046	0.055	
		Rookery yr+1 (pupper)		
Rookery in yr (pupper)	Sandy Bay		0.000	0.002
	Southeast Point	0.087		0.007
	Dundas	0.000	0.007	

Implications

The outputs of this assessment are consistent with a relocation of breeding females from Southeast Point to Sandy Bay during the period of resighting effort. This is consistent with the findings from a visual inspection of the mark-recapture observations (Figure 64), which also suggests that a number of puppers at Southeast Point were born at Sandy Bay and have relocated there sometime between birth and first pupping. Thus the rapid decline in pup production at Southeast Point (Figure 62) would have been accelerated by relocations to Sandy Bay, which would conversely have slowed the rate of decline at that rookery. As such, models using Sandy Bay mark-recapture observations and census data should consider fitting the sum of census estimates for the two rookeries.

The almost complete lack of relocations between Figure of Eight and any other rookery at the Auckland Islands suggests that this is a demographically independent population. This is consistent with the very different pup census trends for this population (Figure 62).

APPENDIX 10 CAMPBELL ISLAND ASSESSMENT

Introduction

Outside of the Auckland Islands, Campbell Island is the only other significant sea lion breeding colony. The sea lion population at Campbell Island has been surveyed several times since 1990 (Childerhouse & Gales 1998; Childerhouse et al. 2005; Maloney et al. 2012). In 2010, it was estimated to comprise approximately 27% of the total pup production for the species (Maloney et al. 2012).

Here, pup counts from surveys completed since 1990 were fitted in a Leslie matrix model to assess its current growth rate and also to assess threat mitigation. Modelling is limited because only pup counts are available, so apart from pup survey in its first year, other demographic rates are uncertain because in fitting to the data, several on their own or in different combinations can fit the data, i.e., we cannot identify which other demographic variable has changed.

Method

The three most recent pup count surveys have almost the same sampling protocols: Maloney et al. (2010) with the survey conducted in January-February 2008, Maloney et al. (2012) in December 2009–February 2010, and Childerhouse et al. (2015) in December 2014 to January 2015. There were three other pup count surveys that we also considered: 1992, 1993, and 2003 (Childerhouse & Gales 1998, Childerhouse, et al. 2005). Female pup count data are shown in Table 46.

Table 46: **Female pup counts (census totals divided by 2) on Campbell Islands with an assigned subjective CV.**

Year	Census	Subjective CV
1992	61	0.3
1993	75	0.3
2003	193	0.1
2008	292	0.06
2010	341	0.06
2015	348	0.06

For early mortality estimate, dead pups were counted and either marked or discarded at sea to prevent double counting. A sample of pups were autopsied and an opinion reached about the cause of death. These results should be treated as provisional and they will need histopathological assessment for an accurate result. In 2015, some dead pups showed symptoms of two or more type of mortality and only the most likely mortality agent was recorded (Childerhouse et al. (2015)). Two earlier surveys also completed this analysis, but it was not clear which was the primary cause of death and the sum of categories did not add up so there may be some double counting and uncertainty about the results, especially in 2008. Results are shown in Table 47 along with the mean over the three surveys.

Table 47: **Early mortality rates and importance of sources (% of mortality) based on autopsy samples. In 2008, classifications overlapped, but finer catalogued data were not presented.**

Year	Mortality (%)	Autopsied sample size	Starvation (%)	Trauma (%)	Bacterial infection (%)
2014–15	58	60	62	30	7
2009–10	55	50	36	44	9?
2008	40	49	45	53	31
Mean	54		48	42	?

The largest threats were trauma and starvation so these were used in find how the population would respond when each of them was completely mitigated (*see* later).

A Leslie model was used that was based on the Otago model structure, i.e., females only. The values for parameters were Otago's median MCMC values. The model was started in 1990 with the Otago equilibrium age structure. Parameters used and their codes were:

N0:	number of females in 1990
S0:	survival age 0
S1.5:	survival ages 1–5
S6.14:	survival age 6–14
S15:	survival age 15+
PrP:	pupping rate at age 7+
relPrP4.6:	relative pupping rate at ages 4–6 (i.e., proportion of PrP)

Parameters estimated were N0 and one or more of S0, S6.14, and PrP, When S0 was not being estimated, it was set to 0.46 – 0.12 = 0.33. The 0.46 is the average survival from the proportion of dead pups seen on the pup count surveys, and 0.12 was used to account for mortality for the rest of the year, which was chosen subjectively, but in good survival years, Auckland Island has about 12% mortality for the first year.

Two types of fits were explored: fitting to all data and fitting the last 2 or 3 survey counts.
When fitting to all data, S0 was varied in one case, and then S0 was fixed to 0.33 and S6.14 varied, then both S6.14 and PrP varied. When fitting the last 2 or 3 survey counts, S0 was fixed to 0.33 and both S6.14 and PrP were varied. Another sensitivity was tried with S0 fixed to 0.25. The latter two analyses capture the recent dynamics and so are probably the more relevant. Evaluations were achieved using the growth rate of the Leslie matrix λ.

Results

It was impossible to fit all surveys at once. Either the first 5 survey fitted (using Otago S0 and varying the other 1 or 2 parameters), with the 2015 an outlier, or we can fit the last 3 surveys, and ignored the early 3 surveys (using S0 of 0.33). It is clear that the dynamics have changed some time since 2010. When fitting to the last 3 survey counts, λ was either 1.002 or 1.026, depending on the S0 used (Figure 68). Fitting to the last two surveys gave a λ of 1.004. These are much reduced from the λ obtained from fitting to the first 5 surveys (which ignores 2015) of 1.091 to 1.097. If these data are to be believed, then the population growth of the Campbell Island sea lion rockery has slowed considerably.

Table 48 shows the resultant λ when the threats starvation or trauma are removed (adjusted S0 to take that part of mortality out). Removing either gives healthy population growth. Trauma is the only threat that potentially can be mitigated.

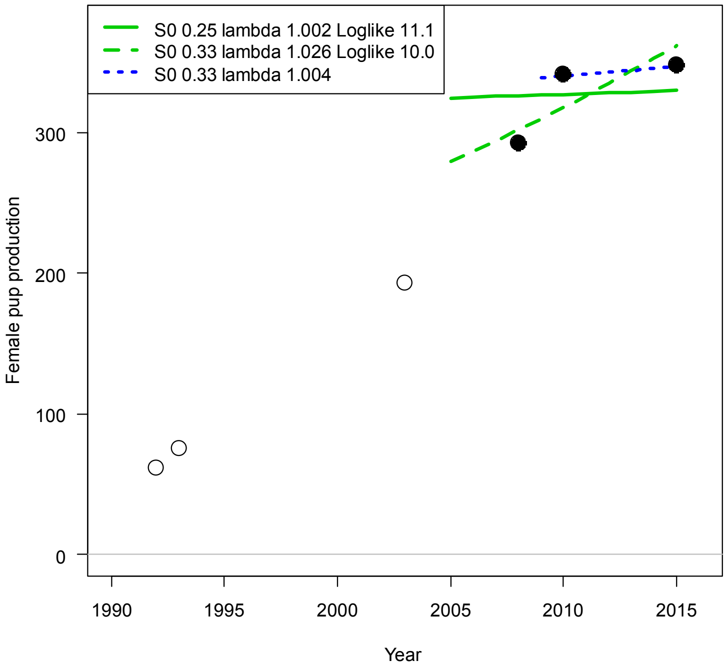


Figure 68: **Campbell Island NZSL: Fits of Leslie model to the last 2 or 3 survey counts. "Loglike" is the log-likelihood from the fit.**

Table 48: **Campbell Island NZSL, λ when starvation and trauma are removed from pup mortality. Fitting to 3 surveys with full pup mortality, λ was 1.028; to 2 surveys, λ was 1.004.**

Number of surveys fitted	S0 when threat removed	Threat removed	λ
3	0.60	starvation	1.087
3	0.63	trauma	1.093
2	0.60	starvation	1.063
2	0 .63	trauma	1.068

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APPENDIX 11 POPULATION ESTIMATE OF NZ SEA LIONS IN 2014/15

Introduction

A population estimate of all NZ sea lions was generated for the year 2014/15. This was based on estimates of population size for the four known breeding populations for the species at the Auckland Islands, Otago Peninsula, Campbell Island and Stewart Island.

Method

For the Auckland Islands and Otago Peninsula, total population size estimates were produced by SeaBird from demographic assessment models. The model estimates were for females only and so were doubled to give the total number of males and females. The base MCMC outputs were used in each instance (15+ configuration for the Auckland Islands; see the main body of this report), taking the median output of population size in 2015 generated from the MCMC samples.

There was no demographic assessment model for the Campbell Island and Stewart Island populations, so population size was estimated using whole-of-population to pup multipliers. The multipliers used were obtained by Leslie matrix eigenvector analysis, confirmed by iterating the model to stability (100 year iterations). Demographic rates used gave a population growth rate (λ) of 1.06 (Table 49), consistent with the growth in pup production at Campbell Island since the 1980s, allowing for underestimation in years prior to 2003. The pup multipliers were applied to the 2014/15 pup production estimates of 696 for Campbell Island and 36 for Stewart Island.

Table 49: Leslie Matrix model estimates of whole-of-population to pup multiplier with two alternative scenarios of first-year survival and pupping rate at age, while maintaining population growth rate (λ) at 1.06.

Demographic scenario	Parameter	Age						Pup multiplier
		0	1 to 3	4	5	6	7+	
Late maturation	Survival	0.5	0.95	0.95	0.95	0.95	0.95	5.40
	Pupping rate	0	0	0.05	0.25	0.5	0.85	
Early maturation	Survival	0.4	0.95	0.95	0.95	0.95	0.95	4.51
	Pupping rate	0	0	0.85	0.85	0.85	0.85	

Population estimate

Mortality will reduce the population size from a maximum towards the end of pupping up until the beginning of pupping in the next year. A total species population estimate of 11 800 was obtained including pups (immediately after pupping) and 9400 excluding pups (immediately prior to pupping) (Table 50), with the population size on a given date falling somewhere between these values. The total pup production for the species in 2014/15 was 2316 and the pup multiplier required to obtain the population estimate of 11 800 individuals was 5.08, within the range of pup multipliers used in this assessment (4.51 and 5.40).

Pup counts in 2006 were previously used to estimate a total population size of about 12 000 (95% confidence interval: 10 259–13 625) (Campbell et al. 2006). Pup production at Campbell Island has increased since (385 in 2003 and 696 in 2015 – an increase of 311; Childerhouse et al. 2005; Childerhouse et al. 2015a) with a third of all the species' pups now born here. This has offset about 60% of the decline at the Auckland Islands since 2006 (2089 in 2006 and 1576 – a decrease of 513; Childerhouse et al. 2015b), with some additional pupping at Stewart Island and the NZ mainland since 2006 (about 40 pups). As such we should expect the population estimate for 2015 to be close to that of 2006, and the estimate obtained here was lower by only 200 individuals.

Table 50: Population estimate for each population of NZ sea lions in 2014/15 and for the species. For the Auckland Islands and Otago Peninsula the range of values obtained from using pup multipliers of 4.51 and 5.40 was shown in parentheses after the mean of these values.

Population	Population size	
	Including pups (range)	Not including pups (range)
Auckland Islands	8 091	6 486
Otago Peninsula	37	31
Campbell Island	3 449 (3 139 – 3 758)	2 753 (2 443 – 3 062)
Stewart Island	178 (162 – 194)	142 (126 – 158)
All NZ sea lions	11 755	9 412

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