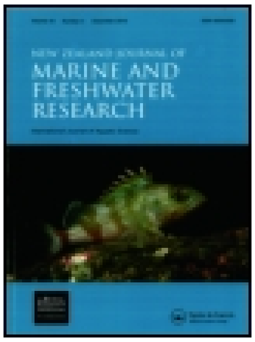

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New Zealand sea lion, *Phocarctos hookeri*, pup production—1995 to 2006

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Abstract The New Zealand sea lion (NZ sea lion), *Phocarctos hookeri*, is New Zealand's only endemic pinniped. Classified as vulnerable, it is one of the world's rarest pinnipeds. During the 1994/95 austral summer, a long-term population-monitoring programme of the Auckland Island colonies was initiated using standard procedures to estimate annual pup production. This paper reports the pup production estimates for the known NZ sea lion population over the last 12 years (1994/95 to 2005/06), and the variation in pup production estimates for the Auckland Islands. Sixty-four percent of the pup production for the entire NZ sea lion population occurred at Dundas Island, followed by Enderby Island (19%), and Figure of Eight Island (3%). These three sites are all at the Auckland Islands, making this area the primary breeding site for this species with 86% of all pup production occurring here. The remaining 14% were born at Campbell Island, with Otago Peninsula representing <0.1%. The pup production estimates for the NZ sea lion population varied considerably by year and breeding area. The most significant change recorded was at the primary breeding site for this species, the Auckland Islands, which had a 31% decline in pup production between 1997/98 and 2005/06 owing to a combination of disease events and incidental by-catch from commercial fishing activity.

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Keywords pinniped; pup production; sub-antarctic; Campbell Island; Auckland Islands

INTRODUCTION

The New Zealand sea lion (NZ sea lion), *Phocarctos hookeri* (Gray, 1844), is New Zealand's only endemic pinniped (Bryden et al. 1998). It is one of the world's rarest pinnipeds, with a highly restricted breeding range between 50°S and 53°S, primarily on the Auckland (50°S, 166°E) and Campbell islands (52°33′S, 169°09′E, Gales & Fletcher 1999; McNally 2001; Childerhouse et al. 2005). Occasional births have been recorded at the Snares Islands (166°35′, 48°02′, Crawley & Cameron 1972), Stewart Island (47°S, 168°E, Childerhouse & Gales 1998) and Otago Peninsula (46°S, 170°40′E, McConkey et al. 2002a,b) (Fig. 1).

The majority of the species breeds on two islands (Dundas and Enderby islands) within a 10 km radius in the Auckland Island group (Gales 1995; Fig. 1). These two islands are considered one breeding location owing to their close proximity and the high interchange between the islands of breeding males within a breeding season (Robertson et al. 2005).

Haul-out sites of NZ sea lions are more widespread, extending from Macquarie Island (54°30′S, 159°E) in the south, where a few adult males haul out each year (McMahon et al. 1999; Robinson et al. 1999), north to Stewart Island and associated islands, the Catlins (46°30′S,169°45′E) and the Otago Peninsula in the southern New Zealand mainland where regular

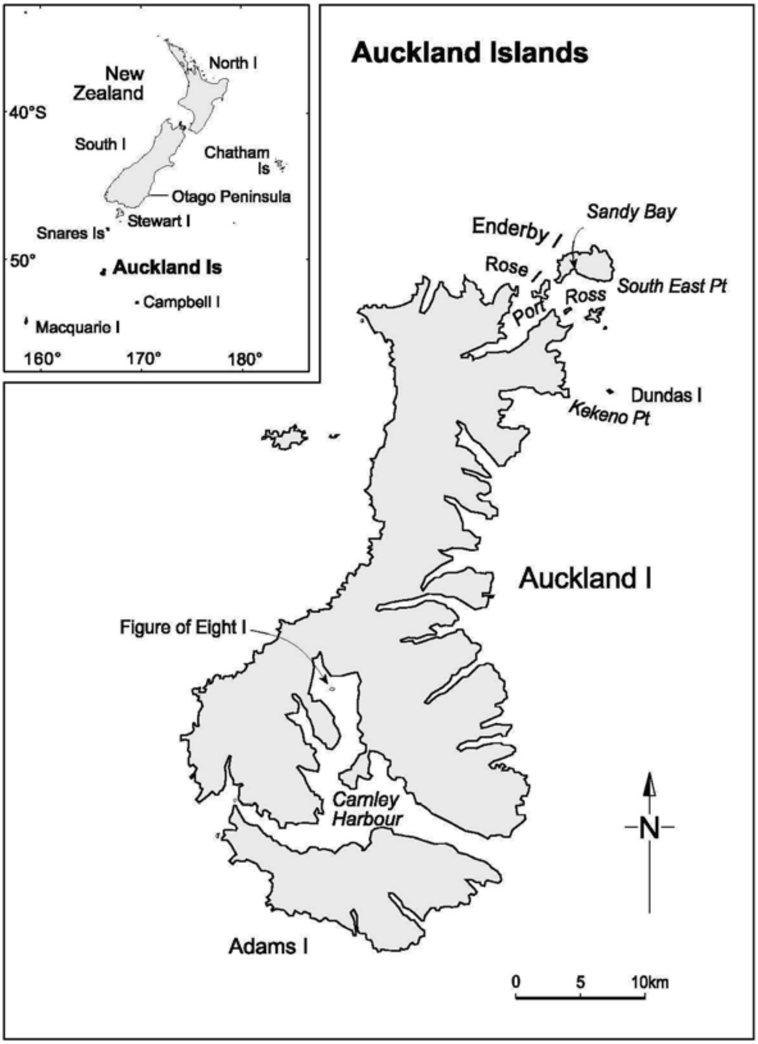

Fig. 1 New Zealand mainland and subantarctic showing Otago Peninsula, Stewart Island, Snares Islands, Auckland Island and Campbell Island. Auckland Islands main breeding areas for New Zealand sea lion (*Phocarctos hookeri*) are Sandy Bay and South East Point on Enderby Island, Dundas Island, and Figure of Eight Island in Carnley Harbour.

sightings occur (McConnell 2001; McNally 2001; McConkey et al. 2002a,b).

The NZ sea lion is classified as "vulnerable" by the IUCN (Reijnders et al. 1993) and "threatened" owing to range restriction under the New Zealand Marine Mammals Protection Act 1978 and the New Zealand Threat Classification Status (Hitchmough 2002). The last published abundance estimates for NZ sea lions were from the 1994/95 and 1995/96 seasons when estimates were 11 700 (CI 10 500-13 100) and 12 500 (CI 11 100-14 000) respectively (reported to the nearest 100, Gales & Fletcher 1999). These estimates were calculated from total pup production data of 2640 and 2807, respectively (Gales & Fletcher 1999).

Calculations of NZ sea lion abundance were undertaken for the 1994/95 and 1995/96 seasons owing to the concern that the bycatch of NZ sea lions in the trawl fishery for arrow squid (*Nototodarus sloanii*) were impacting the species, either causing a decline or not allowing the population to recover from turn-of-the-century sealing impacts. Up to 140 sea lions are caught and killed annually as bycatch in the arrow squid trawl fishery (Ministry of Fisheries 2006). The fishery operates on the Auckland Island shelf between February and May each year, the period of early lactation for NZ sea lions (Gales 1995). Squid comprises part of the sea lion's diet (Childerhouse et al. 2001) and with both sea lions and trawlers pursuing the same prey in the same area

(Chilvers et al. 2005, 2006a), interactions result in bycatch deaths (Baird 1996; Ministry of Fisheries 2006). There are also presumed indirect effects of competition for resources and possible marine habitat and biodiversity alteration from trawling activities (Wilkinson et al. 2003). Disease is also thought to play an important role in the regulation of this species through episodic events such as in 1997/98, when an epidemic thought to be caused by *Campylobacter* killed over 70 breeding females and up to 58% of the pups born that year (Baker 1999). In the 2001/02 and 2002/03 breeding seasons, disease epidemics of *Klebsiella pneumonia*, an opportunistic bacterial pathogen, resulted in the deaths of 33% and 21% of each season's pup production, respectively (Wilkinson et al. 2006).

In 1994/95 a long-term population-monitoring programme of the Auckland Island colonies was initiated which included annual pup production estimates using standard procedures. For pinnipeds, estimates of pup production are the best index of relative population status and best measure from which overall population size and variation can be estimated (Berkson & DeMaster 1985). Pups represent the only age class that is readily recognisable, and is restricted to land, thus making it the only component of the population that can be counted in its entirety. In this paper we report the pup production estimates for the known NZ sea lion population from 1994/95 to 2005/06 and the variation in pup production estimates for the Auckland Islands where the majority of pupping occurs.

METHODS

There have been seven pupping sites confirmed and recorded for the NZ sea lion species. Four of these are at the Auckland Islands and one at each of Campbell and Snares islands and on the Otago Peninsula, mainland New Zealand (Fig. 1).

The four pupping sites at the Auckland Islands (Fig. 1), Sandy Bay (50°30′S, 166°17′E) and South East Point (SEP) on Enderby Island (50°30′S, 166°19′E), Dundas Island (50°35′S, 166°19′E) and Figure of Eight Island (50°46′S, 166°01′E) have been monitored annually since 1994/95, with the methods used at each site varying in relation to its logistical constraints and size. SEP on Enderby Island and Figure of Eight Island were counted using direct counts, whereas at Sandy Bay/Enderby Island and Dundas Island the primary estimation method was a mark-recapture estimate (Gales & Fletcher 1999; Wilkinson et al. 2003).

Direct counts

Direct counts were conducted at SEP using daily surveys during the breeding season (December 4 to January 20). SEP is a small, open, rocky coastal area which is easily surveyed (B. L. Chilvers pers. obs.). All counts were conducted from the rocky beach margin, with hand tally counters and daily counts recorded. Pup production was based on the daily count of live pups and the cumulative total of dead pups (Gales & Fletcher 1999; Wilkinson et al. 2003).

The remote location of Figure of Eight Island (over 60 km south of Enderby Island) prevented multiple visits during a season, and pup production was based on the mean of counts conducted by two to three people made on a single day in early/mid January (Range 6–25 January; Gales & Fletcher 1999; Wilkinson pers. comm.). Counts of alive and dead pups were undertaken during surveys of the entire island using hand tally counters.

Mark-recapture experiments

For the 12 years, 1994/95 to 2005/06 each year a single Mark-Recapture (M-R) experiment was conducted at Sandy Bay/Enderby Island on 15 and 16 January and at Dundas Island on 20 and 21 January. The M-R study was timed to occur when pupping had ceased, but before the pups had started to disperse from their natal birth beach (Gales & Fletcher 1999). The best time for counts was estimated from pup production curves produced at Sandy Bay and Dundas Island (Gales & Fletcher 1999). The date of maximum pup numbers at Sandy Bay (mid-January) changes by only 1 or 2 days between years (Wilkinson et al. 2003; Chilvers et al. 2006b). Pups were marked with circular, 6-cm-diameter, flexible vinyl discs that were glued to the crown of their heads with a fast-setting cyanoacrylic glue (Loctite 454). The number of pups marked was approximately 25/50% of previous pup production estimate (Sandy Bay 200 marked pups, Dundas Island 400 marked pups). Marking was spread as evenly as possible through the breeding area (based on pup density). Most discs were shed a few days to a few weeks after the experiment. Recaptures involved three observers moving systematically through the entire sea lion pupping area counting pups, with each observer conducting three replicate counts. Each pup was classified as either marked or unmarked and a tally of each was maintained by each observer using two hand-tally counters. Only pups where the entire head was visible were included in the counts, to minimise the risk associated with undercounting unmarked pups. As the discs were clearly visible on the heads of pups if only part of the head is viewed, there is a greater probability that a marked pup would be correctly identified than an unmarked pup. This greater probability of viewing marked pups could have lead to an overestimate of the proportion of marked pups and underestimate of pup production. Consequently, any pups that could not be categorised as marked or unmarked, i.e., where the entire head was not visible, were excluded from the count. All recapture operations were conducted on the day following the marking operation to allow time for even mixing of marked and unmarked individuals, and where possible at a time when pups were not clumped in "pup piles" (a thermoregulatory behaviour displayed by pups particularly in cold weather (B. L. Chilvers pers. obs.)) to make resighting of pups easier.

Results of each recapture were used to calculate a modified Petersen estimate of pup production P_i (Chapman 1952), namely:

$$P_i = \left[\frac{(M+1)(C_i+1)}{(R_i+1)}\right] - 1$$

where, for replicate i, M is the number of previously marked sea lion pups, C_i is the number of pups examined in the recapture sample, and R_i is the number of marked pups in the recapture sample. The overall estimate of pup production, P, is the mean of the Q individual estimates, i.e.,

$$P = \frac{\sum_{i=1}^{Q} P_i}{Q}$$

The standard error, of P was calculated directly from the individual estimates (Chapman 1952), as:

$$SE = \sqrt{\frac{1}{Q(Q-1)} \sum_{i=1}^{Q} (P_i - P)^2}$$

(see Gales & Fletcher 1999 for details).

The assumptions for the M-R model were: (1) all pups were born by 15 and 21 January at Sandy Bay/Enderby Island and Dundas Island, respectively; (2) all pups were accessible for marking (i.e., capture probability was constant); (3) all pups were mobile and mixed well after being marked; (4) marks were not lost before M-R counts the following day; (5) mortality was negligible and assumed to be zero in the 24 h between marking and recapturing; and (6) pups were not yet swimming and females had not started to move their pups away from the island (no emigration or immigration to the study area).

Numbers of pups known to have died up to the date of the M-R estimate were then added to produce a figure for total pup production (Gales & Fletcher 1999; Wilkinson et al. 2003). All pups that died during the breeding season from Sandy Bay and SEP, Enderby Island were counted and removed on a daily basis for autopsy, which resulted in the accurate assessment of numbers of dead pups from these two sites. For Dundas and Figure of Eight islands, dead pup numbers were estimated by counting all visible pup carcases the day of pup production estimate. Carcases were counted by up to four observers systematically covering the islands at the same time calling out and identifying carcases, so as not to overlap observer search areas, with one observer using a hand counter to tally total carcase count. This procedure was conducted three times each year for each island and the mean calculated to provide a dead pup estimate.

Mark-recapture estimates were validated by comparing the M-R estimate taken at Sandy Bay/Enderby Island with the number of pups flipper-tagged at Sandy Bay/Enderby Island, as all live pups were tagged using coffin-shaped Dalton DAL 008 Jumbotags® (Dalton Supplies Ltd, Henley-on-Thames, United Kingdom) within 2 days of the M-R. This procedure was carried out to validate and determine the accuracy of the M-R procedure for NZ sea lions.

Other pupping locations

Pup production estimates for Otago Peninsula and Snares Islands were derived from direct counts (McNally 2001; McConkey et al. 2002a,b; McConkey unpubl. data). Continuous monthly monitoring of NZ sea lions on the Otago Peninsula and the Catlins has occurred since May 1994 (McConkey et al. 2002a,b). For Snares Islands, direct counts were undertaken on the eastern side of Northeast Island, usually between Punui and HoHo bays (48°01′S, 166°38′E) in late summer/autumn (February – May 1997 and 1998, McNally 2001; 1992–2006, P. Sagar pers. comm.). A M-R estimate of flipper-tagged pups was conducted from January to April 2003 covering the entire Campbell Island from which pup production was derived (Childerhouse et al. 2005).

RESULTS

Over the last 12 years the pup production estimates at the four Auckland Island pupping sites have been highly variable, from 3021 ± 94 pups in 1997/98 to 2089 ± 34 pups in 2005/06 (Tables 1 and 2). The pup production estimate appeared to increase from 1994/95 through to 1997/98 then drop slightly and level out for 3 years. From 1997/98 there were two major reductions in pup production in 2001/02 and 2004/05 (Tables 1 and 2) and in total a decline in pup production of 31% between 1997/98 (3021 ± 94) and 2005/06 (2089 ± 34) (Tables 1 and 2).

The proportion of mortality recorded for NZ sea lion pups, before pup production estimates were derived each year, varied significantly over the last decade, with 5–26% and 5–21% mortality for Dundas Island and Sandy Bay, respectively (Table 1). Mortality at approximately 5 weeks after M-R estimates at Sandy Bay ranged from 9 to 33% (Table 1).

A single M-R pup production estimate was undertaken at Campbell Island in 2002/03 with an estimate of 385 ± 28 (Childerhouse et al. 2005; Table 2). Before the 2002/03 estimate a value of 122 (M. Fraser pers. comm.), which was obtained from a direct count of 98 tagged and 24 dead pups in 1991/92, had been used (Gales & Fletcher 1999; Wilkinson et al. 2003, Table 2). Occasional births have been reported on Stewart Island but none have been confirmed. In the last 10 years, one pup sighting was documented at Snares Islands in 1997 (McNally 2001), however there have been no recorded sightings since (Table 2). There have been regular records of pup(s) at Otago Peninsula (46°S, 170°40′E) since 1994 (McConkey et al. 2002a,b; McConkey unpubl. data, Table 2).

Between 2002/03 and 2005/06, with the more rigorous estimate of Campbell Island pup production (Childerhouse et al. 2005), the pup production composition of the entire NZ sea lion population is represented as Enderby Island 19%, Dundas Island 64%, Figure of Eight Island 3%, Campbell Island 14%, and Otago Peninsula <0.1%.

Table 1 Pup production and mortality estimates for the four Auckland Island NZ sea lion (*Phocarctos hookeri*) breeding areas. (*, mortality at date of pup production estimate each year. †, mortality of pups in late February each year 5 weeks after pup production count. Mortality data collected only in 1997/98 for other locations except Sandy Bay.) (n.a., data not available.)

	Sandy Bay, Enderby Island				South East Point, Enderby Island		Dundas Island		Figure of Eight Island	
Season	M-R ± SE	No. pups tagged[1]	Mortality %*	Mortality %†	Direct count	Mortality %*	M-R ± SE	Mortality %*	Direct count	Mortality %*
1994/95[3]	467 ± 5	n.a.	10	n.a.	71	17	1837 ± 26	13	143	12[2]
1995/96[3]	455 ± 4	n.a.	8	n.a.	69	29	2017 ± 20	10	144	22
1996/97	509 ± 3	n.a.	7	n.a.	63	38	2260 ± 22	8	143	6
1997/98	477 ± 9	480	2	42	51	27/45†	2373 ± 24	26/58†	120	19/28†
1998/99	513 ± 4	525	8	9	59	29	2186 ± 90	10	109	8
1999/00	506 ± 10	503	5	11	50	26	2163 ± 33	6	137	4
2000/01	562 ± 5	557	6	10	55	15	2148 ± 57	16	94	2
2001/02	403 ± 4	400	21	33	27	22	1756 ± 23	21	96	6
2002/03	489 ± 4	478	16	21	43	39	1891 ± 30	18	95	5
2003/04	507 ± 4	511	8	15	52	25	1869 ± 38	6	87	1
2004/05	411 ± 8	443	7	12	37	16	1587 ± 32	5	83	5
2005/06	422 ± 3	423	9	16	24	17	1581 ± 31	15	62	11

[1]No. pups tagged represent the number of pups tagged at Enderby Island plus known-to-be-dead pups for comparison with mark-recapture estimates which also include known-to-be-dead pups.
[2]Mortality estimated from mean mortality rates derived from Sandy Bay and Dundas Island.
[3]Gales & Fletcher 1999

Table 2 New Zealand sea lion, *Phocarctos hookeri*, total pup production including Auckland Islands, Campbell Island, Snares Island, and Otago Peninsula, mainland New Zealand. Mean ± SE from mark-recapture experiments, all other data direct counts. (Total*, sum of pup production from each breeding location each year with Campbell Island being represented by 122 between 1994/95 to 2001/02 and 385 from 2002/03 onwards.)

Season	Auckland Islands	Campbell Island	Snares Island	Otago[4] Peninsula	Total*
1994/95	2518 ± 21[1]	122[1]	0	0	2640
1995/96	2685 ± 22[1]		0	1	2807
1996/97	2975 ± 26		0	0	3097
1997/98	3021 ± 94		1[3]	2	3146
1998/99	2867 ± 33		0	1	2990
1999/00	2856 ± 43		0	1	2979
2000/01	2859 ± 24		0	3	2984
2001/02	2282 ± 34		0	3	2407
2002/03	2518 ± 42	385 ± 28[2]	0	3	2906
2003/04	2515 ± 40		0	3	2903
2004/05	2148 ± 44		0	4	2537
2005/06	2089 ± 34		0	7	2481

[1]Gales & Fletcher 1999.
[2]Childerhouse et al. 2005.
[3]McNally 2001.
[4]McConkey et al. 2002; McConkey unpubl. data.

Mark-recapture estimates were validated by comparing the M-R estimate taken at Sandy Bay/ Enderby Island with the number of pups flipper-tagged at Sandy Bay, given that numbers of flipper-tagged pups represented absolute estimates of pup production at Sandy Bay (Table 1). M-R estimates as a proportion of total pup production ranged from 97.7% in 1998/99 to 102.3% in 2002/03, with a mean across these 9 years of 100.02% (Table 1).

DISCUSSION

For pinnipeds, estimates of pup production are the best index of relative population status and when combined with other population parameters provide the best estimate of overall population size and trends (Berkson & DeMaster 1985). Pups represent an estimate for the number of reproductive females within a population, they are relatively easy to handle and represent good experimental animals for M-R experiments to estimate abundance (Gales & Fletcher 1999). The close agreement between absolute pup numbers (obtained through flipper-tagging) with the estimates derived from the M-R estimate at Sandy Bay provides strong evidence for the validity of the latter technique used in this study and for its use to estimate pup production on Dundas Island, the largest breeding area.

Not all breeding areas for NZ sea lions have been studied with the same effort or consistency over the last decade. However, the methodology and timing of pup production estimates have been consistent at each site since 1994/95 in the northern Auckland Islands (Enderby and Dundas islands), where 83% of pup production occurred. The timing of the direct counts at Figure of Eight Island varied between 6 to 25 January each year owing to logistical difficulties. However, it is unlikely that there would be much variation in counts from this location and hence little effect on the total pup production estimates owing to this colony producing a small percentage of the total pup production and, assuming animals at Figure of Eight Island have similar pupping characteristics to those at Sandy Bay, there being little or no pupping after early January. For the last 5 years, counts were always made on 10 January. In the 1998/99 season counts were made on 6 and 17 January and the counts were 108 and 109 pups, respectively. This was the only year that two counts spaced apart were made at Figure of Eight Island. The mean pupping date for the Sandy Bay colony occurs either on 26 or 27 December with 69% of all pups born one week either side of this date (Chilvers et al. 2006b). Most pups are born by 2 January and births drop off quickly within another week (Gales & Fletcher 1999; Chilvers et al. 2006b).

Campbell Island has had only one thorough survey to estimate pup production in the last decade (Childerhouse et al. 2005). The threefold difference between this 2002/03 estimate (385 ± 28) and the previous minimum pup production estimate (122, Gales & Fletcher 1999) creates difficulties when calculating population numbers and variations for Campbell Island, especially as these estimates were undertaken at different times and using different techniques (M-R versus direct count). There is a need for more frequent surveys of Campbell Island to fully resolve uncertainties about absolute numbers and year-to-year fluctuations

No specific NZ sea lion research has been conducted at Snares Islands since 1997/98. However, annual scientific research on Buller's Albatross (*Thalassarche bulleri*) have surveyed the coastal areas where NZ sea lions have been observed previously and have confirmed no further breeding at the Snares Islands (P. Sagar pers. comm.). The Otago Peninsula is a well surveyed, small population from a single matriarchal line for which all females are identified frequently (monthly) and any breeding that occurs is observed and recorded (McConkey et al. 2002a,b).

Pup production variation and mortality

Overall, pup production estimates of NZ sea lions show an overall decline during the last 8 years (Table 2). This decline is driven by a decline in the number of pups born at the main colonies located on the Auckland Islands. Although there is some evidence of an increase in pup production at the Otago Peninsula colony, the small number of animals born there have little impact on overall trends.

Pup production estimates are a record of the numbers of pups born including pre-survey mortality, but do not provide any indication of the level of post survey mortality. Pup mortality for NZ sea lions was highly variable (Table 1) ranging from 1% to 39% of total pup production at 1 month of age depending on breeding area and up to 58% at 2 months of age for the northern Auckland Island colonies (Baker 1999; Wilkinson et al. 2003). Between 1997/98 and 2003/04, three episodic mass mortality events resulted in high levels of early pup mortality in the Auckland Islands (Table 1). These epidemics also appear to have been present at Campbell Island (Baker 1999; Childerhouse et al. 2005; McNally pers. comm.). These variable levels of mortality in early life can have significant impacts on the dynamics of the population and permissible incidental catch limits (Wilkinson et al. 2003, 2006). Although these figures of early mortality are not an estimate of annual mortality for this age class (mortality can only be greater or equal to this level after a year), they do provide minimal bounds for any estimates of juvenile mortality in population modelling.

Pup production in pinniped populations can vary for many reasons, including environmental variability, age structure of the breeding population, female fecundity, anthropogenic influences, disease or any combination of these variables (i.e., Boyd 1993; Guinet et al. 1994; Forcada et al. 2005). There is insufficient information to investigate the effects of all of these factors for NZ sea lions in the Auckland Islands area, however information is available for disease and direct anthropogenic influences.

There have been three mass mortality events caused by bacterial infections in the northern Auckland Island sea lion breeding area since 1997/98 (Baker 1999; Wilkinson et al. 2006). The first epidemic in 1997/98 did not impact on pup production, however resulted in a significantly high post-survey pup mortality reaching 58% at Dundas Island (Table 1, Baker 1999).

During the 2001/02 breeding season, an epidemic thought to be caused by a bacterial infection from *Klebsiella pneumoniae* (Wilkinson et al. 2006), directly impacted pup production with a 20% drop relative to the previous season (Table 1). Along with the reduction in pup production, pup mortality to 2 months of age was significantly higher at 33% in 2001/02 than would be expected in an average year. The same bacteria infection resulted in a 21% mortality of pups in the following year 2002/03 (Table 1, Wilkinson et al. 2006). The elevated mortality levels observed in 1997/98, 2001/02, and 2002/03 along with the reduced pup production in 2001/02 will impact on future pup production by reducing the number of females available to recruit and breed within the population (Wilkinson et al. 2006).

Over the last 5 years there has been an estimated total 466 incidental deaths of NZ sea lions in the subantarctic arrow squid (*N. sloanii*) fishery around the Auckland Islands. For the last 11 years the estimate was 898 sea lions (Ministry of Fisheries 2006). Of these mortalities approximately 50% are females (Duignan et al. 2003a,b), representing 233 fewer females in the Auckland Island area in the last 5 years and 449 in the last 11 years. These numbers of adult females lost from the population as a result of fisheries bycatch would represent an approximate 10% decrease in the number of breeding females in the Auckland Islands over the last 5 years, or approximately 1–2% per year. A reduction of normal adult female survival through loss from fisheries interactions or other influences is an important cause of population regulation and decline in pinnipeds (e.g., Pistorius et al. 1999, 2004).

CONCLUSION

The current level of pup production decline for the Auckland Island population could represent an escalation of the NZ sea lions IUCN Red threatened species listing (2001) which is currently vulnerable (VUD2) "Population with a very number of breeding locations" to vulnerable (VUA3) "A population projected or suspected to have ≤30% reduction within the next 10 years or three generations, whichever is the longer" (Reijnders et al. 1993).

Accurate effective monitoring of bycatch within fisheries and new approaches that would reduce catches of breeding females such as seasonal or area closures or alternative fishing methods need to be considered. The consistent yearly monitoring of annual pup production at the Auckland Islands needs to be expanded to include more frequent monitoring at Campbell Island.

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