NIWA
Taihoro Nukurangi

Census & individual size of New Zealand fur seal/kekeno pups on the West Coast South Island from 1991 to 2016

Prepared for Department of Conservation

November 2016

Prepared by:
Roberts J., Neale D.

For any information regarding this report please contact:
Dr Rosemary Hurst
Chief Scientist
Fisheries Science
+64-4-386 0867
Rosemary.Hurst@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 14901
Kilbirnie
Wellington 6241

Phone +64 4 386 0300

NIWA CLIENT REPORT No: 2016005WN
Report date: November 2016
NIWA Project: DOC16305

Quality Assurance Statement		
	Reviewed by:	Suze Baird
	Formatting checked by:	Chloe Hauraki
	Approved for release by:	Rosemary Hurst

This report should be referenced in the style of this example:
Roberts, J., Neale, D. (2016). Census & individual size of New Zealand fur seal/keneko pups on the West Coast South Island from 1991 to 2016. *NIWA Client Report* DOC-XXXX: XXX.

Contents

Tables

Figures

Executive summary

- A long time series (1990/91-2015/16; hereafter referred to by end year, e.g. 1991-2016) of New Zealand fur seal pup population size was estimated for three major breeding rookeries of the West Coast South Island of New Zealand: Wekakura Point, Cape Foulwind and Taumaka Island (largest of the Open Bay Islands), using a mark-recapture methodology.
- All three of the WCSI rookeries have declined in terms of estimated pup numbers, by ~80% at Wekakura Point, ~70% at Cape Foulwind and ~35% at Taumaka Island within the study period (comparing 2016 estimates with the respective maximum for that rookery). The demographic causes of the protracted decline in pup numbers are unknown.
- A sharp drop in pup numbers was estimated in 1999 and 2000. In these years, pups were in particularly poor condition, consistent with poor nutritional status of mothers at this time. The lowest pup mass estimates at Wekakura Point were obtained towards the end of the reported study (2012 to 2014), which were also the years of lowest pup census estimates.
- It is recommended that field observations continue at all 3 rookeries: Wekakura Point and Cape Foulwind are identified as priority populations due to their poor status and close proximity to commercial trawl fishing grounds; Taumaka is a large and relatively stable rookery that provides a valuable control site for comparison with more steeply declining populations. Future field research should adopt a methodology consistent with that of previous years.
- In addition, it is recommended that resighting effort is undertaken of the large flipper-tagged population to determine the demographic causes of population change and to identify marker years when external stressors impacted on the population.

1 Introduction

The New Zealand (NZ) fur seal/kekeno (*Arctocephalus forsteri*) breeds on the mainland and islands of New Zealand and Australia (Baird 2011). Their breeding range around New Zealand was reduced by subsistence hunters after the 13th Century and the remaining populations were brought to near-extinction by commercial sealing in the 19th Century (Smith 1985). NZ fur seal breeding range and population size have increased since the cessation of commercial sealing (Baird 2011) and the species is generally considered to still be in the process of recovering (Lalas & Bradshaw 2001).

Concern about large numbers of NZ fur seal deaths in the commercial trawl fishery for hoki on the West Coast South Island (WCSI) of NZ in the winters of 1989 and 1990 led to the initiation of a long-term population study of WCSI NZ fur seal breeding rookeries by the Department of Conservation (DOC). This study has operated continuously since the 1990/91 breeding season (hereafter referred to by end year, e.g. 1991) and has focussed on pups born at Wekakura Point, Cape Foulwind and Taumaka Island (Figure 1-1), collecting mark-recapture observations for population size estimation and individual biometric measurements according to a consistent methodology. These study rookeries comprise approximately one-third of NZ fur seal pup births along the WCSI, including the Fiordland region (derived from pup count estimates summarised by Baird 2011).

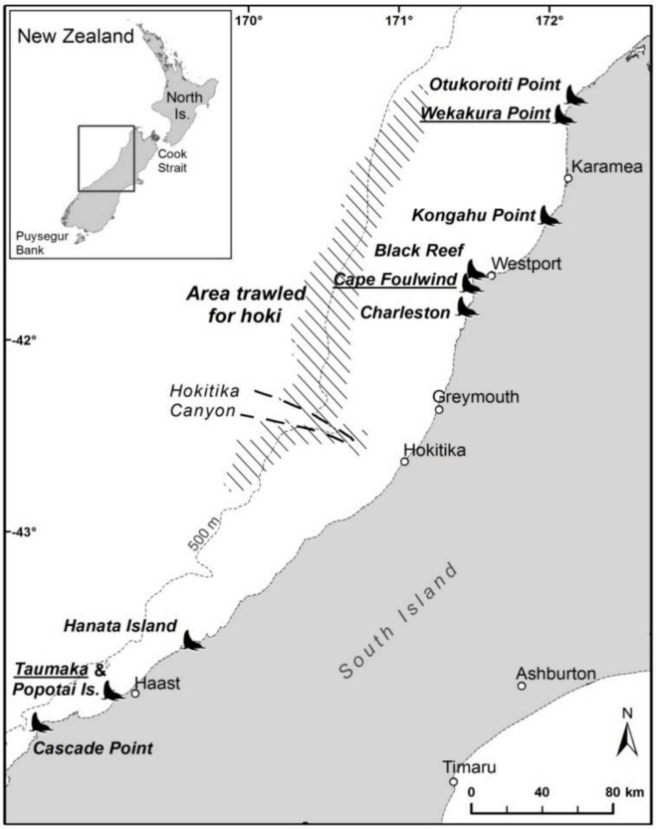

Figure 1-1: Location of known breeding rookeries of NZ fur seal in the NZ West Coast South Island (excluding the Fiordland region), including the three rookeries in this study – Wekakura Point, Cape Foulwind, and Taumaka Island. The hatched region is the area where effort in the commercial trawl fishery for spawning hoki (*Macruronus novaezelandiae*) is most concentrated.

We use mark-recapture observations to produce a long time series (1991-2016) of pup population size estimates at the three WCSI study rookeries. We also use biometric measurements of pups to produce model-standardised estimates of pup length, mass, and condition over the corresponding time period. We then briefly discuss the evidence for demographic and external drivers of population change and make recommendations with respect to future field research, population/demographic assessment and the assessment of potential threats to NZ fur seals of the WCSI.

2 Methods

2.1 Pup census

Field data were collected at Wekakura Point, Cape Foulwind and Taumaka Island in all years from 1991 to 2016, according to a consistent methodology. Pup census estimates were derived using a combination of mark-recapture methods for live pups and direct counts of dead pups. The mark-recapture study at each colony was undertaken as close as possible to the last week of January – when pupping was completed, though pups have not yet started to leave the colony. Pup population size was estimated by a closed population mark-recapture method with >50% of all pups marked each year. At each colony, one marking session was followed by five recapture counts. Pups were marked as encountered during a walk through the rookery, with the aim of achieving a spatial spread consistent with the distribution of pups. Pups were either double-marked with plastic livestock tags (*Allflex* button tags, 28 mm diameter; one tag inserted 15 mm from the trailing edge of each fore-flipper), or had a patch of outer-fur clipped from the forehead (Best et al. 2010).

Pups were marked over a number of days and recapture counts commenced >12 hours after the completion of marking at a rookery to allow mixing of marked and unmarked pups. In 1995, 1998, 1999, 2002 and 2003, recapture counting at Taumaka Island commenced on the final day of marking due to poor weather conditions. In these instances, the first recapture count was during high-tide, 5-8 hours after marking at low-tide. Pups were not included in the tallies of marked or unmarked pups in each recapture count if the mark-zone (i.e. fore flipper or forehead) was not clearly visible. Recapture count procedures differed between colonies due to terrain-related constraints, though adopted a consistent methodology at each respective colony throughout the study period: at Wekakura Point recapture counts were made by a line of people walking across the colony and adjoining tidal-flats; at Cape Foulwind recapture counts were made by a single person from 5 standard locations from the cliff edge overlooking different sectors of the colony; and at Taumaka Island, recapture counts were made by a single person walking the length of the colony area in which tagging was done consistently each year (Best et al. 2010).

The estimated number of live pups on the colony ($\widehat{N}$) was a modified Petersen Estimate, as used by Shaughnessy et al. (1995) and Taylor et al. (1995). $\widehat{N}_i$, the estimate of pups on the colony at the time of the *i*th recapture is

$$\widehat{N}_i = \frac{(M+1)(n_i+1)}{(m_i+1)} - 1$$

where *M* = number of pups originally marked, m_i = number of marked pups counted in the *i*th recapture sample, and n_i = total number of pups in the *i*th recapture sample.

The variance of each estimate is

$$Var(\hat{N}_i) = \frac{(M+1)(n_i+1)(M-m_i)(n_i-m_i)}{(m_i+1)^2(m_i+2)}.$$

The mean of the annual estimates per colony, $\widehat{N}$, is

$$\hat{N} = \frac{1}{q}\sum_{i=1}^{q}\hat{N}_i$$

where q was the number of estimates for a respective colony, i.e., the number of recapture sessions.

The standard error (SE) of each colony estimate was calculated as:

$$\sqrt{\frac{1}{q^2}\sum_{i=1}^{q}Var(\hat{N}_i)}$$

The confidence interval was calculated as ±1.96*SE.

Counts of pups judged to have died after the date of marking were recorded since 1997. These were ignored for the purposes of mark-recapture estimation of population size, in order to maintain a consistent methodology across the study period. Counts of all dead pups observed during marking (that died previous to marking) were also made at all study rookeries since 1997. These annual dead pup counts do not represent all of the pup mortality that may have occurred prior to the mark-recapture study and should be considered as minimum numbers of dead pups.

2.2 Pup size & condition observations

Individual biometric measurements were made at the time of pup marking. Pup mass (kg) and standard length (cm) were recorded for the first 100, 50, and 75 of each sex marked at Taumaka Island, Cape Foulwind, and Wekakura Point, respectively. Pups were placed in a polypropylene or light canvas weighing bag and weighed using 20 kg Pesola hook scales (precision of ±0.1kg), which were calibrated prior to each field season with 4 kg, 7 kg, and 10 kg weights and regularly zeroed during tagging operations. A flexible draper's tape measure was used to record standard length, which was calibrated against a solid 1 m ruler. Standard length was recorded as the linear distance from nose-tip to tail-tip of pups held in an outstretched position (i.e., not curved, bent, twisted or overstretched).

2.3 Calculation of Body Condition Index

Body condition index (BCI) is a measure of individual somatic condition, derived from raw measurements of standard length and mass, according to the methodology of Guinet et al. (1998). The equation predicting individual mass = 0.187 * *standard length* - 6.73 was obtained with the significant regression ($r^2 = 0.475$, $F_{9,741} = 8{,}802$, $p < 0.001$) between the standard length and mass of all pups for which both measurements were taken (Figure 2-1). Individual BCI was then calculated as the observed mass minus the predicted mass from this regression.

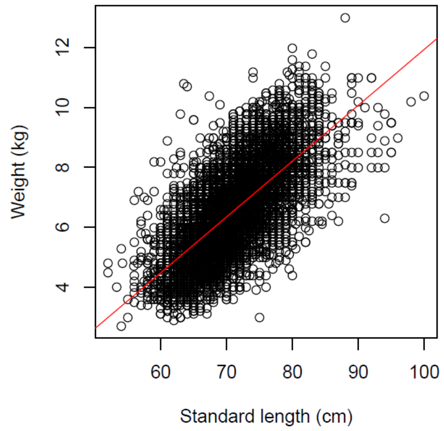

Figure 2-1: Scatterplot of individual standard length against mass of all measured NZ fur seal pups across the three study rookeries. The red line is the regression predicting mass from standard length (= 0.187*standard length - 6.73), which was used to calculate individual BCI (i.e. pups above this line had positive BCI).

2.4 Standardised estimates of pup size & condition

Pup measurements (including BCI) were corrected for year, sex, date, colony effects and interactions between these, in order to estimate standardised year effects. Linear models were fitted to the observations in *R* (R Core Team 2016) to predict either pup mass, standard length or BCI in response to candidate explanatory variables. Model structure selection was by second-order Akaike's Information Criterion (*AICc*) – this method can favour overfitting, so model structures that would introduce very large numbers of parameters (e.g., an interaction term between year and any other parameter) were avoided.

For pup measurements (standard length, mass, and BCI) the most complex model structure considered was:

lm (*pup measurement* ~ *sex* + *season* + *colony* + *day* + *colony* : *sex* + *sex* : *day*)

A Gaussian error distribution was assumed in all cases and conformity to this assumption was assessed for the optimal model structure through visual examination of quantile-quantile (*q-q*) plots (Appendix B).

3 Results

3.1 Pup census

Mark-recapture observations were available for all years of the study (1991-2016) at all rookeries, except for 2012-2015 at Cape Foulwind and Taumaka Island (Table 3-1) (though population estimates where available for these years; Best, unpublished data). Narrow 95% confidence intervals associated with live pup census estimates indicate that the mark-recapture population estimates were precise (Figure 3-1).

At all three rookeries, the maximum pup census estimates were obtained in the mid-1990s: 1,097 pups at Wekakura Point in 1996 (95% CI 1,077–1,118); 484 pups at Cape Foulwind in 1993 (95% CI 445–522); and 1,432 pups at Taumaka Island in 1995 (95% CI 1,381–1,483) and all study rookeries have declined markedly since. The corresponding 2016 estimates were 232 pups at Wekakura Point

(95% CI 225–239); 148 pups at Cape Foulwind (95% CI 138–158); and 950 pups at Taumaka Island (95% CI 906–993). These estimates correspond with declines of 79% at Wekakura Point, 69% at Cape Foulwind and 34% at Taumaka Island within the study period.

Abrupt drops in pup numbers were obtained for all three rookeries in 1999-2000 and 2012-2014 and at just Cape Foulwind and Taumaka Island in 1991 (though there was no estimate for this year at Wekakura Point). These breeding seasons were characterised by much higher estimates in the years immediately before and after.

Counts of dead pups were made during mark-resighting periods since 1997 (Table 3-2). Much greater numbers of dead pups were observed at Taumaka Islands, where they frequently exceeded 10% of the live pup estimate (this did not happen in any year at the other two study rookeries). Large dead pup counts were obtained at Taumaka Island and Wekakura Point in 1999, 2004-05, 2010 and 2013 (counts at Cape Foulwind were too low to allow a meaningful comparison) (Table 3-2).

Table 3-1: Summary of mark-recapture observations by rookery and year "WP" = Wekakura Point, "CF" = Cape Foulwind, "TI" = Taumaka Island; Population size was calculated as the mean of mark-recapture estimates across 5 samples, though in this table resighting observations are pooled across samples.

Year	Marked individuals			Resighted (marked)			Resighted (unmarked)			Resighted (mark status unknown)		
	WP	CF	TI	WP	CF	TI	WP	CF	TI	WP	CF	TI
1991	0	200	659	-	230	1 119	-	78	196	-	-	-
1992	700	200	725	1 343	202	827	176	201	688	-	137	-
1993	700	200	687	1 203	258	1 240	276	375	1 245	-	114	-
1994	790	195	786	896	155	1 184	245	161	811	-	-	-
1995	703	200	793	994	357	1 018	282	333	825	-	-	-
1996	816	200	742	1 678	219	1 047	584	210	822	-	-	-
1997	702	200	700	1 543	134	1 003	602	55	640	-	-	-
1998	688	199	717	1 315	290	1 464	688	198	1 102	-	-	-
1999	388	140	436	835	200	1 095	317	74	475	-	-	-
2000	340	131	401	797	148	927	277	23	229	-	162	-
2001	458	193	549	877	226	1 153	306	90	801	-	77	212
2002	557	200	474	1 365	202	738	403	121	230	-	88	-
2003	453	182	692	880	367	1 268	239	157	603	-	102	-
2004	395	200	634	835	481	1 371	388	303	673	-	-	-
2005	429	180	669	922	413	1 539	198	330	903	-	-	-
2006	378	200	699	796	220	1 457	352	78	736	-	66	-
2007	313	200	738	712	310	1 477	260	160	787	-	-	-
2008	412	187	849	837	483	1 924	257	213	816	-	133	-
2009	217	162	633	519	304	1 461	211	65	670	-	-	-
2010	268	183	809	603	274	1 741	202	57	392	-	37	-
2011	240	175	729	609	286	1 588	153	47	430	-	43	191
2012	171	-	-	445	-	-	134	-	-	-	-	-
2013	151	-	-	423	-	-	136	-	-	-	-	-
2014	165	-	-	449	-	-	155	-	-	-	-	-
2015	190	-	-	486	-	-	159	-	-	-	-	-
2016	163	130	438	502	117	681	218	22	803	-	-	-

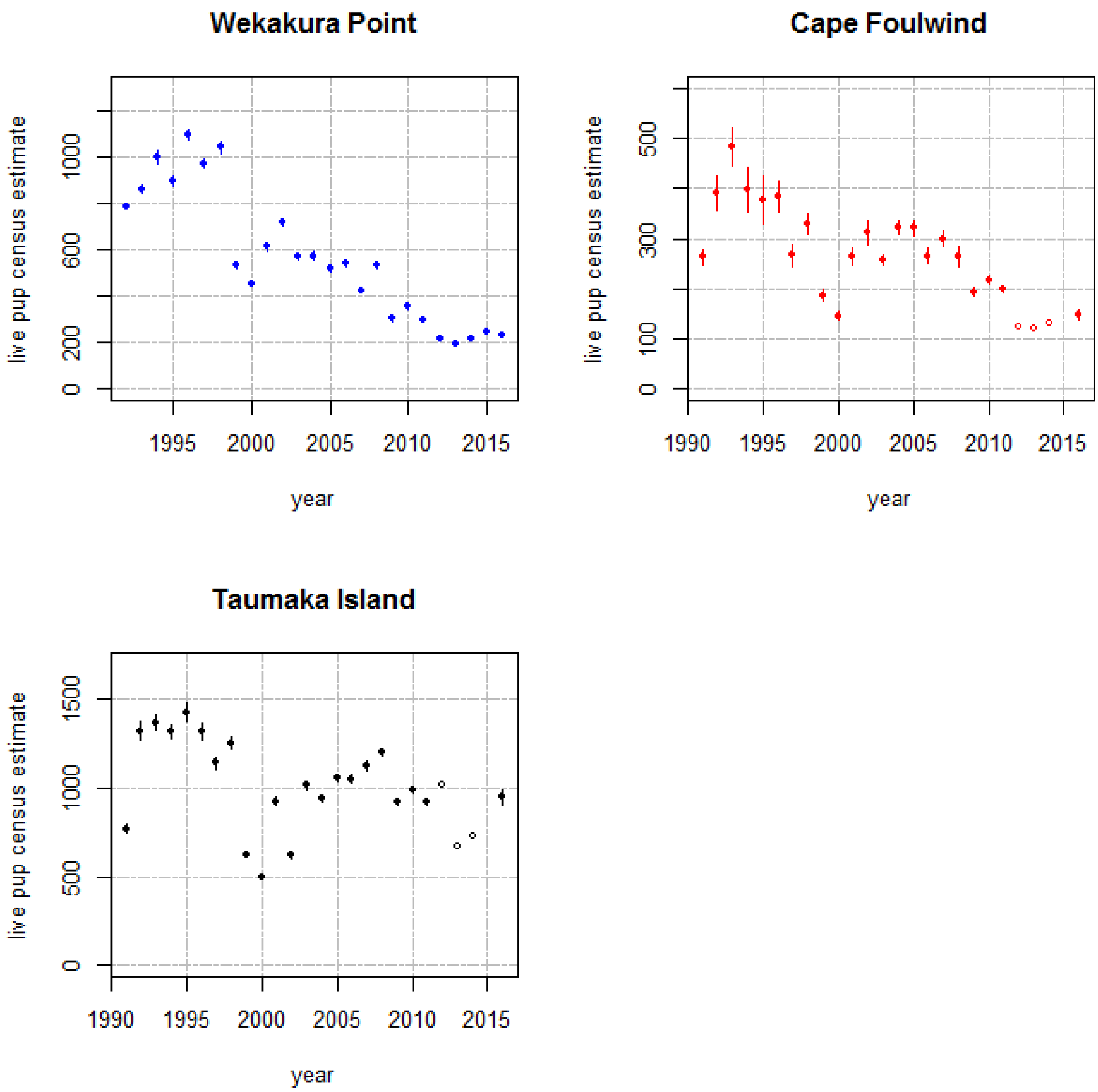

Figure 3-1: Mark-recapture estimates of live pup numbers at Wekakura Point, Cape Foulwind and Taumaka Island on the West Coast South Island from 1991-2016. Closed points are estimates from mark-recapture observations in this study and whiskers are 95% confidence intervals; Open points are unpublished estimates from Hugh Best outside of the analysis reported here.

Table 3-2: Counts of dead pups observed at the time of tagging since 1997 (not recorded in previous years). The count at Taumaka Island in 2015 was not available for this analysis.

Year	Colony		
	Wekakura Point	Cape Foulwind	Taumaka Island
1997	11	0	83
1998	11	0	140
1999	28	4	204
2000	12	11	129
2001	8	0	94
2002	16	0	151
2003	3	10	106
2004	28	0	164
2005	28	5	152
2006	10	2	144
2007	9	2	160
2008	2	3	53
2009	7	0	75
2010	14	0	134
2011	9	20	54
2012	6	0	106
2013	7	10	225
2014	5	5	182
2015	7	2	-
2016	5	6	119

3.2 Pup size and condition

At all three study rookeries, standard length and mass measurements were collected in most years of the study (1991-2016), with at least 100 individuals measured at each rookery in nearly all years that measurements were taken (Table 3-3). The mean date of measurement was consistently within the last week of January, apart from some variation early in the study period: at Cape Foulwind, measurements were undertaken in February during a number of years in the early-1990s; and at Wekakura Point in 1991 (Figure 3-2).

Table 3-3: Counts of pups measured by colony, year and measurement type. Rookeries are denoted by "WP" – Wekakura Point, "CF" – Cape Foulwind and "TI" – Taumaka Island; Standard length was not measured in 1996 and 1997; Observations were recorded at Taumaka Island in 2012-2015, though were not available to the author.

Year	Mass			Standard length		
	WP	CF	TI	WP	CF	TI
1991	100	100	202	100	100	202
1992	100	100	220	100	100	219
1993	100	100	208	100	100	208
1994	100	100	211	100	100	211
1995	100	100	200	100	100	200
1996	100	100	198	-	-	-
1997	100	100	200	-	-	-
1998	299	150	302	299	150	302
1999	100	100	204	100	100	204
2000	150	101	202	149	101	202
2001	150	100	102	150	100	102
2002	150	100	200	150	100	200
2003	150	100	199	150	100	199
2004	150	100	200	150	100	200
2005	150	100	200	150	100	200
2006	150	100	200	150	100	200
2007	150	101	201	150	102	201
2008	150	99	200	150	97	200
2009	150	102	100	150	102	100
2010	150	100	102	150	100	102
2011	58	100	200	58	100	200
2012	150	98	-	150	98	-
2013	148	91	-	148	91	-
2014	150	100	-	150	100	-
2015	150	101	-	150	102	-
2016	150	100	200	150	100	200

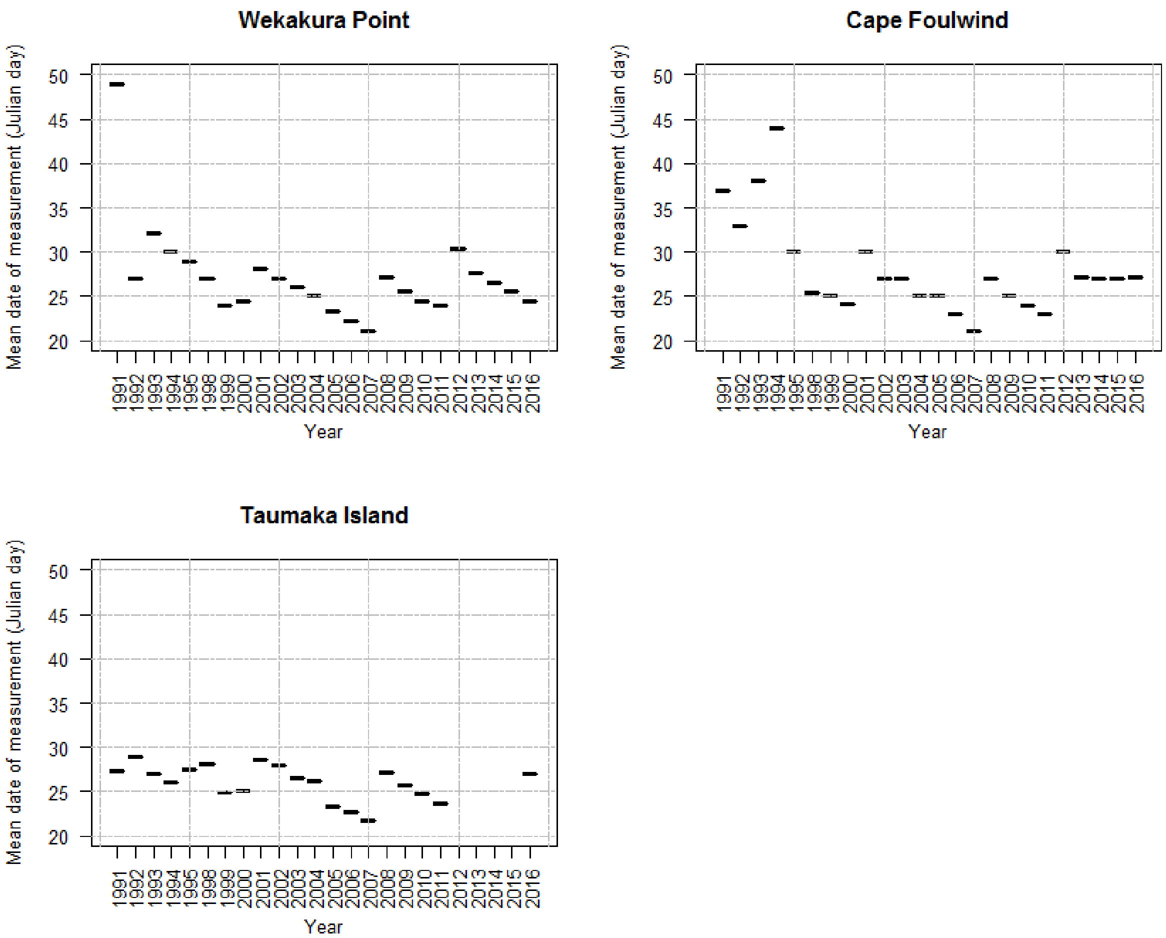

Figure 3-2: Mean date of pup measurement of New Zealand fur seals at West coast rookeries by year from 1991-2016.

The optimal model structures for predicting individual pup length (r^2 = 0.195, $F_{9,713}$ = 81.19, $p <$ 0.001), mass (r^2 = 0.230, $F_{9,715}$ = 107.6, p < 0.001) and BCI (r^2 = 0.159, $F_{9,713}$ = 63.13, p < 0.001) were:

lm (*length* ~ *sex* + *day* + *colony* + *season* + *colony* : *sex*)

lm (*weight* ~ *sex* + *colony* + *season* + *day*)

lm (*BCI* ~ *sex* + *colony* + *season* + *day*)

Tables comparing models at model selection are shown in Appendix A. Diagnostic plots and coefficients of the optimal model coefficients are shown in Appendix B and Appendix C, respectively.

Across all colonies, models estimated that pups gained 3.8 mm day^{-1} (95% CI = 3.4-4.2), gained 0.037 kg day^{-1} (95% CI = 0.027-0.047) and lost 0.034 units of BCI day^{-1} (95% CI = 0.026-0.042). Males were estimated to be 27.4 mm (95% CI = 23.7 – 31.1 mm), 0.69 kg (95% CI = 0.64 – 0.74 kg), and 0.25 units of BCI (95% CI = 0.21 – 0.29; equivalent increase in kilograms for a given length) larger than females. Pups at Cape Foulwind were similar in size to those at Wekakura Point. Pups at Taumaka Islands were > 0.5 kg lighter (in terms of absolute mass and BCI) than at Wekakura Point or Cape Foulwind, though they were similar in length (see model coefficients in Table C-1, Table C-2 and Table C-3). Individual length and BCI were notably less variable at Taumaka Island than at the other rookeries (see Figure 3-3).

The optimal model structures were retained to produce colony-specific estimates of each response variable (i.e., fit to the respective subset of observations for each rookery), with colony removed as a predictor. Because the spread of days with records was low for some rookeries (particularly Taumaka Island; Figure 3-2), the day effect was fixed to the respective values obtained from the all-colonies model shown above.

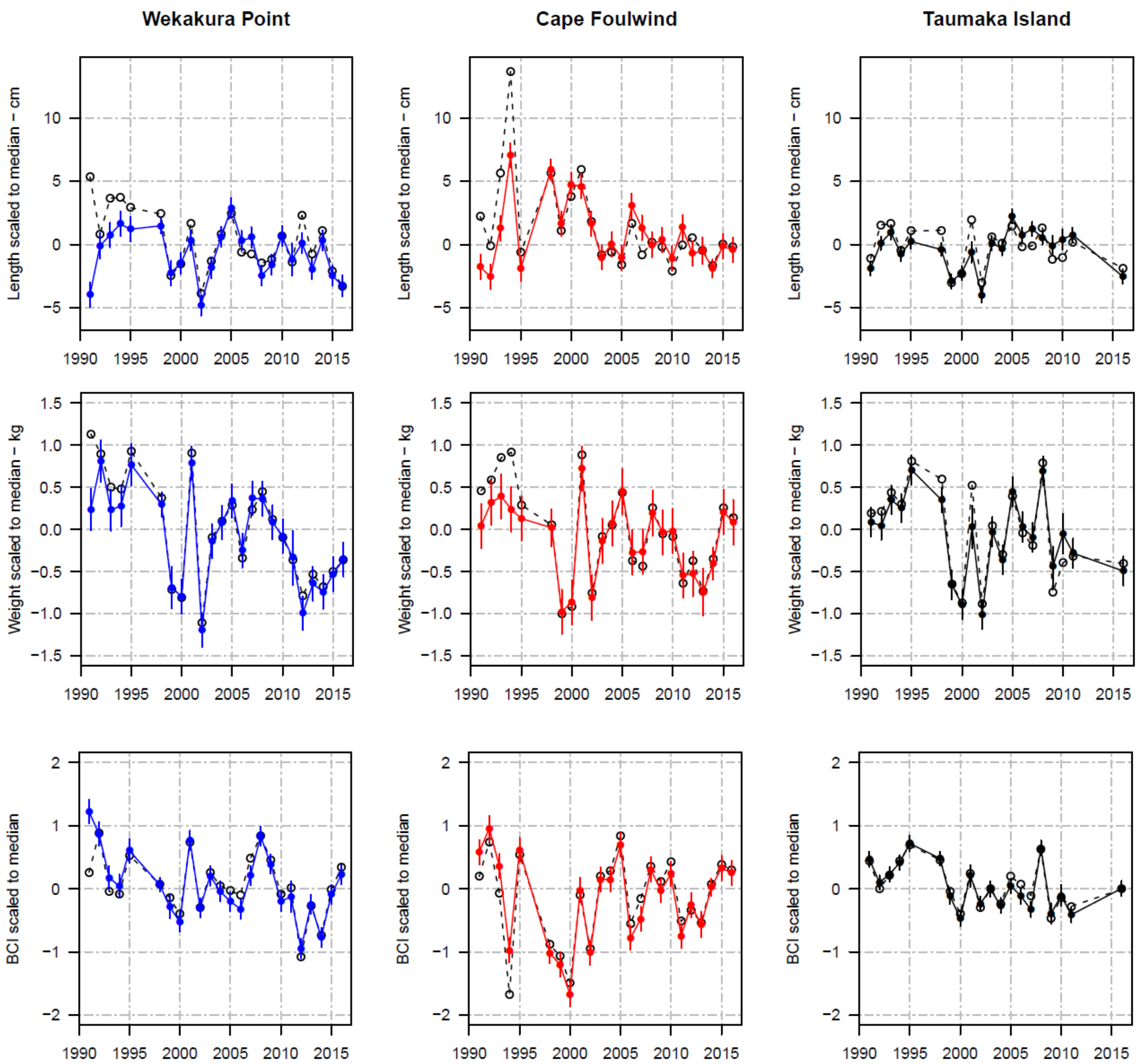

Figure 3-3: Standardised standard length (top); mass (middle); and BCI (bottom) of NZ fur seal pups at Wekakura Point (left); Cape Foulwind (centre) and Taumaka Island (right). Closed points are standardised model estimates; open points are raw means.

Model estimated year effects on length, mass, and BCI are shown in Figure 3-3. The standardisation reduced the relative standard length and mass of pups in 1991 at Wekakura Point and from 1991-1995 at Cape Foulwind, corresponding with years when pup measurements were at a later date (see Figure 3-2). Otherwise standardised estimates were close to raw values. Years of high pup mass (1991-1997, 2001, 2005, and 2008) and low pup mass (1999-2000, 2002, and 2012-2014) were the same for all three rookeries and years with low pup mass corresponded with years with sharp declines in pup census estimates (see Figure 3-1). There was less between-rookery correspondence with respect to standard length and BCI. However, BCI was low at all rookeries in 1999-2000, when pup mass and pup numbers were also low (see Figure 3-1). At Wekakura Point, pups were approximately 1 kg lighter towards the end of the time series relative to the beginning and a decline in BCI was also estimated across the period of the study.

4 Discussion & Conclusions

4.1 Population & biometric trends

Live pup census estimates reported here will be lower than total pup production, because pup mortality between birth and tagging was not fully accounted for. Mattlin (1978b) estimated pup mortality at Taumaka Island to be ~20% of all births in the first 50 days after birth. However, assuming early pup mortality was a relatively constant proportion of births through time, trends in live pup population estimates reported in this study will approximate to trends in total pup production. Also, assuming that pupping rates per female have also been constant through time, trends in live pup population estimates will also approximate to trends in the numbers of breeding-age females.

All three of the WCSI rookeries have declined across the study period (1991-2016), with a decline in estimated pup numbers of ~80% at Wekakura Point, ~70% at Cape Foulwind and ~35% at Taumaka Island within the study period (comparing 2016 estimates with the respective maximum for that rookery) (Figure 3-1). The maximum late-January live pup population estimate for Taumaka Island from this study (1,432 in 1995; 95% CIs 1,380–1,484) is between Mattlin's (1978a) estimates of pup production at Taumaka Island in the mid-1970s (1,303 in 1975 and 1,628 in 1976). Assuming 20% pup mortality (Mattlin 1978b) up to the date of tagging, the 1995 estimate is at the upper end of the mid-1970s estimates, suggesting that the breeding population at Taumaka in the early 1990s was similar to that of the mid-1970s (assuming pupping rate was similar in the two periods). There was a north-south trend in the rate of decline over the 1991-2016 period, with the greatest decline in pup numbers at the northernmost rookeries of Wekakura Point and Cape Foulwind (Figure 3-1).

Years of low pup census estimates relative to long term trends occurred at all study rookeries in 1999-2000, 2002 and 2012-2014 – coinciding with years of low pup mass. The pattern of abrupt decrease immediately followed by partial recovery is consistent with years of low pupping rate. However, protracted periods of population decline, as has occurred at WCSI rookeries, is more likely to be explained by poor survival than poor pupping rate (Roberts & Doonan, 2016).

The model estimates of daily growth in terms of length 3.8 mm day^{-1} (95% CI = 3.4-4.2) and mass – 0.037 kg day^{-1} (95% CI = 0.027-0.047 kg) – are consistent with those of daily length increase (2.9-3.2 mm day^{-1} for males and 2.8-3.0 mm day^{-1} for females) and mass increase (0.044 kg day^{-1} for males and 0.037 kg for females) reported from previous longitudinal studies of pups at WCSI rookeries

(Chilvers et al. 1995, Mattlin 1978a), though there are likely to be strong year effects that could not be estimated with the available data. The model selection process eliminated models that specified colony effects on individual growth rate, though colony effects on individual size were retained and Taumaka Island pups were estimated to be lighter (by 0.71 kg; 95% CI = 0.64-0.78 kg) and of lower BCI (by 0.55 units; 95% CI = 0.50-0.60 units) than pups at Wekakura Point. Potential explanations for this include rookery-variation birth date and growth rate. Regardless of the cause, smaller pup mass at Taumaka (though with less temporal variation) and increased pup mortality rate are consistent with poorer nutritional status of mothers at Taumaka. However this population has declined less than Wekakura Point and Cape Foulwind, suggesting that nutrition is not the only driver of decline at the two northern rookeries.

4.2 Potential causes of population change

The discussion in this section makes the assumption that population trends have been driven by changes in survival or pupping rate at age, rather than migration in or out of the WCSI area. Resighting observations at post-weaning ages are required for an assessment of breeding site fidelity on pup population trends and of the demographic drivers of population change, i.e., the timing and relative importance of changes in pup and adult survival or pupping rate. Without information of the demographic processes affecting populations the discussion is limited to indirect evidence for the potential drivers of population change.

Pinniped populations can respond to an array of external factors: e.g., changes in prey availability (such as driven by climate variation and resource competition with fisheries); direct incidental mortality relating to fishing operations; predation; human disturbance on-land; factors affecting pup mortality including disease; and many others (e.g. Roberts 2015). Here, we discuss a selection of potential threats that have been related to WCSI NZ fur seal populations by previous studies: the direct mortality of NZ fur seals in commercial trawls; and climate or fishery effects on nutrition status via changes in prey species availability (Best et al. 2008, Wilson 1992). These are discussed in relation to trends in pup population and individual size identified in this study.

4.2.1 Direct fishery mortality

Annual incidental mortalities of NZ fur seals in WCSI trawl fisheries have been estimated for the fishing seasons 1990/91 to 2012/13 - exceeding 100 mortalities in a number of years since 1991 (Abraham et al. 2016; Baird & Smith 2007; Ministry for Primary Industries 2014; Thompson et al. 2013). The maximum annual mortality estimate in WCSI hoki trawls since 1990/91 was 1,032 individuals (c.v. = 17%) in 1997/98 (Baird & Smith 2007). This was the year before a drop in pup census estimates for all three rookeries in 1999, though pup numbers partially rebounded in 2001 and 2002 (Figure 3-1). This indicates that the dip in pup numbers from 1999-2000 was primarily caused by low pupping rate, though the rebound in pup numbers was weak at Wekakura Point, suggesting that the survival of breeding-age females was poor at this rookery, at a time when direct fishery mortality was high.

A preliminary correlative analysis by Best et al. (1998, unpublished study) found no obvious relationship between the number of mortalities in the WCSI hoki fishery and pup census estimate in the next year, though this relationship will be masked by variation in pupping rate unless mortalities claim a large proportion of the breeder population in a single year. Resighting effort of marked individuals at post-weaning ages would provide the information requirements for a more robust assessment of direct fishery effects on adult survival. This would be complemented by genetic analyses to determine the rookery of origin of bycaught NZ fur seals (Robertson & Gemmell 2005).

4.2.2 Stressors of prey availability

Comparison of the pup production and pup mass time series for the 3 WCSI rookeries shows broad similarities in temporal trends (see Figure 3-1 and Figure 3-3) indicating common stressors affecting rookeries along the length of the WCSI. Dietary and foraging studies indicate that WCSI fur seals are primarily mesopelagic foragers with a mean dive depth of < 100 m throughout the year (Mattlin et al. 1998) and effort is concentrated ~30 km offshore (Sinclair & Wilson 1994). The diet is rich in diurnally migrating species including lanternfish (*Symbolophorus* sp. and *Lampanyctodes hectoris*), anchovy (*Engraulis australis*) and hoki (*Macruronus novaezelandiae*) (Boren 2010, Carey et al. 1992) and the availability of these species is likely to be sensitive to variation in the WCSI upwelling system.

Best et al. (1998, unpublished study) conducted a preliminary correlative assessment of the relationship between climate predictors and pup production estimates or pup mass and found a strong negative correlation between sea surface temperature, pup numbers and individual pup mass, though the time series of observations was short for a correlative assessment (17 years). Future studies relating demographic and biometric trends to climate predictors will have at least another 9 years of observations for a correlative analysis (see Figure 3-1 and Figure 3-3). Resighting at post-weaning ages of the large number of marked individuals would allow the identification of demographic marker years and a more direct prediction of climate effects on processes affecting population growth rate.

Previous dietary sampling at Cape Foulwind was conducted in the early 1990s when the population size was greater (Carey et al. 1992) and a new study could assess for potential changes in diet given the current declining population trend. Hoki are likely to be a seasonally important component of NZ fur seal diet along the WCSI (Carey et al. 1992), where spawning aggregations are also targeted by commercial trawl fisheries. Future diet studies should seek to assess the relative importance of hoki to fur seal nutrition and to assess the potential for resource competition between NZ fur seals and commercial fisheries.

4.3 Recommendations for future monitoring & research

NZ fur seals are a major high-level predator of NZ marine ecosystem. This study has identified a major decline in the WCSI fur seal population that requires further investigation with respect to the demographic and external causes of decline, so that effective conservation measures can be identified.

4.3.1 Continuation of mark-recapture study

This study demonstrates the value of collecting a long time series of demographic and biological observations for the monitoring of population size and nutritional status and we recommend that this is continued in future years, adopting a consistent methodology with the 1991-2016 period. Because variation in pupping rate can mask changes in breeder numbers, we recommend that sampling continues on an annual basis. Annual data are also required for assessing relationships with ocean climate, the WCSI hoki trawl fishery and other factors that the study populations may be responding to.

We recommend that monitoring continues at all three rookeries. Wekakura Point and Cape Foulwind rookeries have undergone the greatest decline from 1991-2016 and are located closest to the trawl fishery for winter spawning hoki, centred on the Hokitika Canyon (Figure 1-1). A declining pup mass trend was also identified at Wekakura Point, which merits further investigation with respect to potential causes and the effects of declining pup mass on survival. Taumaka Island has a more stable population, yet has the lightest pups and greatest pup mortality. Hence, Taumaka Island provides a valuable reference point for interpreting climate/fishery effects on nutrition and for comparing trends in pup production and individual size/condition at the other two rookeries.

The current field sampling protocol is effective in producing precise estimates of pup population size and individual size and condition. Marked numbers in future years could potentially be reduced without compromising the assessment of temporal trends. However, reducing tagged numbers will lead to a reduction in the numbers of marked individuals in each cohort, constraining our ability to identify the demographic causes of population change in future years. As such, we recommend that a similar marked population size is used in future years.

4.3.2 Threat-specific research

Given that multiple indicators of nutritional stress were identified (e.g. years of low pup condition and probable low pupping rate) we recommend that scat/regurgitate samples are routinely collected to identify key prey species and monitor temporal variation in diet composition. We also recommend an updated analysis relating climate predictors to pup production trend and individual mass or condition, informed by the relationships provisionally identified by Best et al. (1998, unpublished study). This would ideally use pup measurements that are standardised for sex and date of tagging and use spatial foraging studies to refine area constraints for sub-setting ocean climate data. Stock assessment and trawl/acoustic survey outputs can also be used to relate demographic and biological trends of NZ fur seals to the availability of hoki and other prey species.

A declining pup weight trend was identified at Wekakura Point, and to a lesser degree at Taumaka Island (Figure 3-3). Future field work could estimate the annual pup mortality rate for these two populations i.e., from birth to late-January, when the mark-recapture study is undertaken. Field-based necropsies would allow preliminary assessment of the causes of pup death.

Foraging ranges and time-depth dive profiles of lactating fur seals at all three rookeries are required to determine the extent of overlap with trawl fisheries operations in the WCSI hoki fishery. Few fur seals are captured with flipper tags still attached, though the genetic analysis of tissue samples shows promise for identifying the natal rookery of origin, which can then be used to partition captures to the three WCSI study populations (Robertson and Gemmell 2005).

4.3.3 Demographic assessment

Resighting effort at post-weaning ages is required to identify the underlying demographic causes of population change. Thousands of pups have now been double flipper-tagged at all three study rookeries (see Table 3-3). We recommend at least three consecutive years of tag resighting effort is undertaken during the breeding season at Wekakura Point and/or Cape Foulwind to provide the information requirements for an assessment of the demographic drivers of population change and to facilitate the quantitative assessment of human and natural threats.

5 Acknowledgements

We want to thank numerous DOC staff, tangata whenua representatives and volunteers who have partaken in fieldwork at the WCSI rookeries. We also thank Dr. Mana Stratton (animal health and marine mammal veterinarian), Nathaniel Scott (Taumaka me Popotai Trust) and Scott Freeman. DOC West Coast/Tai Poutini, the Hoki Fishery Management Company, ALLFLEX NZ, HeliVentures and Morrow Bassett & Co. made contributions towards operational funding of the study. The NZ fur seal/kekeno is listed as a taonga species under the Ngai Tahu Settlement Act. Pup capture and handling procedures were approved by the Department of Conservation Animal Ethics Committee and Te Runanga o Ngai Tahu Group Management, and followed the Canadian Council on Animal Care guidelines for wildlife handling. Fieldwork on Taumaka Island was sanctioned by Taumaka me Popotai Trust. The demographic database for WCSI NZ fur seals was developed and maintained by Dragonfly Data Science. We thank Suze Baird, Laura Boren, Ingrid Gruner and Helen Otley for reviewing earlier drafts of this report. This analysis was funded by DOC.

6 References

Abraham E.R., Richard Y., Berkenbusch K., Thompson, F. (2016). Summary of the capture of seabirds, marine mammals, and turtles in New Zealand commercial fisheries, 2002–03 to 2012–13. New Zealand Aquatic Environment and Biodiversity Report No. 169.

Baird, S.J. (2011) New Zealand fur seals – summary of current knowledge. *New Zealand Aquatic Environment and Biodiversity Report No. 72*. 50 p.

Baird, S.J., Smith, M.H. (2007) Incidental capture of New Zealand fur seals (Arctocephalus forsteri) in commercial fisheries in New Zealand waters, 2003–04 and 2004–05. New Zealand Aquatic Environment and Biodiversity Report No. 14.

Best, H., Unwin, M., Uddstrom, M. (2008) Annual variation in New Zealand fur seal (*Arctocephalus forsteri*) pup production in relation to local sea-surface temperature and chlorophyll-a anomalies. NIWA Client Report: CHC2008-025, Unpublished report prepared for the Department of Conservation.

Best, H., Neale, D., Hopkins, G. (2010) A Field Manual for Mark-Recapture Monitoring of NZ Fur Seal (Kekeno) Pups, West Coast South Island - DRAFT. Report for the West Coast Tai Poutini Conservancy, Department of Conservation, Te Papa Atawhai.

Boren, L. (2010) Diet of New Zealand fur seals (*Arctocephalus forsteri*): a summary. *DOC Research & Development Series 319*.

Bradshaw, C.J.A., Davis, L.S., Lalas, C., Harcourt, R.G. (2000) Geographic and temporal variation in the condition of pups of the New Zealand fur seal (*Arctocephalus forsteri*): evidence for density dependence and differences in the marine environment. *Journal of Zool. Lond., 252*: 41-51.

Carey, P.W. (1992) Fish prey species of the New Zealand fur seal (*Arctocephalus forsteri*, Lesson). *New Zealand Journal of Ecology 16*: 41-46.

Chilvers, B.L., Wilson, K.-J., Hickling, G.J. (1995). Suckling behaviours and growth rates of New Zealand fur seals, *Arctocephalus forsteri*, at Cape Foulwind, New Zealand. New Zealand Journal of Zoology, 22:3, 263-270.

Guinet, G, Roux, J.P., Bonnet, M., Mison, V. (1998) Effect of body size, body mass, and body condition on reproduction of female South African fur seals (*Arctocephalus pusillus*) in Namibia. *Canadian Journal of Zoology, 76*: 1418-1424.

Lalas, C., Bradshaw, C. (2001) Folklore and chimerical numbers: review of a millennium of interaction between fur seals and humans in the New Zealand region. *New Zealand Journal of Marine and Freshwater Research, 35*: 477-497.

Mattlin, R.H. (1978a) Population Biology, Thermoregulation and site preference of the New Zealand fur seal, *Arctocephalus forsteri* (Lesson, 1828), on the Open Bay Islands, New Zealand. Ph.D Thesis. University of Canterbury.

Mattlin, R.H. (1978b) Pup mortality of the New Zealand fur seal (*Arctocephalus forsteri* Lesson). *New Zealand Journal of Ecology, 1*: 138-144.

Mattlin, R.H., Gales, N.J., Costa, D.P. (1998). Seasonal dive behaviour of lactating New Zealand fur seals (*Arctocephalus forsteri*). Canadian Journal of Zoology, 76: 350-360.

Ministry for Primary Industries (2014) Aquatic Environment and Biodiversity Annual Review 2014. Compiled by the Fisheries Management Science Team, Ministry for Primary Industries, Wellington, New Zealand. 560 p.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Roberts, J. (2015). Review of threats to the recovery of NZ sea lions and other otariid species. Report prepared for the Department of Conservation.

Roberts, J., Doonan, I. (2016). Quantitative risk assessment of threats to New Zealand sea lions. New Zealand Aquatic Environment and Biodiversity Report No. 166.

Robertson, B.C., Gemmell, N.J. (2005). Microsatellite DNA markers for the study of population structure in the New Zealand fur seal *Arctocephalus forsteri*. DOC science internal series 196.

Sinclair, J.G., Wilson, K.-J. (1994). A radio tracking study of the movements and foraging ecology of female New Zealand fur seals (*Arctocephalus forsteri*) at Cape Foulwind. Lincoln University Wildlife Management Report 5.

Shaughnessy, P.D., Goldsworthy, S.D. and Libke, J.A. (1995). Changes in the abundance of New Zealand fur seals, *Arctocephalus forsteri*, on Kangaroo Island, South Australia. *Wildlife Research 22*: 201-15.

Smith, I.W.G. (1985). Sea mammal hunting and prehistoric subsistence in New Zealand. PhD Thesis, Anthropology, University of Otago.

Taylor, R.H., Barton, K.J.; Wilson, P.R.; Thomas, B.W.; Karl, B.J. (1995) Population status and breeding of New Zealand fur seals (*Arctocephalus forsteri*) in the Nelson-northern Marlborough region, 1991–94. *New Zealand Journal of Marine and Freshwater Research 29*: 223–234.

Thompson, F.N., Berkenbusch, K., Abraham, E.R. (2013) Marine mammal bycatch in New Zealand trawl fisheries, 1995–96 to 2010–11. *New Zealand Aquatic Environment and Biodiversity Report No. 105*.

Wilson, G.J. (1981). Distribution and abundance of the New Zealand fur seal, *Arctocephalus forsteri*. Fisheries Research Division Occasional Publication No. 20.

Wilson, K.-J. (1992). Fur seals and the South Island hoki fishery. Paper presented at the Workshop on seals and seabirds – fisheries interactions, 27-30 April 1992.

Appendix A Biometric model comparison

Table A-1: Comparison of models for predicting individual standard length of pups born at West Coast South Island rookeries. Models are displayed in ascending order of AICc.

Terms included in model									
Intercept	colony	day	season	sex	colony : sex	day : sex	d.f.	delta AICc	Weight
67.98	+	0.3803	+	+	+		31	0	0.392
68.00	+	0.3645	+	+	+	+	32	0.38	0.325
68.18	+	0.3606	+	+		+	30	1.75	0.163
68.17	+	0.3804	+	+			29	2.36	0.12
67.44		0.3974	+	+		+	28	47.41	0
67.44		0.4146	+	+			27	47.43	0
71.51	+		+	+	+		30	400.27	0
71.71	+		+	+			28	402.43	0
70.80			+	+			26	558.15	0
69.35	+	0.3815	+				28	573.51	0
68.61		0.4163	+				26	616.87	0
70.10	+	0.3051		+	+	+	9	752.59	0
70.08	+	0.3267		+	+		8	753.46	0
70.25	+	0.3032		+		+	7	754.26	0
70.26	+	0.3268		+			6	755.83	0
69.93		0.3173		+		+	5	786.93	0
69.94		0.3392		+			4	788.02	0
72.90	+		+				27	953.32	0
71.98			+				25	1102.83	0
71.48	+	0.3322					5	1329.62	0
71.16		0.3446					3	1359.04	0
70.38	+			+	+		7	1400.1	0
70.53	+			+			5	1402.69	0
69.84				+			3	1504.22	0
71.78	+						4	1960.65	0
71.08							2	2056.62	0

Table A-2: Comparison of models for predicting individual mass of pups born at West Coast South Island rookeries. Models are displayed in ascending order of AICc.

		Terms included in model							
Intercept	colony	day	season	sex	colony : sex	day : sex	d.f.	delta AICc	Weight
6.738	+	0.03692	+	+			29	0	0.563
6.738	+	0.03542	+	+		+	30	1.80	0.229
6.716	+	0.03692	+	+	+		31	2.66	0.149
6.717	+	0.03579	+	+	+	+	32	4.55	0.058
7.081	+		+	+			28	52.95	0
7.059	+		+	+	+		30	55.60	0
6.107		0.06624	+	+			27	484.81	0
6.107		0.0667	+	+		+	28	486.80	0
6.643			+	+			26	664.11	0
7.084	+	0.03726	+				28	698.89	0
7.431	+		+				27	748.97	0
6.466	+	0.06064		+			6	1122.7	0
6.465	+	0.05829		+		+	7	1124.22	0
6.448	+	0.06058		+	+		8	1124.56	0
6.450	+	0.05829		+	+	+	9	1126.11	0
6.451		0.06673	+				26	1154.24	0
6.991			+				25	1324.02	0
6.517	+			+			5	1432.57	0
6.503	+			+	+		7	1433.82	0
6.207		0.07075		+			4	1443.42	0
6.207		0.06972		+		+	5	1445.34	0
6.820	+	0.06223					5	1786.03	0
6.187				+			3	1863.91	0
6.562		0.0723					3	2083.46	0
6.877	+						4	2091.00	0
6.546							2	2494.88	0

Table A-3: Comparison of models for predicting individual body condition index of pups born at West Coast South Island rookeries. Models are displayed in ascending order of AICc.

			Terms included in model						
Intercept	colony	day	season	sex	colony : sex	day : sex	d.f.	delta AICc	Weight
0.735	+	-0.0340	+	+			29	0	0.539
0.7345	+	-0.0319	+	+		+	30	1.22	0.293
0.7501	+	-0.0340	+	+	+		31	3.11	0.114
0.7477	+	-0.0322	+	+	+	+	32	4.59	0.054
0.4178	+		+	+			28	79.42	0
0.433	+		+	+	+		30	82.55	0
0.8612	+	-0.0339	+				28	164.92	0
0.5449	+		+				27	242.39	0
0.2404		-0.0075	+	+		+	28	511.89	0
0.2405		-0.0111	+	+			27	512.06	0
0.1502			+	+			26	519.07	0
0.3662		-0.0109	+				26	670.36	0
0.2772			+				25	676.95	0
0.07353	+			+			5	1138.7	0
0.07384	+	-0.0003		+			6	1140.68	0
0.08757	+			+	+		7	1141.97	0
0.07429	+	0.00168		+		+	7	1142.03	0
0.08795	+	-0.0004		+	+		8	1143.95	0
0.08638	+	0.0013		+	+	+	9	1145.52	0
0.201	+						4	1288.99	0
0.2008	+	0.0001					5	1290.99	0
-0.1251		0.0074		+			4	1471.75	0
-0.1242		0.0104		+		+	5	1472.36	0
-0.1272				+			3	1477.98	0
0.001733		0.0079					3	1615.85	0
-2.8E-13							2	1623.22	0

Appendix B Biometric model diagnostic plots

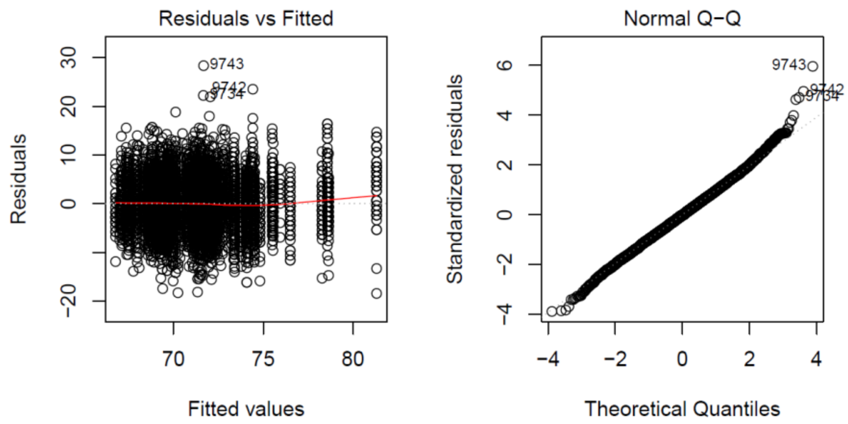

Figure B-1: Model diagnostic plots for optimal model for predicting individual standard length – all rookeries.

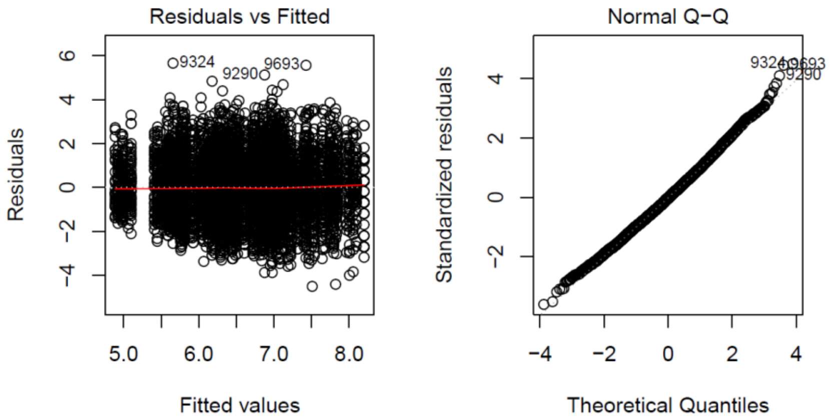

Figure B-2: Model diagnostic plots for optimal model for predicting individual weight – all rookeries.

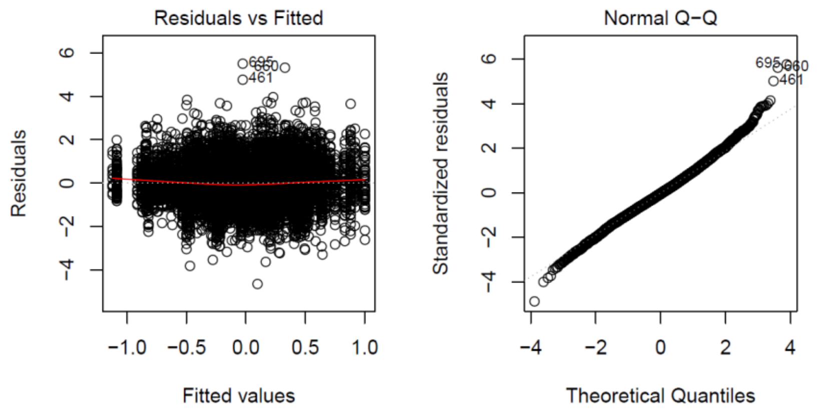

Figure B-3: Model diagnostic plots for optimal model for predicting individual body condition index – all rookeries.

Appendix C Biometric model coefficients

Table C-1: Model coefficients for the optimal model for predicting standard length of pups born at West Coast South Island rookeries. Models are in ascending order of AICc; Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Parameter	Estimate	Std. Error	t value	p-value	
Intercept	67.9751	0.3205	212.093	< 0.0001	***
sexM	2.7426	0.1884	14.559	< 0.0001	***
sexM:colonyTaumaka Island	-0.477	0.2438	-1.956	0.0505	.
sexM:colonyWekakura Point	-0.6081	0.2497	-2.436	0.0149	*
day	0.3803	0.0188	20.235	< 0.0001	***
colonyTaumaka Island	-0.5857	0.179	-3.271	0.0011	**
colonyWekakura Point	0.1588	0.1782	0.891	0.3730	
season1992	1.8114	0.3475	5.213	< 0.0001	***
season1993	3.3809	0.3423	9.877	< 0.0001	***
season1994	4.126	0.3401	12.132	< 0.0001	***
season1995	2.3146	0.3576	6.473	< 0.0001	***
season1998	4.0791	0.3302	12.354	< 0.0001	***
season1999	0.7531	0.387	1.946	0.0517	.
season2000	1.9683	0.3803	5.176	< 0.0001	***
season2001	3.6344	0.369	9.849	< 0.0001	***
season2002	-0.6091	0.3565	-1.709	0.0876	.
season2003	1.6226	0.3642	4.455	< 0.0001	***
season2004	2.4918	0.3716	6.705	< 0.0001	***
season2005	4.1249	0.3903	10.569	< 0.0001	***
season2006	3.5323	0.4024	8.777	< 0.0001	***
season2007	3.4446	0.4162	8.276	< 0.0001	***
season2008	1.848	0.3591	5.146	< 0.0001	***
season2009	1.6739	0.3944	4.244	< 0.0001	***
season2010	2.3883	0.4044	5.906	< 0.0001	***
season2011	2.9472	0.4073	7.236	< 0.0001	***
season2012	1.934	0.4003	4.831	< 0.0001	***
season2013	0.7789	0.4212	1.849	0.0645	.
season2014	0.9501	0.3903	2.434	0.0149	*
season2015	0.6153	0.4264	1.443	0.1490	
season2016	0.1059	0.3664	0.289	0.7725	

Table C-2: Model coefficients for the optimal model for predicting mass of pups born at West coast rookeries. Models are in ascending order of AICc; Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Parameter	Estimate	Std. Error	t value	p-value	
Intercept	6.738	0.082	81.994	< 0.0001	***
sexM	0.689	0.026	26.919	< 0.0001	***
day	0.037	0.005	7.413	< 0.0001	***
colonyTaumaka Island	-0.708	0.035	-20.418	< 0.0001	***
colonyWekakura Point	-0.147	0.034	-4.369	< 0.0001	***
season1992	0.183	0.092	1.991	< 0.0001	***
season1993	0.220	0.091	2.431	0.0465	*
season1994	0.145	0.090	1.605	0.0151	*
season1995	0.467	0.095	4.924	0.1085	
season1998	0.147	0.087	1.677	< 0.0001	***
season1999	-0.855	0.103	-8.338	0.0937	.
season2000	-0.969	0.101	-9.620	< 0.0001	***
season2001	0.430	0.098	4.399	< 0.0001	***
season2002	-1.140	0.094	-12.067	< 0.0001	***
season2003	-0.203	0.097	-2.105	< 0.0001	***
season2004	-0.231	0.098	-2.341	0.0353	*
season2005	0.297	0.103	2.868	0.0192	*
season2006	-0.245	0.107	-2.301	0.0041	**
season2007	-0.091	0.110	-0.824	0.0214	*
season2008	0.361	0.095	3.790	0.4100	
season2009	-0.219	0.104	-2.102	0.0002	***
season2010	-0.176	0.107	-1.648	0.0356	*
season2011	-0.472	0.108	-4.369	0.0994	.
season2012	-0.938	0.106	-8.846	< 0.0001	***
season2013	-0.814	0.112	-7.289	< 0.0001	***
season2014	-0.676	0.103	-6.540	< 0.0001	***
season2015	-0.367	0.113	-3.249	< 0.0001	***
season2016	-0.433	0.097	-4.461	0.0012	**

Table C-3: Model coefficients for the optimal model for predicting body condition index of pups born at West coast rookeries. Models are in ascending order of AICc; Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Parameter	Estimate	Std. Error	t value	p-value	
(Intercept)	0.735	0.062	11.800	< 0.0001	***
sexM	0.252	0.019	12.957	< 0.0001	***
colonyTaumaka Island	-0.554	0.026	-21.078	< 0.0001	***
colonyWekakura Point	-0.120	0.025	-4.695	< 0.0001	***
day	-0.034	0.004	-9.030	< 0.0001	***
season1992	-0.155	0.070	-2.220	0.0264	*
season1993	-0.411	0.069	-5.975	< 0.0001	***
season1994	-0.626	0.068	-9.161	< 0.0001	***
season1995	0.034	0.072	0.479	0.6322	
season1998	-0.615	0.066	-9.274	< 0.0001	***
season1999	-0.996	0.078	-12.812	< 0.0001	***
season2000	-1.337	0.076	-17.504	< 0.0001	***
season2001	-0.247	0.074	-3.334	0.0009	***
season2002	-1.026	0.072	-14.334	< 0.0001	***
season2003	-0.506	0.073	-6.920	0.0000	***
season2004	-0.696	0.075	-9.323	< 0.0001	***
season2005	-0.474	0.078	-6.044	< 0.0001	***
season2006	-0.905	0.081	-11.196	< 0.0001	***
season2007	-0.734	0.084	-8.782	< 0.0001	***
season2008	0.015	0.072	0.214	0.8303	
season2009	-0.534	0.079	-6.753	< 0.0001	***
season2010	-0.625	0.081	-7.697	< 0.0001	***
season2011	-1.022	0.082	-12.491	< 0.0001	***
season2012	-1.299	0.080	-16.158	< 0.0001	***
season2013	-0.957	0.085	-11.315	< 0.0001	***
season2014	-0.854	0.078	-10.891	< 0.0001	***
season2015	-0.482	0.086	-5.630	< 0.0001	***
season2016	-0.453	0.074	-6.156	< 0.0001	***