



Department of
Conservation
Te Papa Atawhai

Department of Conservation Progress Report

Title of Report: Demographic modelling – Initial Results

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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, Correlative assessment relating time-varying demographic rates to candidate drivers of population change

Milestone: 4, Initial Results

1 Executive Summary

- A correlative assessment was conducted with the objectives of identifying the ultimate causes of the observed decline of the Auckland Islands sub-population of NZ sea lions, focussing on nutritional stress, disease-related pup mortality and the direct effects of fishing.
- Time-varying demographic rates (1990-2012), including survival-at-age and pupping rate were obtained from the demographic modelling component of this project, using observations of females marked and re-sighted at Sandy Bay, Auckland Islands. An array of correlative datasets were collated for the same time period, including climatic, dietary, biological and fishery-related observations.
- Hypothetical models were developed that related the different datasets. These models were developed through expert consultation at two international project workshops and a literature review that encompassed relevant aspects of mammalian reproductive biology. Hypothetical responses to candidate drivers of population change were identified prior to the correlative assessment.
- In most cases the time series of available data were short and were mostly available for the period of probable population decline at the Auckland Islands since 2000; both of these factors compromise the power of correlative assessments made in this study.
- Variation in age at first pupping, depressed pupping rates, as well as variable maternal condition, milk quality and pup mass at 3 weeks are all consistent with nutritional stress compromising maternal survival, reproductive output and survival of offspring. However, some of these may also occur in the response to variable pup mortality that is not driven by nutritional stress.
- Pup mass was greatest when the mean age of breeder was high and pup/yearling survival in the previous year was low. Pup/yearling survival was positively correlated with pup mass of the same cohort, though only when using observations prior to 2005.
- The results of the correlative assessment were consistent with disease-related mortality (from 8 weeks after sampling began) affecting a decline in pup/yearling survival. The frequency of disease-related mortality prior to 8 weeks was not a good indicator of pup survival and a large proportion of pup/yearling mortality is likely to have occurred late in the field season or after the field team had left Enderby.
- Climate indices were not well correlated with commercial fishery catch-per-unit-effort (a proxy for abundance) of a number of prey species, though Inter-decadal Pacific Oscillation (IPO) and sea surface height (SSH; indicative of temperature throughout

the water column) were well-correlated with frequency of occurrence of a number of key prey in diet (scats). This is consistent with changes in ocean climate affecting the foraging ecology of sea lions or relative availability of prey species. Two climate regimes were evident from this analysis and a longer time series would be needed with cyclic fluctuations to establish a causative correlation.

- Poor correlations between survival at ages 2-5 (juveniles) and 6-14 (adults) and estimated fishery-related captures or estimated interactions in the Southern arrow squid trawl fishery at the Auckland Islands did not indicate that variation in vulnerable age classes is primarily driven by the direct effects of fishing. A strong negative correlation between survival at ages 6-14 and survival to age 2 of pups born in the previous year (from 1998 to 2004) indicated that the energetic costs of nursing a pup have had a greater effect on survival at breeding ages.

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2 Introduction to correlative assessment

In the previous project component (reported on at Milestones 2 and 3), candidate demographic models were developed for estimating time-varying demographic rates – including survival-at-age, pupping rates and age at first pupping – of female New Zealand sea lions (*Phocarctos hookeri*) at Sandy Bay, Auckland Islands. This had the aim of identifying the proximate causes 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 commercial fishing operations to directly or indirectly affect the Auckland Islands sub-population.

This correlative assessment was conducted in fulfilment of project milestone 4 and the results are reported on in a series of three presentations given to a meeting of the DOC Conservation Services Programme (CSP) Technical Working Group. This document provides supporting guidance material for this correlative assessment and a brief summary of the key results and recommendations stemming from this analysis.

3 Objectives of project component and research activities

The objectives of this component of the project were to

“Identify potential demographic mechanisms through which both direct and indirect effects of fishing can impact on sea lion population size at the Auckland Islands, or increase susceptibility of the population to such effects.”

Specific research activities in this project component included:

- Preliminary correlative assessments at workshops with international (Mark Hindell & Andrew Trites) and NZ experts on pinniped ecology:
 - Workshop 1 – June 2013
 - Workshop 2 – December 2013
- A literature review of relevant aspects of mammalian reproductive biology
- A presentation of results to the DOC CSP technical working group:
 - Presentation 1 – Introduction and hypothetical models relating datasets
 - Presentation 2 – Dataset summary
 - Presentation 3 – Results of correlative assessment

4 Hypothetical model relating observations and estimates

Hypothetical models relating environmental, biological and demographic observations were developed with expert consultation at two international workshops and a subsequent literature review encompassing relevant aspects of mammalian reproductive biology (e.g. Clutton-Brock et al. 1989; Trillmich 1990). These models provide a framework for assessing the degree of correlation between datasets obtained for the time period 1990 and 2012 (Figure 1).

This assessment focussed on three of the candidate drivers of population change in NZ sea lions: direct fishery-related mortality; nutritional stress caused by variation in prey abundance

(climate or fishery-driven) and disease-related mortality of pups. The models for some candidate drivers included a number of different hypothetical relationships: ID 1a-h (responses to nutritional stress); 2a-c (responses to pup mortality not-driven by nutritional stress); and 3 (responses to predation or the direct effects of fishing). These are listed in Table 1.

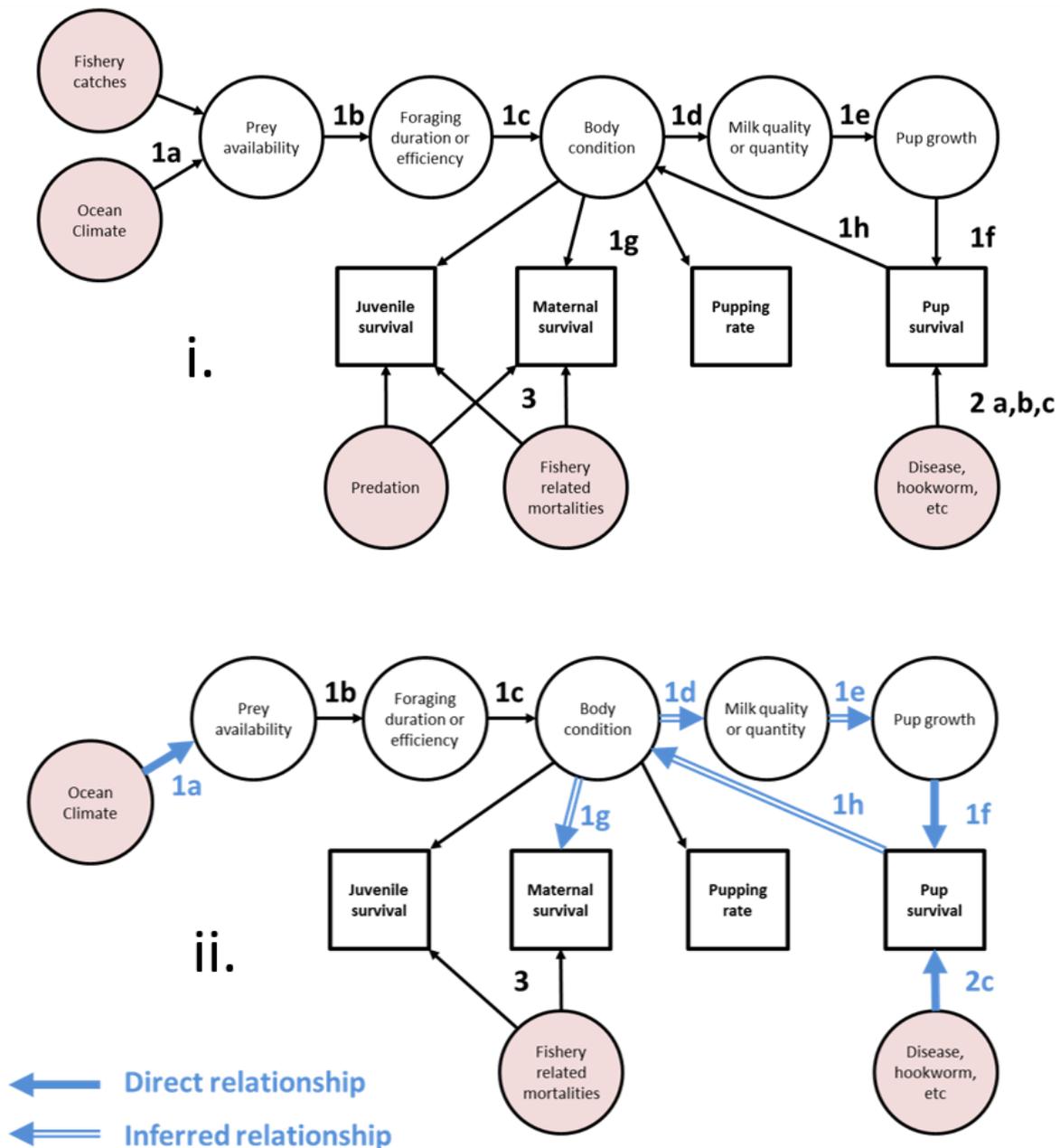


Figure 1. (i) Hypothetical model relating datasets included in this correlative assessment; and (ii) hypothetical model highlighting relationships that were supported by the correlative assessment; Relationships denoted with ID e.g. “1a”, listed in Table 1).

Table 1. List of hypothetical relationships between datasets assessed in this study and degree of correlation obtained. Relationships supported by correlative assessment bolded and highlighted in blue. In addition, relationships 1d, 1e and 1g were inferred by the results of the assessment.

Candidate driver of population change	Relationship ID	Relationships assessed	Correlation
Nutritional stress	1a	Climate and diet	Yes (SSH, IPO)
	1b	Prey abundance and diet	Only one prey species
	1c	Diet and maternal condition	Only one prey species
	1d	Diet and milk quality	Only one prey species
	1e	Maternal condition/milk quality/breeder age and pup mass	Yes – breeder age and pup mass
	1f	Pup mass and pup/yearling survival	Yes
	1g	Maternal condition and maternal survival/pupping rate	No
	1h	Pup/yearling survival and demographic response in yr+1	Yes between pup/yearling survival and adult survival as well as pup mass
Disease-related pup mortality	2a	Pup mortality at 3/7 weeks and pup/yearling survival	No
	2b	Pup mortality by cause and pup/yearling survival – all sampling	No
	2c	Bacterial disease-related mortality and pup/yearling survival	Yes
Direct fishery-related mortality	3	Estimated fishery interactions/captures and juvenile/adult survival	No

5 Key results of correlative assessment

Effects of variation in prey abundance/availability

There were no significant correlations between ocean and atmospheric climate indices and the local abundance of prey species (catch per unit effort in commercial fisheries at the Auckland Islands; Roberts, unpublished data) with the exception of ling (*Genypterus blacodes*) and sea surface height (SSH) (Pearson product-moment correlation – $r = 0.62$, $df = 17$, $p > 0.01$; ID 1b). Much stronger correlations were obtained between the occurrence of prey species in diet (% frequency of occurrence in scats - %O; Childerhouse et al. 2001; Stewart-Sinclair 2013) and climate indices (ID 1a). The Inter-decadal Pacific Oscillation (IPO) had significant negative correlations with %O of arrow squid (*Nototodarus sloanii*), ling, red cod (*Pseudophycis bachus*), opalfish sp. (*Hemerocoetes* sp.), *Octopus* sp. and rattail sp. (*Macrourus* sp.), and was positively correlated with jack mackerel sp. (*Trachurus* sp.) ($r, <$

0.05, $df = 9$). SSH (indicative of temperature throughout the water column) had significant positive correlations with %O of ling, opalfish sp. *Octopus* sp. and rattail sp. and a near-significant positive correlation with red cod ($r, p < 0.05, df = 13$). This may indicate that changes in ocean climate have had a stronger effect on the foraging behaviour of NZ sea lions or the relative availability of prey species rather than their local abundance. However, further research is required to assess the extent to which commercial fishery catch and effort data adequately reflect the local abundance of prey species, given poor correlations between CPUE and %O of all prey species except jack mackerel sp. ($r = 0.95, p < 0.001, df = 13$). Also, climate indices more relevant to local conditions (e.g. temperature at depth) may be considered in a more in-depth analysis. In addition a longer time series of climate data including cyclic fluctuations may be needed to establish causative correlations.

Diet composition and body condition index (BCI) of lactating females were not well correlated (ID 1c), though only a very short time series of BCI was obtained (1997, 1999-2003 and 2005; a reanalysis of data from Riet-Sapiriza et al. 2012). Exceptions to this were a significant positive correlation between diet and %O in scats of jack mackerel sp. ($r = 0.91, p < 0.05, df = 3$) and a near significant negative correlation with %O of red cod ($r = -0.87, p < 0.10, df = 3$). The correlation between diet composition and 3-week pup mass (Chilvers 2012) was also poor (ID 1c & 1d) with the exception of %O of giant octopus (*Enteroctopus zealandicus*) in scats with which there was a highly significant negative correlation ($r = -0.75, p < 0.001, df = 14$). The relationships between diet and variation in reproductive biology may not be resolved without longer time-series of observations.

Pup mass, pup survival, adult survival & pupping rates

Female pup mass at 3-weeks had a significant positive correlation with estimated mean age of breeder ($r = 0.70, p < 0.001, df = 17$; ID 1e) and a significant negative correlation with pup/yearling survival of the cohort born in the previous year ($r = -0.56, p < 0.05, df = 11$; ID 1h; survival estimates confounded with cohort effects on tag loss; Roberts et al. 2013). As such, pup survival should be lowest when the breeding population is relatively young and pup survival in the previous year was high.

Pup/yearling survival was also strongly correlated with female pup mass at 3-weeks when using a subset of years prior to 2005 ($r = 0.92, p < 0.01, df = 6$; ID 1f). Correlations using the entire time series or estimates from 2005-2010 were poor ($r = 0.08, p = 0.78, df = 12$; and $r = -0.45, p = 0.37, df = 4$, respectively) (Figure 2).

These correlations indicate that older females should produce heavier pups with an increased probability of survival, particularly when survival of pups born in the previous year

was low. However, pups born post-2004 were relatively large in size though still had a low probability of survival.

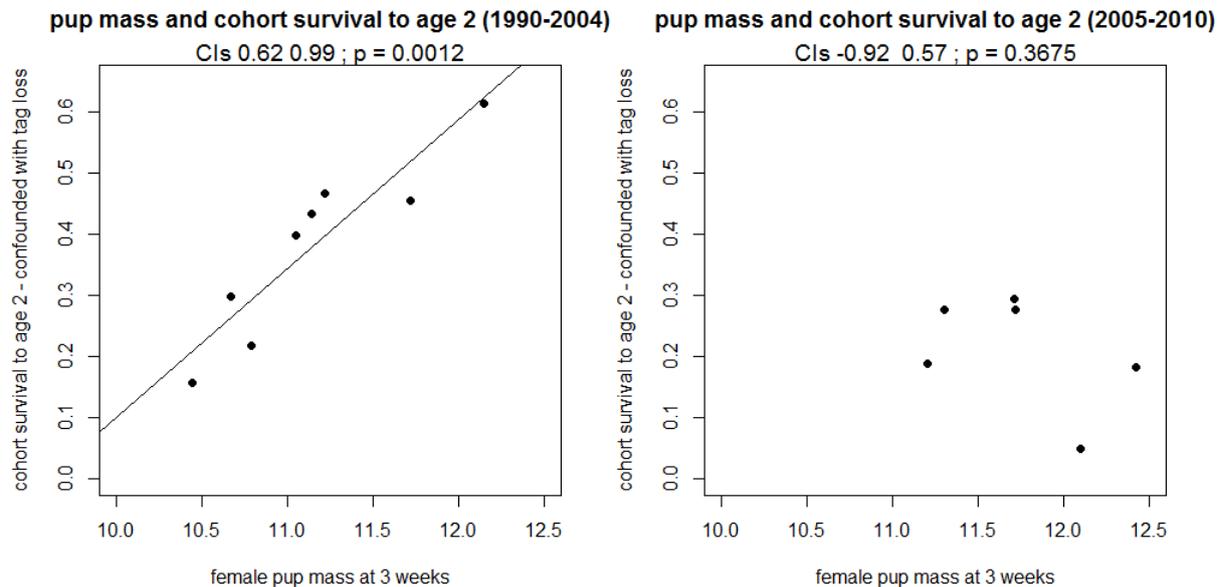


Figure 2 Annual pup mass of females and demographic modelling estimate of pup and yearling survival (confounded with tag loss). Regression line shown for significant correlations.

If a large proportion of the maternal population was unable to fully recover condition before pupping in the next season then adult survival (age 6-14) may be negatively correlated with pup/yearling survival in the previous year (ID 1h). This negative correlation was observed, though only when comparing observations from 1990-2004 ($r = -0.99$, $p < 0.001$, $df = 4$), with no correlation observed in the later period (2005-2010; $r = -0.31$, $p = 0.49$, $df = 5$) when disease-related mortality appears to have affected pup survival in a number of consecutive years (Figure 3). As such, reproductive history appears to be one of the main factors affecting survival of females at reproductive ages. Poor correlations were observed between maternal body condition index (BCI) and pupping rate or maternal survival in the same year, though the time series of BCI used in this analysis was short (1997, 1999-2003 and 2005).

Individual-based models would facilitate the assessment of pup mass effects on survival, as well as the consequences of successfully rearing a pup on maternal condition and reproductive success in the following year.

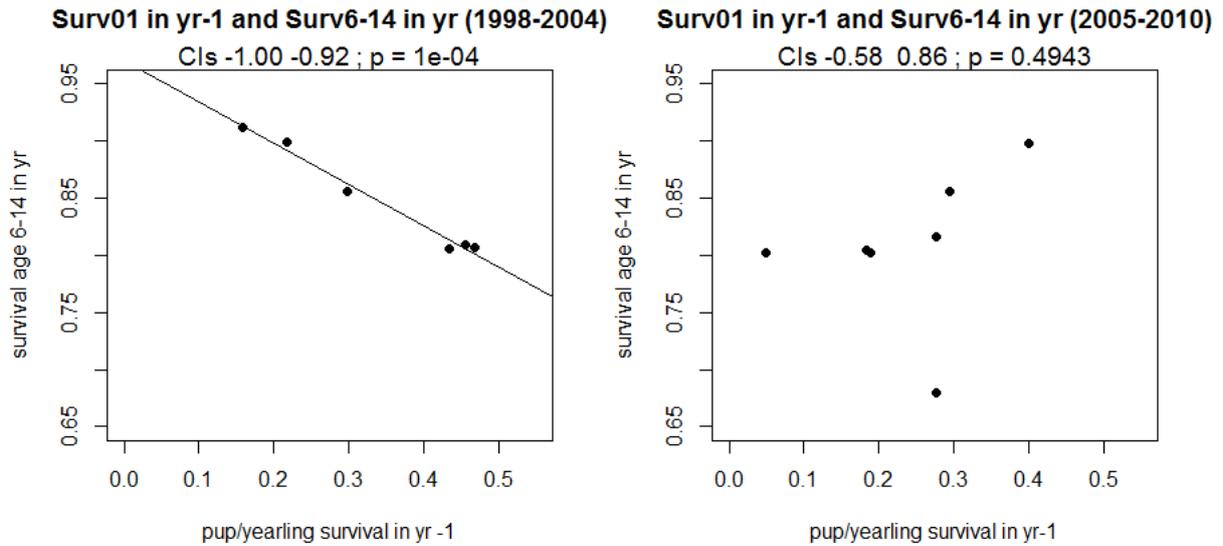


Figure 3 Annual survival at age 6-14 (Surv6-14) in year plotted against pup/yearling (Surv01) survival in the previous year (all estimates confounded with tag loss). Regression line shown for significant correlations.

Disease-related mortality of pups

Estimates of pup/yearling survival were not well correlated with the pup mortality counts at 3 or 7 weeks (Chilvers 2012) ($r = 0.43$, $p = 0.15$, $df = 11$; and $r = -0.20$, $p = 0.52$, $df = 11$, respectively; ID 2a). However pup/yearling survival was negatively correlated with the frequency of disease-related pup mortality (Castinel et al. 2007; Roe 2011; Roe et al. unpublished data) in the period 8-10 weeks after sampling began (approximately corresponding with the first 3 weeks in February) ($r = -0.87$, $p < 0.01$, $df = 7$) and nearly significant when comparing with disease rates at 11-13 weeks ($r = -0.73$, $p = 0.06$, $df = 5$; ID 2c).

Direct effects of fishing

A simple analysis of the degree of correlation between survival estimates (confounded with tag loss) at ages 2-5 (juveniles) and 6-14 (adults) and estimated fishery-related captures or estimated interactions (Thompson & Abraham 2010) did not support the hypothesis that variation in annual survival of vulnerable age classes was primarily driven by interactions or captures in commercial trawls targeting Southern arrow squid at the Auckland Islands (r , $p > 0.30$, $df = 12$; ID 3).

An index of the rate of captures or interactions relative to population size was generated using model estimated of population n in each age category (2-5 and 6-14). In all cases there was no significant correlation between these indices and survival estimates for each

respective age class ($r, p > 0.20, df = 12$). Note that estimated captures/interactions were for males and females at the Auckland Islands, though population estimates were for the Sandy Bay sub-population of females only. In addition there may be annual variation in the age frequency of captures that was not accounted for in this analysis.

6 Conclusions

In most cases the time series of available data was short with the weight of observations collected from the post-2000 period of population decline at the Auckland Islands. Both of these factors compromise the power of correlative assessments in this study.

Multiple sets of evidence point to nutritional stress as being a strong candidate driver of biological and demographic changes in NZ sea lions at the Auckland Islands, including: inter-annual variation in pupping rates, shifts in age at first pupping, variation in female condition, milk quality and pup mass through time (Table 2). Some of these may also occur in response to pup disease not driven by nutritional stress. However, depressed pupping rates and increased age at first pupping would not be expected in response to pup mortality driven purely by disease (Figure 1).

A shift in diet composition appears to have occurred between 1997 and 2000 (Stewart-Sinclair, 2013), which for a number of prey species was correlated with long-term shifts in IPO index and SSH. Hypothesised relationships between diet composition and maternal BCI and milk quality were not obvious from this analysis, though comparison was only possible for a small number of years for which BCI data were available (1997, 1999-2003 and 2005).

Pup/yearling survival was particularly low in the period 2005-2010, despite relatively high pup mass. Between 2007 and 2010, a large proportion of autopsied dead pups were found to be infected with *Klebsiella pneumoniae*, though rates of infection were much higher during the period 8-13 weeks after sampling began (Roe, 2011). A significant negative correlation between pup/yearling survival and rate of disease-related pup mortality at 8-10 weeks indicates that disease is a strong candidate driver of increased pup/yearling mortality from 2007 to 2010. The frequency of disease-related mortality prior to 8 weeks was not a good indicator of pup survival and a large proportion of mortality was likely to have occurred late in the field season or after the field team had left Enderby.

Poor correlations between estimates of Southern arrow squid trawl fishery captures/interactions (Fishery Management Area SQU6T; Thompson & Abraham 2011) and estimated survival at ages 2-5 and 6-14 suggest that fishery-related mortalities are not a strong candidate driver of variation in survival at vulnerable ages. A strong negative correlation between survival at ages 6-14 and survival of pups/yearling in the previous year

(from 1998 to 2004) indicate that the energetic costs associated with nursing a pup had a greater effect on maternal survival during this time period (Figure 3).

Table 2. Summary of hypothetical biological/demographic responses to drivers of population change

Response variable	Predation or fishery captures	Nutritional stress (climate or fishery driven)	Pup disease (but non-nutritional stress driven)
Adult condition	No variation	Will vary in response to changing resources & reproductive success in yr-1	Will increase in response to reduced reproductive success in yr-1
Adult survival	Affects age classes vulnerable to fishery captures or predation	Will vary in response to changing resources & reproductive success in yr-1	Increases adult survival in response to reduced reproductive success in yr-1
Pupping rate (includes age at first pupping)	No variation	Will vary in response to changing resources & reproductive success in yr-1	Increased pupping rate in response to reduced reproductive success in yr-1
3-week pup mass (pup growth)	Reduced pup mass/growth of pups affected by mortality of mother	Will vary in response to changing resources & reproductive success in yr-1	No effect prior to infection
Milk quality	No variation	Will vary in response to changing resources & reproductive success in yr-1	Will vary in response to reproductive success in yr-1
Pup/post-weaning survival	Reduced survival of pups affected by mortality of mother	Will vary in response to pup growth rate & resources available to pup on weaning (disease may be a consequence)	Reduced pup or post-weaning survival of affected cohort

7 References

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- Trillmich F, 1990. The behavioural ecology of maternal effort in fur seals and sea lions. *Behaviour* 114.

Appendix A – list of attendees at Project Workshops

Workshop 2, NIWA, 4-6 June 2013

- Andrew Trites, University of British Columbia
- Mark Hindell, University of Tasmania
- Martin Cryer, NZ Ministry for Primary Industries
- Igor Debski, NZ Department of Conservation
- Jim Roberts, NIWA
- Ian Doonan, NIWA
- Leigh Torres, NIWA
- Dan Fu, NIWA
- David Thompson, NIWA

Workshop 2, NIWA, 4-5 December 2013

- Andrew Trites, University of British Columbia
- Mark Hindell, University of Tasmania
- Rohan Currey, NZ Ministry for Primary Industries
- Martin Cryer, NZ Ministry for Primary Industries
- Michelle Beritzhoff, NZ Ministry for Primary Industries
- Igor Debski, NZ Department of Conservation
- Louise Chilvers, NZ Department of Conservation
- Laureline Meynier, Massey University
- David Middleton, Seafood New Zealand
- Jim Roberts, NIWA
- Ian Doonan, NIWA
- Leigh Torres, NIWA
- Brittany Graham, NIWA
- David Thompson, NIWA
- Sarah Bury, NIWA