



Department of  
Conservation  
*Te Papa Atawhai*

## Department of Conservation Progress Report

**Title of Report:** Demographic modelling - Final model(s) developed

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**Project Title:** 4428 New Zealand sea lion – demographic assessment of the causes of decline at the Auckland Islands

**Project leader:** Ian Doonan

**Expected Project End Date:** 30 September 2014

**Objective:** 1, identify which demographic parameters are the key drivers of the observed population decline of New Zealand sea lions at the Auckland Islands

**Milestone:** 3, Final model(s) developed

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# 1 Background

In the previous project component (reported on at Milestone 2), candidate demographic models were developed for estimating time-varying demographic rates – including survival-at-age, pupping rates and age at maturation – of the Auckland Islands sub-population of New Zealand sea lions (*Phocarctos hookeri*). This had the aim of identifying the proximate cause(s) of the observed decline of the Auckland Islands sub-population since the late 1990s. A secondary aim of the demographic modelling exercise was to produce a long time series of demographic rates, which could then be correlated with biological, environmental and fishery-related correlates for identifying the ultimate causes of population decline and the potential for direct/indirect effects of commercial fishing operations.

In this project update we address recommendations and clarifications requested at the NZ Department of Conservation (DOC) Conservation Services Programme (CSP) Technical Working Group meeting on 1 August 2013, at which the Milestone 2 report was presented.

## 2 Summary of CSP Technical Working Group recommendations

The client and DOC CSP Technical Working Group identified four areas in which clarification or additional text were required in this project update:

- **Clarification of the model development process**
  - Provide interpretative text and figures to simply describe the model development process that has been undertaken and describe the expected future model developments.
  - Develop the Introduction such that there is sufficient guidance to take the reader through the report. Also to provide a “roadmap” of modelling processes undertaken and how outputs will be used in the next phase of the project.
- **Clarification of the use of observations from PIT-tagged and branded individuals**
  - List the sets of observations that were used or omitted in the estimation of demographic rates at each modelling stage.
  - Of those that were omitted, provide clarification as to why it was decided they would not be used.
- **Clarification of analyses conducted to estimate tag loss rate**
  - What are our assumptions of tag loss independence?
  - Do we expect to use branded and/or chip data to estimate tag loss - different resighting probabilities and large increase to number of partitions?

- Where are the issues with flipper tag and chip data (e.g. no recording of when chips/flipper tags were looked for)? Do we have the data we need to estimate time-varying tag loss or do we need different data recording protocols?
- Do we expect to be able to make good estimates of tag loss?
- Clarify which models are estimating tag loss.
- **Clarification of analyses conducted to assess cohort effects on demographic rates**
  - Clarify the extent to which cohort effects on breeding success associated with cohorts born in disease epidemic years (e.g. 1998, 2002 or 2003) will be investigated.
  - Where the inferences made differ from those of previous assessments, identify the reasons for these differences (e.g. differences in data subsets or time series of observations used or caused by differences in modelling approach).

In addition, the CSP Technical Working Group recommended some additional modelling tasks and clarifications that should be addressed in the final project report that will not be directly addressed here. The recommendations were as follows:

- Investigate using a step function for adult survival, or search for a break point to look at potential long-term changes in survival rate.
- Attempt to distinguish year effects from those effects due to legacy of particular cohorts. Where this is not possible explain the reasons why it cannot be done with this modelling approach.
- Re-label survival estimates (“pseudo-survival” or “survival confounded with tag loss”) for model runs where tag loss rate was not simultaneously estimated.
- Comment on issues relating to the usage of observations of flipper-tagged, PIT-tagged and branded individuals for estimating tag shedding rates, i.e. where there are inconsistencies, how could the data collection process and reporting be improved?

Descriptive text and diagrams in the following sections will be incorporated in to the final report.

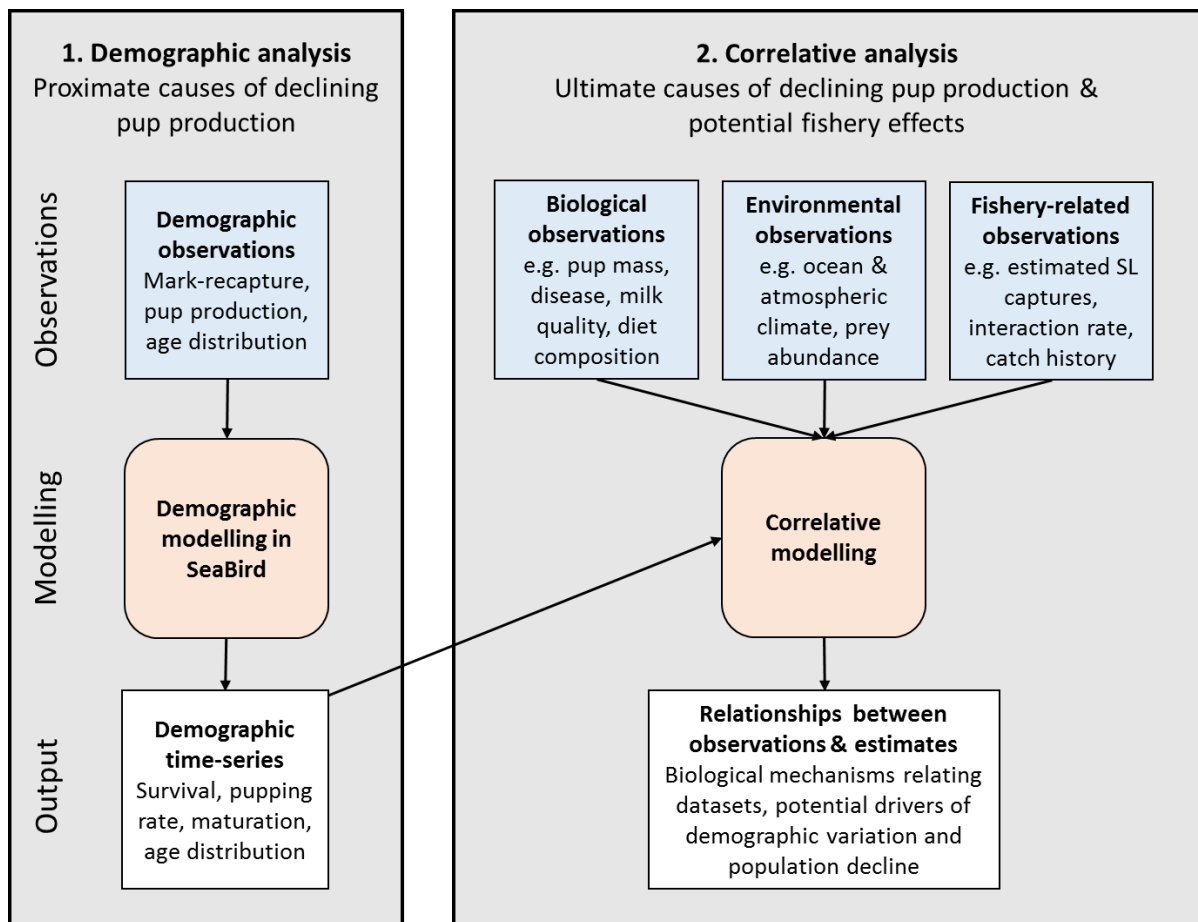
### 3 Clarification of the model development process

The following text includes guidance text and figures that will be incorporated in the final project report.

The project can be split up to two main components (Figure 1):

- **A demographic modelling component in SeaBird**, which deals with the estimation of long-term time series in key demographic rates, i.e. survival-at-age, pupping probability or different demographic groupings, maturation. This has the aims of:
  - Identifying the demographic processes that are likely to be driving the decline in the NZ sea lion population at the Auckland Islands (proximate causes of decline)
  - Provide long-term times-series of demographic rates for project component 2.
- **A correlative analysis component**, which takes demographic time series in component 1 and relates to biological, environmental or fishery-related correlates to identify the ultimate causes of the decline in the Auckland Islands population.

*Figure 1 Methodological overview of project approach. SeaBird is NIWA's mark-resighting analysis package.*



This report deals only with the first of these project components. Due to the inherent flexibility of modelling with SeaBird a wide array of model configurations could be developed. We adopted a sequential model optimisation process in which the most parsimonious parameterisation (lowest AIC) was sought for one demographic rate (e.g. survival) before moving on the next (e.g. resighting probability) (see Table 1). Thus model optimisation proceeded in the following order:

1. An initial **exploration of age, cohort and year effects** on survival, pupping rates and annual resighting probability:
  - Age effects on survival, pupping and resighting probability were explored using different functional forms and step functions to find the most parsimonious parameterisation with respect to age. All parameter estimates were year invariant in this modelling step.

- Cohort effects were also explored with year-invariant estimates, though purely on an investigative bases and the results obtained had no bearing on the model optimisation process.
  - Year effects were also explored on an investigative basis, with separate estimates of survival, pupping and resighting probability for each year for which the data were informative. Different parameterisation of year effects (e.g. year-invariant or all varying) were subsequently explored in more detail in the next phases of model optimisation.
2. A **sequential model optimisation process** was used to identify the most parsimonious parameterisation of (in this order) survival, resighting probability, pupping probability, then maturation. This considered:
- Year invariant versus all year-varying estimates.
  - Estimates for different demographic groupings (e.g. age, or pupping status).

**This concluded the model optimisation process with regards to parameterisation.** The most parsimonious model parameterisation (model run 7a, described in Roberts et al., 2013) was then taken forward to the next model development phase.

3. Survival estimates were adjusted to account for pups that were reported to have died prior to tagging through modification of the mark-recapture observations to include a proportional number of “phantom” tagged pups that were not observed again in subsequent years. The model configuration was not altered from that of run 7a and as such this should not be considered a model optimisation step. SeaBird was used to generate estimates separately using pups tagged at Sandy Bay and at Dundas, using resightings from the Sandy Bay and Dundas respectively. This was the only modelling step in which Dundas observations were used.
4. Markov Chain Monte Carlo (MCMC) samples were then generated using the model 7a configuration to estimate the degree of uncertainty around model estimates (95% prediction intervals reported).
5. A series of model validation steps were then undertaken:
- A retrospective analysis was conducted to assess the effect of the number of resighting years on parameter estimates, e.g. to determine how many years

of resighting effort is normally required before estimates are stabilised. Parameterisation was as for model 7a.

- Model Partitioning I was used to fit to age distribution observations at Sandy Bay in 1998-2001 (Childerhouse et al., 2010a). Parameterisation was as model 7a.
- A second type of model partitioning (Partitioning II, see figure 3) was used to simultaneously estimate survival and tag loss (these are otherwise confounded). Year-invariant estimates of tag loss at age0 and age1+ were generated along with separate survival estimates. Parameterisation was as model 7a.

The tag loss model partitioning was retained in a population model used to fit to pup census observations at Sandy Bay (supplied by NZ DOC). The estimated number of pupping females in a particular year was fit to annual pup count. Parameterisation was as model 7a, except that there were no maturation parameters.



Table 1 Demographic model development process. "MR" is tag-resighting data, PP is pup production. Two different model partition types used. Mark-recapture observations from Sandy Bay (SB), or Dundas Island (DD).

Modelling objective	Run	Model	Observations	Partitioning	Tag shedding	Phantom tags	Year-varying parameters	Area
Initial model parameterisation and description of age, cohort and year effects	1	Age-effects	MR	I	N	N	N	SB
	2	Cohort-effects	MR	I	N	N	N	SB
	3	Year-effects	MR	I	N	N	Y	SB
Sequentially determine optimal parameterisations of survival, resighting, pupping & maturation	4a-m	Survival optimisation	MR	I	N	N	Y	SB
	5a-m	Resighting optimisation	MR	I	N	N	Y	SB
	6a-d	Pupping optimisation	MR	I	N	N	Y	SB
	7a	Maturation optimisation	MR	I	N	N	Y	SB
Account for pups dead at tagging	8	Phantom tag model	MR	I	N	Y	Y	SB & DD
Estimate uncertainty around model estimates	9	MCMC	MR	I	N	Y	Y	SB
Model validation runs	10	Retrospective analysis	MR	I	N	Y	Y	SB
	11	Tag loss model	MR	II	Y	Y	Y	SB
	12	Fit to pup counts	MR, PP	II	Y	Y	Y	SB
	13	Fit to age distribution	MR, Age	I	N	Y	Y	SB

All model runs use observations for female component of the population only and use the strict definition of pupping status detailed in Table 5 of Roberts et al. (2013), as also used by MacKenzie (2011). Demographic modelling assessments of the Auckland Islands sub-population of NZ sea lions have previously been conducted in MARK (Chilvers & MacKenzie 2010), Bayesian multi-state mark recapture models in Winbugs (MacKenzie 2011), using mixture models in ADMB (Gilbert & Chilvers 2008) and integrated population models also in ADMB (Breen et al., 2012). There are a number of differences in the parameterisation and model configuration used when comparing with these other assessments, which may lead to very different estimates when comparing outputs (summarised in Table 2).

In this assessment, a step function was used to estimate discrete survival probabilities for different age groupings, which in the optimal model were time-varying for all groupings except for age15+. McKenzie (2011) and Chilvers and McKenzie (2010) produced annual estimates for all ages, using multipliers to generate estimates of survival for different age groupings (0-3 and 4-14 and 15+), i.e., a fixed age pattern. Thus for a given year, age-specific estimates were not independent of each other (survival of ages 0-3 will have been influenced by observations of 4-14 and 15+ aged individuals). Gilbert and Chilvers (2008) estimated cohort specific survival for pups to age 1 and then a functional form (again a fixed pattern) for all other ages with year-invariant parameters.

As with MacKenzie (2011), pupping rate was estimated separately for animals that pupped or did not pup in the previous year. Exploration of age effects on pupping rate indicated that a step-function would adequately reflect changes in pupping rate with age (as opposed to

using a functional form, as Gilbert & Chilvers, 2008). We estimated maturation parameters using a functional form, which gave the probability of immature individuals between ages 3 and 7 pupping in the next year. Immature individuals were not included in pupping rates calculations and so our estimates of pupping rate for individuals that did not pup in the previous year should be different from those of McKenzie (2011).

Model estimates of year-varying demographic rates (median of MCMC samples from the model configuration as model run 7a in Roberts et al., 2013, see Appendix A) were then carried forward to the correlative analysis phase of the study in which demographic rates were compared with biological (e.g. pup mass or milk quality), environmental (e.g. climate indices) and fishery-related correlates (e.g. estimated captures relating to fishing operations).

Table 2 Table summarising differences comparing this study with other demographic assessments of the NZ sea lion population at the Auckland Islands

Study	Colony and years of mark-recapture observations	Tag type	Survival	Resighting probability	Tag loss	Maturation at age	Pupping rate
Roberts et al., 2013	Females; Sandy Bay & Dundas; marked 1990-1993 & 1998-2011; resighting 1999-2012	Tagged pups, excluding branded pups and resighting where only a PIT tag ID was recorded	Independent estimates for each demographic grouping; survival functional form explored (as Gilbert & Chilvers 2008) though not optimal	Annual resighting probability; independent estimates for each demographic grouping	Year-invariant; assumed can only lose 1 tag each year; 2 parameters: one for age 0 and another for all other ages	Two parameters give probability of pupping for first time at ages 4-7; time-varying	Separate estimates of pupping for females that did or didn't pup in the previous year; dome-shaped functional form explored (as Gilbert & Chilvers 2008) though not optimal
Breen et al., 2013	Females; Auckland Islands; marked 1987, 1990-93 & 1998-2004; resighting 1998-2007.	Tagged and branded as pups and adults	Annual survival at specified ages with survival at intermediate ages determined through linear interpolation. Density dependent pup survival.	Year-invariant with separate estimates for breeding and non-breeding females tagged as pups and non-breeding females that were branded	Not estimated	Implicitly incorporated in to age specific pupping rate	Age specific pupping rate. Functional form given by age at 50% maturity
Childerhouse et al., 2010b	Females; Sandy Bay; marked [not specified]; resighting 1999-2005.	Tagged as pups and branded as pups and adults	Not estimated	Not estimated – estimates of pupping rate for all individuals for which pupping status was confirmed and also for an additional dataset including individuals not seen though known to be alive (assumed to be non-puppers)	Not estimated	Implicitly incorporated in to age specific pupping rate	Estimated as a domed function of age with five parameters
Chilvers &	Males and	Tagged and	Multiplier related	Annual resighting	Year-invariant;	Not estimated	Not estimated

MacKenzie 2010	females; Sandy Bay; marked 1990-1993 & 1998-2005; resighting 1999-2006	branded pups; including resighting where only a PIT tag ID was recorded	estimates for each age grouping	probability, with separate estimates for individuals with 1 or 2 flipper tags and by age group.	separate estimates for losing both tags or just one tag; 2 parameters: one for age0 and another for all other ages.		
Chilvers et al., 2010	Females; Sandy Bay; marked 2000; resighted 2001-2005	Branded as adults	Estimated as a domed function of age with four parameters; year-invariant	Year-invariant estimates for different demographic groupings relating to pupping status and survival of pup	Not applicable to branded individuals	Implicitly incorporated into functional form of pupping rate at age	Estimated as a domed function of age with five parameters; separate estimates depending on pupping status and survival of pup in the previous year
Gilbert & Chilvers, 2008	Females; Enderby; marked 1987 & 1990-1993 & 1998-2003; resighting 2000-2007	Tagged and branded pups	Estimated first years survival for each cohort, then a functional form across all other ages with year-invariant estimation	Multipliers gave observation frequencies for different demographic groupings (not estimated independently)	Not estimated separately of survival	Implicitly incorporated into functional form of pupping rate at age	Estimated as a domed function of age with five parameters; separate estimation for each cohort; no separate estimation based on pupping status in previous year
MacKenzie, 2011	Females; Enderby (Sandy Bay and SE Point); marked 1990-1993 & 1998-2005; resighting 1999-2010	Tagged and branded pups; including resighting where only a PIT tag ID was recorded	Multiplier related estimates for each age grouping	Daily resighting probability estimated for PIT-tagged, branded and flipper tagged individuals; ages 0-3 and 4+. Converted to annual resighting probability.	Year-invariant; separate estimates for losing both tags or just one tag.	Not estimated	Separate estimates of pupping for females that did or didn't pup in year+1

## 4 Clarification of the use of observations from PIT-tagged and branded individuals

In addition to flipper tagging, a number of pups born at Sandy Bay were branded (2000 only) or PIT-tagged (1999-2003 and since 2010). Observations of these individuals have been used in previous demographic assessments to obtain more accurate estimates of tag loss. Branded and PIT-tagged individuals may be used to estimate the probability of losing both tags in one year where the probabilities of losing each tag are not independent.

All models reported on in Roberts *et al.* (2013) only used observations of individuals that were flipper-tagged as pups. We did not use mark-recapture observations of pups that were branded. In addition we did not use any resighting observations where a PIT tag ID was recorded though not a flipper tag ID. Branded and PIT-tagged individuals have a different resighting probability than individuals that are flipper-tagged only (Chilvers & MacKenzie 2010; MacKenzie 2011) and would necessitate an additional set of partitions for each mark-recapture observation type. Models configured to estimate tag loss using only mark-recapture observations of flipper-tagged individuals required a very large number of partitions and took a very long time to run.

In addition, PIT tagging and branding of pups was not conducted in all years that pups were flipper-tagged:

- Pups were branded in 2000 only and the probability of losing two tags in one year may vary by cohort (tag manufacture and tagging method effects on tag loss rate);
- Pups were also PIT-tagged in only a limited number of years (1998-2002 and since 2010) and so would not be informative for separating cohort effects on tag loss and survival for the majority of the cohorts assessed in this study. This would be a major limitation given that long time series of demographic rates are required in the second phase of the project to relate to biological, environmental and fishery-related correlates;

It was decided not to use observations of individuals branded as pups or resightings of animals based on PIT tag readings in this assessment, given time constraints and the limited improvements that would be made in the estimation of parameters not relating to tag loss.

A brief analysis of tag type effects on resightings was conducted for cohorts that were PIT-tagged as pups. For the 1998 cohort, the relatively large proportion of resightings based on PIT-tag ID and that did not have flipper tags suggests that tag loss rates were particularly high for this cohort (Figure 2). Round flipper tags were used in this year and were thought to

have a greater tag loss rate relative to coffin flipper tags used in all subsequent years (Louise Chilvers pers. comm.). Even so, the relatively low resighting rate per individual for this cohort (from all mark types) indicates that survival of this cohort was still low relative to other cohorts, though SeaBird model estimates will have a strongly negative bias. We do not intend to correct for this bias within this project though may omit pup/yearling survival estimates for the 1998 cohort (and also the 2008 cohort for which a high tag pull out rates was estimated) from the correlative assessment as a sensitivity analysis.

This analysis also suggests that tag loss rate was relatively high for the 1999 cohort relative to all subsequent cohorts (2000 to 2002) and this may reflect the learning experience of taggers in the field with respect to tag application.

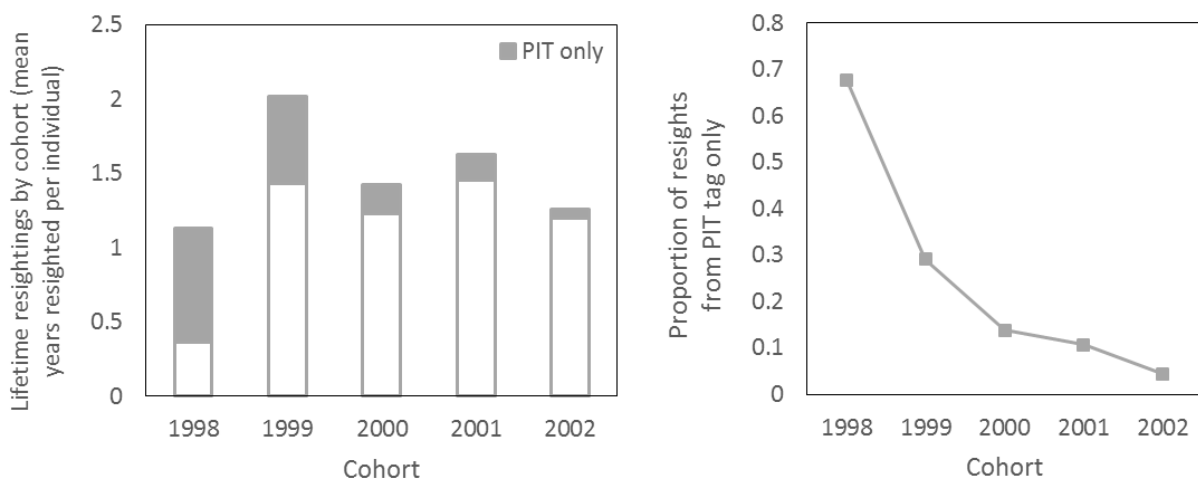


Figure 2 Cohort effect on resightings of females over lifetime that were recorded as PIT-tagged only at the time of resighting (and not flipper tagged or branded) as a proportion of resightings from all mark types. Lifetime resightings are defined as the number of years in which an individual was resighted. Data subset included only individuals that were PIT-tagged as pups at Sandy Bay and subsequently resighted at Sandy Bay.

## 5 Clarification of analyses conducted to estimate tag loss rate

Some prior grooming of the mark-recapture data was required to obtain the number of flipper tags present for each resighting recorded in the mark-recapture database. The number of tags is recorded in the Dragonfly database in field “n\_tags” with values of “L1,R1”, “L1,R0”, “L0,R1” or “L0,R0”, depending on which combination of left and right flippers were present on the observed individual. When the presence of a tag on a flipper could not be determined this recorded as “L1,R?” (tag observed on left flipper, not known if tag was present on the right flipper). Some key inconsistencies were identified in the recording of tag frequency in this field:

- A flipper tag may be reported as missing when subsequent records indicated that the tag was still present (e.g. “sea lion” ID 20030123-4529 or 20040115-4745). Where this was the case the tag was assumed still be present up to the date after which it was consistently reported as lost.
- A flipper tag may be reported as present when previous and subsequent records indicate that the tag had been lost (e.g. “sea lion” ID 20040115-4764 or 20040115-4851). Where this was the case the tag was assumed to have been lost prior to the first time it was reported as absent.

In addition there currently is no field in the mark-recapture database to indicate whether flipper tags were looked for. Future analyses would be facilitated by ensuring that this field is always populated (“L?,R?” has been used to signify that flipper tags were not checked in some cases and could be used as standard).

We used a different partitioning (Type II; this and other partitioning types are described in Roberts et al. 2013) to estimate tag loss rates simultaneously with survival, using the optimised model parameterisation (as model 7a). This was necessary in order to generate estimates of survival separately of tag loss and also to fit to pup census observations (where not including these would lead to the underestimation of breeder numbers in later years).

The Type II partitioning has a separate set of partitions (i.e., replicated model 7a’s partition three times) for individuals that have two tags, one tag or no tags (see figure 3). Two parameters gave the probability of losing a single tag in a year: one at age 0 and the other at all other ages, respectively.

## PARITITIONING II

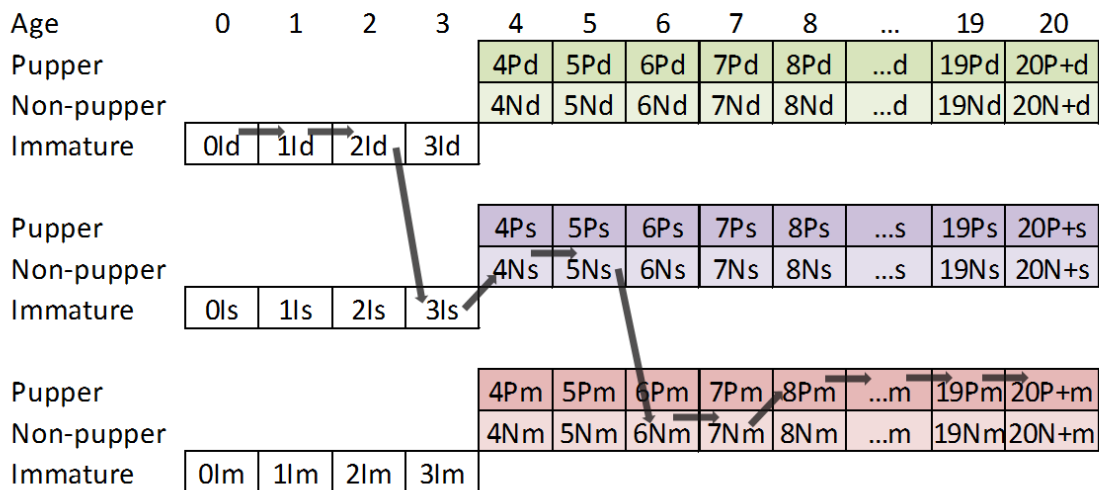


Figure 3 Model partitioning used in model runs estimating tag loss parameters (Partitioning Type II). Cell notation is <age><breeding status><number of tag code>, where breeding status is I (immature), N (did not pup in year-1), and P (pupped in year-1, and the number of tags is given by the "d" = double (2 tags); "s" = single (1 tag); "m" = missing (0 tags). In this illustrative example (grey arrows), the sea lion was double flipper tagged as a pup, lost one tag between ages 2 and 3, lost the other tag between ages 5 and 6 and produced a first pup at age 8. Note that there are no resighting observations of individuals in the bottom set of partitions for which there are no tags.

Models were configured to obtain year-invariant estimates of tag loss because:

- When using only flipper tag observations cohort effects on tag shedding rates would be confounded with cohort effects on survival at age 0;
- The tag loss model took several hours to run with year-invariant tag loss parameters.

It is known that some individuals may lose both tags in a year and this probability was derived as the square of the probability of losing a single tag. However, it is known that the rate at which double tag loss occurs is greater than the combined probability of losing a single tag in one year and another tag in the next year (MacKenzie 2011; Chilvers & MacKenzie 2010) and, so, the models as configured will produce slightly decreased estimates of survival. However, assuming that there is no temporal variation in the probability of losing both tags, the shape of the response to year effects will be approximately similar and so this should not greatly affect the outputs of the correlative modelling phase of the project.

Preliminary tag loss estimates from this study are presented alongside those of previous studies. A number of differences exist comparing data subsets and model configurations used that might explain different estimates of tag loss in these different studies. In addition there were differences in the way that the rate of losing both tags in a single year were estimated (Table 3).



Table 3 Preliminary annual female tag loss rates estimates compared with estimates from other studies. Estimates for individuals tagged as pups. Studies used data observations from different time series (see Table 2).

Study	Parameter	Value	Comments
Roberts <i>et al.</i> (2013)	Age 0; 2tags > 0tag	0.007	Separate tag loss probability for individuals ages 0 and 1+. Probability of losing two tags in the same year taken as the square of the probability of losing a single tag. Tag loss probabilities were assumed constant with respect to year.
	Age 1+; 2tags > 0tag	0.002	
	Age 0; 2tags > 1tag	0.156	
	Age 1+; 2tags > 1tag	0.093	
	Age 0; 1tags > 0tag	0.085	
	Age 1+; 1tags > 0tag	0.049	
Chilvers & Mackenzie (2010)	Age 0; 2tags > 0tag	0.10	Tag loss estimates use observations based on resightings of brands and PIT tags. Independent estimates for losing both tags in a single year. Tag loss probabilities were assumed constant with respect to year.
	Age 1+; 2tags > 0tag	0.01	
	Age 0; 2tags > 1tag	0.21	
	Age 1+; 2tags > 1tag	0.13	
	Age 0; 1tag > 0tag	0.13	
	Age 1+; 1tag > 0tag	0.13	
Mackenzie (2012)	2tags > 0tag	0.04	Tag loss estimates use observations based on resightings of brands and PIT tags. Tag loss probabilities were assumed constant with respect to animal age and year.
	2tag > 1tag	0.14	
	1tag > 0tag	0.11	

Given that separate year-invariant tag loss probabilities were estimated for age 0 and all ages 1-20+, cohort-specific estimates of survival (ages 0 and 1) will be confounded with the yearly deviations of tag loss from the mean. Given that we will not be using resightings based on PIT-tag observations (used to tag pups in a limited number of years) it will not be possible to estimate cohort effects on tag loss. A potential method to overcome this flaw that uses 4-week flipper tag pull out rate is briefly described below.

## **6 Clarification of analyses conducted to assess cohort effects on demographic rates**

The current version of SeaBird cannot be used to separate cohort and year effects and we have no plans to change SeaBird to allow this within the scope of this project. However, a limited assessment of cohort effects on demographic rates was achieved by running SeaBird on cohort subsets of mark-recapture observations. For each cohort (birth year), the data subset comprised all females tagged as pups in that year and all resighting observations for those individuals in subsequent years, i.e., a separate model run was made for each cohort. As such, cohort effects were not truly separated from year effects, though cohort effects would be relatively stronger for parameters estimated over broader age groupings (e.g. survival at ages 6-14).

The model configuration used to estimate cohort-specific demographic rates is described in Roberts et al (2013). Briefly, the parameters estimated were year-invariant, there were no tag loss parameters and parameters were estimated for the same demographic groupings as with model 7a.

Cohort effects on survival are shown in Roberts et al. (2013), with separate estimates for individuals that did and did not produce a pup in the previous year. In this update we have used model estimates of numbers in each age partition in the model fit to pup census observations to derive cohort specific pupping rates for all individuals at ages 4-7 (during maturation) and 8-14 (all assumed to be mature) (Figure 4).

The results indicate that the pupping rate of the 1998 cohort was relatively good. In a previous analysis this cohort was previously found to have a low pupping rate, though there are some major differences in model configuration, which may lead to these opposing results (Gilbert & Chilvers 2008). Gilbert & Chilvers (2008) estimated year-invariant survival for age 0 only and a functional form was used to estimate survival at all other ages, with year-invariant parameter estimation. In our assessment (model 7a), survival was estimated separately for ages 0, 1, 2-5, 6-14 and 15+ and survival of the 1998 cohort at age 2-5 was the lowest of any cohort (see figure 5 of Roberts et al., 2013). Thus the model configuration adopted by Gilbert and Chilvers (2008) will have underestimated pre-breeding mortality of this cohort and overestimated the number of non-breeding individuals (which have a low resighting probability). In any case, given that pup/yearling of this cohort was relatively low and very few individuals were observed at breeding age, there will be a high degree of uncertainty in the estimates of pupping rate from this cohort and this will generally be the case for all cohorts for which few individuals survived to breeding age.

Estimated pupping rates for the 1999 and 2001 cohorts were relatively low, whilst those of the 2000 cohort and all born since 2002 are relatively high at ages 8-14 (also high pupping rate for cohort born since 2003 for ages 4-7) (Figure 4).

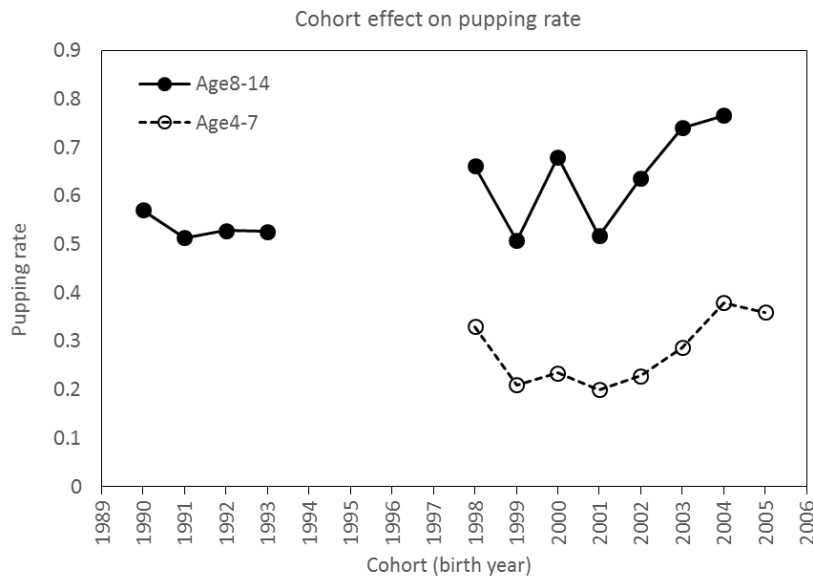


Figure 4 Pupping rate derived from model estimates of numbers in each model partition, from the model run fit to pup census observations.

Using the same model estimates of numbers in each demographic partition, we also found evidence for cohort effects on the age at first pupping, with an increased proportion of individuals from cohorts born since 2004 pupping by age 6 (Figure 5). This was detected in the model development phase as a change in maturation in parameters since 2010 (see figure 12 of Roberts et al., 2013) and it is not possible to differentiate year from cohort effects on maturation.

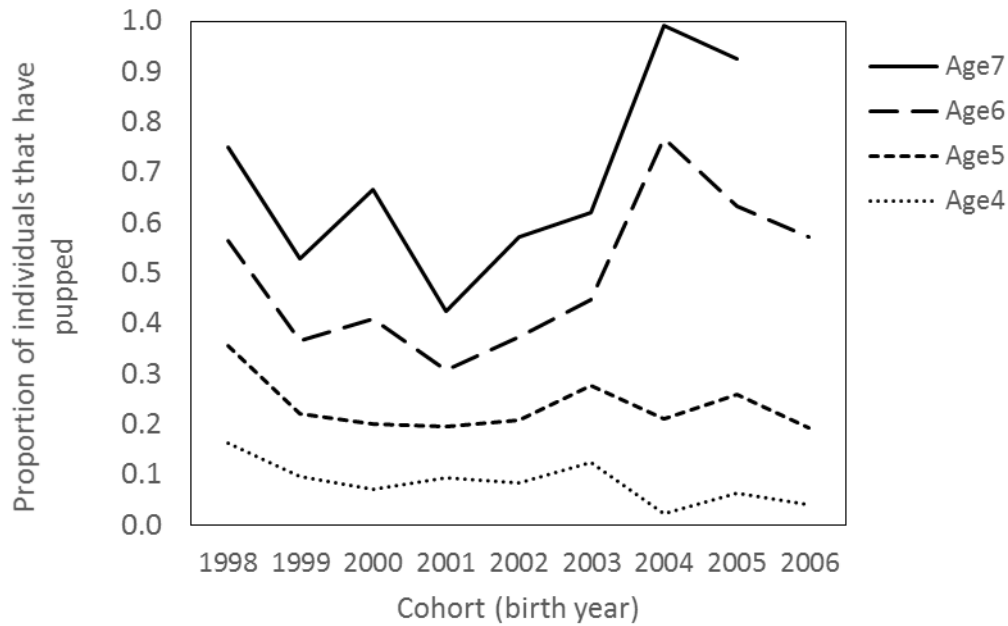


Figure 5 Cohort effects on the proportion of individuals that have pupped at age. Derived from model estimates of numbers in each model partition, from the model run fit to pup census observations.

## 7 Proposed handling of additional recommendations to be addressed in the Final reporting phase

Additional suggestions for model development and reporting of model outputs have been raised since the Milestone 2 report was presented (Roberts et al., 2011).

### Model development

- It was suggested that 4-week tag-pull out rate observations could be used to estimate year-varying tag loss rates at age 0, in years for which these data are available (Table 4). These data indicate that there may be cohort effects on tag loss, such as high tag pull-out rate of the 2008 cohort for which the SeaBird pup/yearling survival estimates were very low. We intend to investigate the usage of these data to separate cohort effects on tag loss at age 0 and pup/yearling survival. Note that tag loss in the first year is thought to result from a combination of tag placement and tag durability (relating to selected tag design and quality of manufacture), whereas tag loss after age 1 is thought to result primarily from tag durability. As such, where cohort effects on tag pull out rate at 4 weeks have arisen from variable tag durability, these rates may also be used to estimate relative tag loss rates at ages 1+.
- It was noted that estimates of 15+ survival were very high when fitting to pup census observations – much greater than estimates obtained from model runs using only

mark-recapture observations. When fitting to pup census observations we intend to fix survival of the 15+ age group to the value estimate from the mark-recapture model with equivalent parameterisation.

*Table 4 Provisional annual tag pull-out rate of flipper tags in pups at 4-weeks of age (DOC, unpublished data).*

Year	4-week tag pull out rate (%)
2000	0.3
2001	0.2
2002	0.5
2003	0.2
2004	0.4
2005	1.4
2006	0.6
2007	1.3
2008	3.5
2009	0.8
2010	0.0
2011	0.0
2012	1.8

#### Presentation of model outputs

- Suggestions were given as to methods for graphical representation of model estimates, such as bubble plots for representing estimated population size at age for different cohorts (see Figure 6).
- Where model estimates of survival are made from models that do not also estimate tag loss, estimates of survival are confounded with tag loss and should be referred to as such in relevant plots and text.

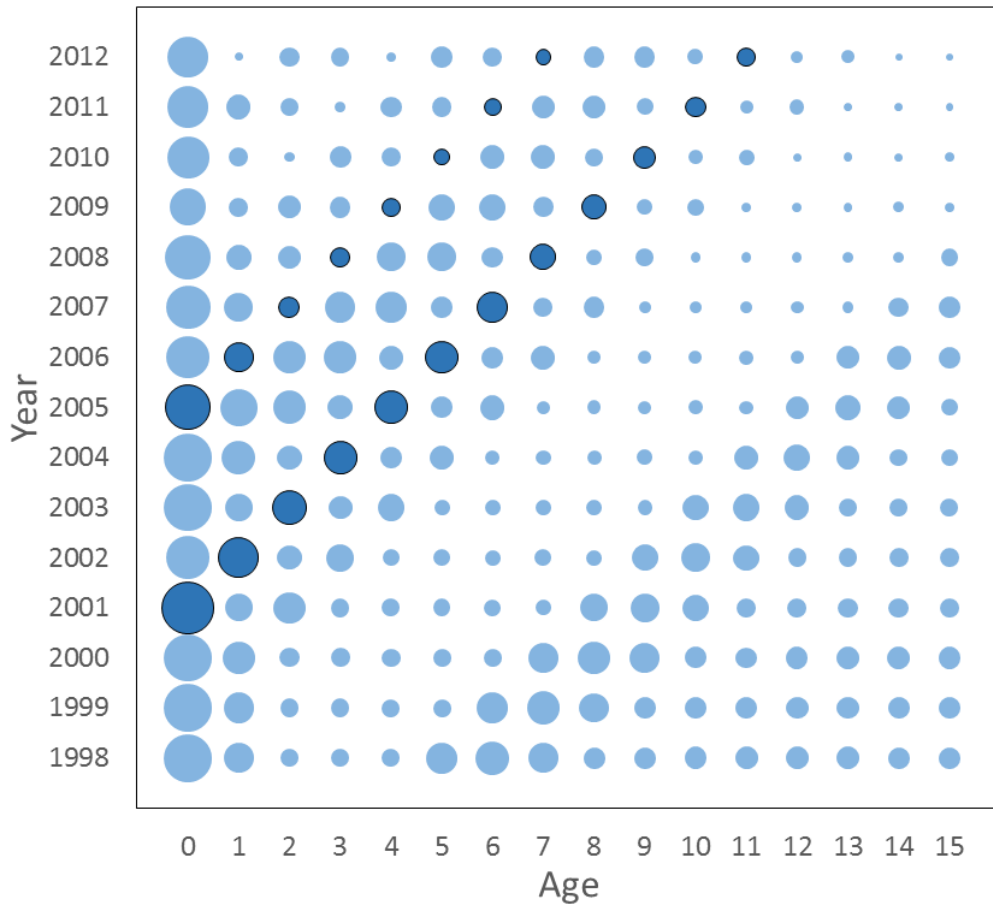


Figure 6 Example bubble plot of model estimated female population numbers at age for a given year. Two cohort are highlighted, 2001 for which pup/yearling survival was relative high and 2005 for which pup/yearling survival was low. Model estimates of survival for cohorts born 1994 to 1997 may be unrealistically low as there are no mark recapture data to inform survival estimates for these cohorts

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## Appendix A – Demographic modelling outputs carried forward to the correlative analysis

Table 5 Demographic parameter estimates to be carried forward to the correlative modelling phase of the project. Median MCMC estimates from model configured as model run 7a (see Roberts et al., 2013); estimates used may change depending on further model development as described in this report. Parameter notation is <demographic rate><age range><year>, where “Surv” are estimates of survival to year+1 (confounded with tag loss); “Mat” are maturation parameters 1 and 2; “NP” and “PP” are estimates of puppers and non-puppers pupping in year+1.

Parameter	Value	Parameter	Value
Surv 0_1990 * Surv 1_1991	0.56 (0.40 - 0.90)	Surv 6_14_1998	0.94 (0.83 - 1.00)
Surv 0_1991 * Surv 1_1992	0.61 (0.43 - 0.81)	Surv 6_14_1999	0.91 (0.84 - 0.96)
Surv 0_1992 * Surv 1_1993	0.52 (0.40 - 0.69)	Surv 6_14_2000	0.81 (0.74 - 0.87)
Surv 0_1993 * Surv 1_1994	0.46 (0.37 - 0.57)	Surv 6_14_2001	0.90 (0.85 - 0.95)
Surv 0_1998 * Surv 1_1999	0.16 (0.11 - 0.22)	Surv 6_14_2002	0.81 (0.74 - 0.87)
Surv 0_1999 * Surv 1_2000	0.45 (0.35 - 0.62)	Surv 6_14_2003	0.86 (0.78 - 0.91)
Surv 0_2000 * Surv 1_2001	0.22 (0.13 - 0.32)	Surv 6_14_2004	0.81 (0.71 - 0.88)
Surv 0_2001 * Surv 1_2002	0.43 (0.38 - 0.52)	Surv 6_14_2005	0.90 (0.82 - 0.97)
Surv 0_2002 * Surv 1_2003	0.30 (0.24 - 0.36)	Surv 6_14_2006	0.80 (0.69 - 0.89)
Surv 0_2003 * Surv 1_2004	0.47 (0.38 - 0.55)	Surv 6_14_2007	0.68 (0.59 - 0.77)
Surv 0_2004 * Surv 1_2005	0.40 (0.32 - 0.49)	Surv 6_14_2008	0.82 (0.76 - 0.90)
Surv 0_2005 * Surv 1_2006	0.19 (0.14 - 0.25)	Surv 6_14_2009	0.80 (0.73 - 0.87)
Surv 0_2006 * Surv 1_2007	0.28 (0.20 - 0.35)	Surv 6_14_2010	0.86 (0.80 - 0.92)
Surv 0_2007 * Surv 1_2008	0.28 (0.22 - 0.35)	Surv 6_14_2011	0.80 (0.73 - 0.92)
Surv 0_2008 * Surv 1_2009	0.05 (0.03 - 0.08)		
Surv 0_2009 * Surv 1_2010	0.29 (0.19 - 0.41)	Surv 15+	0.58 (0.50 - 0.66)
Surv 0_2010 * Surv 1_2011	0.18 (0.07 - 0.28)		
Surv 2_5_1992	0.64 (0.35 - 0.98)		
Surv 2_5_1993	0.73 (0.54 - 0.98)		
Surv 2_5_1998	0.88 (0.75 - 1.00)		
Surv 2_5_1999	0.97 (0.92 - 1.00)		
Surv 2_5_2000	0.90 (0.71 - 1.00)		
Surv 2_5_2001	0.63 (0.49 - 0.75)		
Surv 2_5_2002	0.89 (0.81 - 0.97)		
Surv 2_5_2003	0.81 (0.74 - 0.88)		
Surv 2_5_2004	0.98 (0.93 - 1.00)		
Surv 2_5_2005	0.94 (0.83 - 0.99)		
Surv 2_5_2006	0.84 (0.75 - 0.91)		
Surv 2_5_2007	0.91 (0.84 - 0.98)		
Surv 2_5_2008	0.86 (0.77 - 0.95)		
Surv 2_5_2009	0.78 (0.72 - 0.86)		
Surv 2_5_2010	0.96 (0.89 - 1.00)		
Surv 2_5_2011	0.84 (0.71 - 0.93)		



Parameter	Value	Parameter	Value
Mat_1_1998	0.40 (0.25 - 0.62)	NP_1999	0.56 (0.45 - 0.36)
Mat_1_1999	0.47 (0.12 - 0.72)	NP_2000	0.59 (0.47 - 0.36)
Mat_1_2000	0.33 (0.08 - 0.61)	NP_2001	0.51 (0.38 - 0.24)
Mat_1_2001	0.07 (0.01 - 0.16)	NP_2002	0.73 (0.54 - 0.44)
Mat_1_2002	0.02 (0.01 - 0.07)	NP_2003	0.68 (0.49 - 0.34)
Mat_1_2003	0.16 (0.08 - 0.26)	NP_2004	0.41 (0.24 - 0.13)
Mat_1_2004	0.08 (0.04 - 0.13)	NP_2005	0.37 (0.24 - 0.15)
Mat_1_2005	0.04 (0.02 - 0.09)	NP_2006	0.41 (0.28 - 0.18)
Mat_1_2006	0.09 (0.05 - 0.19)	NP_2007	0.60 (0.48 - 0.25)
Mat_1_2007	0.11 (0.05 - 0.19)	NP_2008	0.62 (0.46 - 0.29)
Mat_1_2008	0.11 (0.07 - 0.18)	NP_2009	0.62 (0.51 - 0.39)
Mat_1_2009	0.10 (0.06 - 0.19)	NP_2010	0.61 (0.49 - 0.36)
Mat_1_2010	0.32 (0.17 - 0.48)	NP_2011	0.50 (0.37 - 0.25)
Mat_1_2011	0.20 (0.09 - 0.32)		
		PP_1999	0.74 (0.62 - 0.52)
Mat_2_1998	0.21 (0.00 - 0.69)	PP_2000	0.88 (0.82 - 0.75)
Mat_2_1999	1.20 (0.84 - 2.28)	PP_2001	0.75 (0.66 - 0.58)
Mat_2_2000	0.85 (0.54 - 1.45)	PP_2002	0.89 (0.80 - 0.69)
Mat_2_2001	1.07 (0.03 - 3.66)	PP_2003	0.90 (0.83 - 0.76)
Mat_2_2002	3.11 (0.57 - 6.72)	PP_2004	0.54 (0.42 - 0.33)
Mat_2_2003	1.85 (0.91 - 2.86)	PP_2005	0.54 (0.42 - 0.30)
Mat_2_2004	2.00 (1.23 - 3.10)	PP_2006	0.86 (0.76 - 0.62)
Mat_2_2005	1.75 (1.16 - 3.03)	PP_2007	0.83 (0.75 - 0.67)
Mat_2_2006	1.55 (0.98 - 2.07)	PP_2008	0.56 (0.46 - 0.35)
Mat_2_2007	1.77 (1.24 - 2.67)	PP_2009	0.86 (0.77 - 0.65)
Mat_2_2008	1.29 (0.96 - 1.66)	PP_2010	0.80 (0.71 - 0.61)
Mat_2_2009	1.75 (1.24 - 2.31)	PP_2011	0.81 (0.70 - 0.60)
Mat_2_2010	0.98 (0.69 - 1.47)		
Mat_2_2011	1.75 (1.20 - 2.68)		