Discussion paper on New Zealand sea lion pup mortality: causes and mitigation

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1. Introduction

New Zealand sea lions (*Phocarctos hookeri*, hereafter NZSL) are our only endemic seal species and historically bred all around NZ, though were extirpated from the mainland by early human settlers. The current population is estimated at fewer than 10,000 individuals, with more than 99% of breeding occurring at a small number of breeding sites at the Auckland Islands and Campbell Island of the NZ Subantarctic. Much smaller breeding sites are slowly increasing at Otago and Stewart Island.

Pup production is recognised as the best indicator of population status, and since 1998 there has been an approximate 50% decrease in pup production at the Auckland Islands, resulting in the species being classified as 'nationally critical' as of 2010 (Figure 1). Adult female mortality was initially believed to be the driver for the decline and therefore management has focussed on minimising adult/sub-adult mortality, but more recent analyses suggest that low fecundity and pup survival may also be important. In addition, the disease *Klebsiella pneumoniae* has been recognised as an additional (and potentially new) source of pup mortality. This disease is responsible for significantly increasing early pup mortality to at least two or three times average levels in some years.

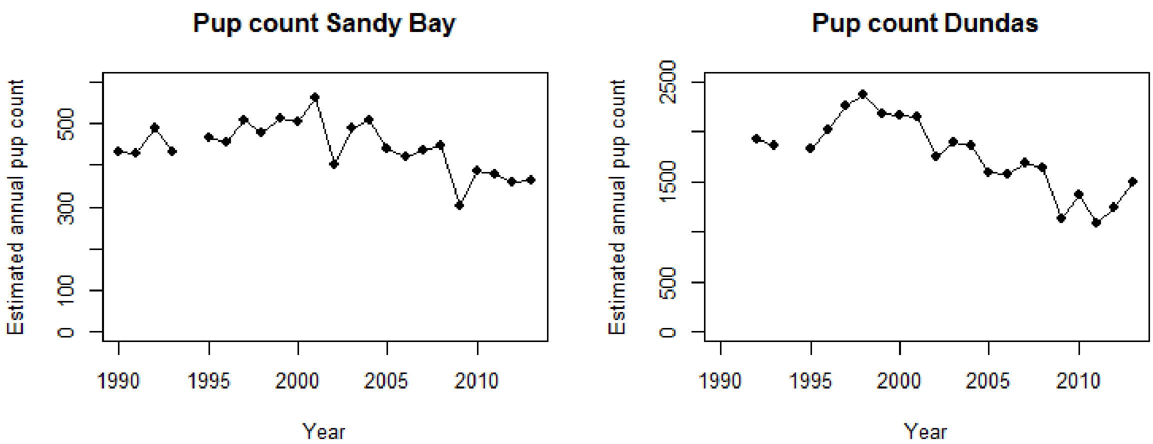

Figure 1. Estimated annual pup production at Sandy Bay and Dundas Island, the two largest breeding colonies of NZ sea lions at the Auckland Islands.

The preliminary results of a demographic assessment of the main breeding colonies at the Auckland Islands (POP2012-02) indicate variation in a number of key demographic rates since the early 1990s including: pup/yearling survival, juvenile/adult survival, pupping rate and age at first pupping (Figure

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2; Roberts et al. 2013). Together these will explain the observed variation in pup production through time. A reduction in adult survival can have a large an instantaneous effect on pup production because it affects breeders of a broad range of ages. At the Auckland Islands this is likely to have been exacerbated by low pup/yearling survival since 2004/05 that will have a delayed negative effect on breeder numbers and future pup production.

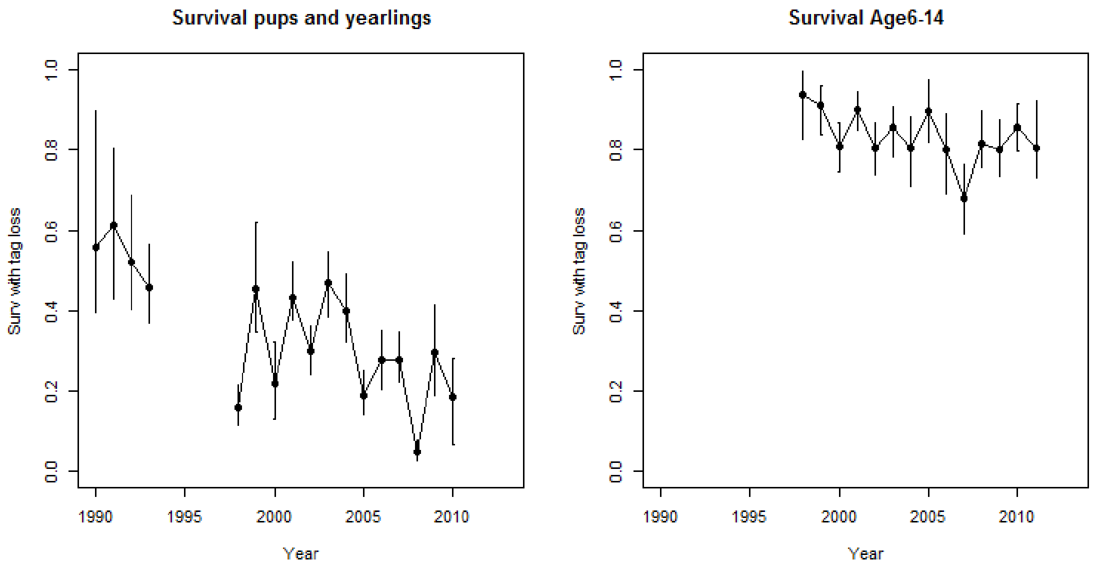

Figure 2. Model estimates of survival of pups/yearlings (cohort birth year) and adult females (age 6-14) at Sandy Bay, Auckland Islands. Bars are 95% confidence intervals, all estimates of survival confounded with tag loss rate. Source: Roberts et al. 2013

Over the last decade the Government and other groups have devoted considerable resources to the understanding, mitigation and management of the effects of fishing. However, little attention or resources have been allocated to focus on other issues that may be contributing to the decline of NZSLs. The focus of this discussion paper is to improve the understanding of the potential causes of sea lion mortality other than the direct effects of fishing and to explore other options for management and conservation action that could aid in halting the decline of the NZSL and directly aiding their recovery.

The aim of this discussion paper is to review and summarise what is known about pup mortality in NZSLs and to explore active management and future research options that could be implemented to reduce pup mortality. This discussion paper is not intended to be highly detailed, but to highlight and summarise issues with a view to generating discussion and positive action. The primary focus for this discussion paper is pup mortality at the Auckland Islands (and mainly Dundas Island and Sandy Bay). Some consideration is also given to Campbell Island, although optimal management actions may be different for each sub-population (e.g. Auckland Islands, Campbell Island, Stewart Island, Otago).

We note from the outset that increased pup mortality is only one of a range of factors likely contributing to this decline. We would like to strongly stress that all of these contributing factors should be carefully considered and managed appropriately but have chosen to review pup mortality here as we believe this is an area in which targeted management action in the short term could potentially lead to positive outcomes for pup mortality and the overall population in the longer term.

2. What are the proximal causes of pup mortality?

Accurate diagnosis of the cause of death of a pup requires both gross necropsy findings and supplementary testing, including histology, microbiology and molecular diagnostics. A preliminary diagnosis can usually be made based on gross necropsy findings alone, but further testing will often result in additional findings that change the diagnosis. The general categories of pup mortality are:

- Stillbirth;
- Starvation;
- Congenital anomalies;
- Hookworm;
- Trauma;
- Bacterial infection; and
- "Open" (either too decomposed/scavenged for a diagnosis to be made or no obvious cause of death).

Figure 3 shows a breakdown of diagnoses for breeding seasons 1998/99 to 2004/05 and 2009/10 to 2013/14. Note that in earlier years (shaded box) these are preliminary diagnoses only since little or no supplementary diagnostic work has been done, hence some of the apparent changes in prevalence are artefactual. This is particularly true for 'bacterial infection' which is likely to be underdiagnosed without full diagnostic testing.

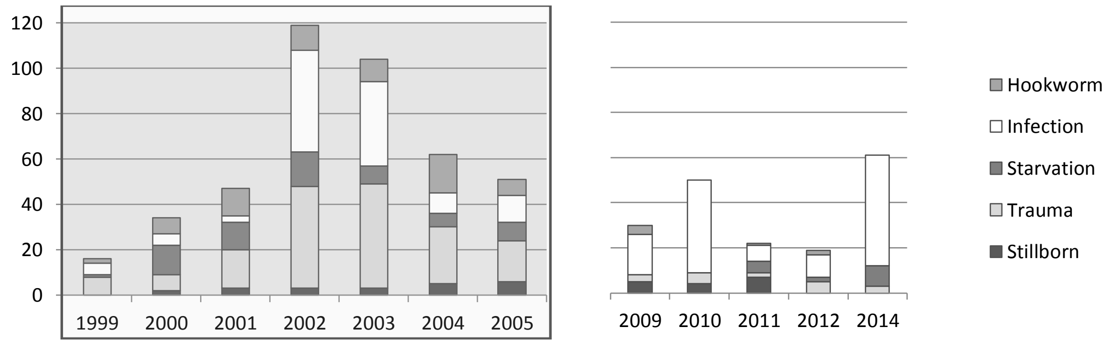

Figure 3. Distribution of the primary causes of pup mortality at Sandy Bay from 1998/99 to 2004/05 and 2008/09 to 2013/14. The year designation is for the second part of the breeding season (e.g. 2004/05 is shown as 2005).

The major changes between the last five years (2009-2014) and earlier years are an increase in the relative importance of deaths due to infection (predominantly *Klebsiella pneumoniae*), with a concurrent decrease in importance of trauma and hookworm infection. Whether these are true trends or artefacts due to increased testing could only be established by conducting more diagnostic tests on samples archived at Massey University.

Klebsiella pneumoniae was first diagnosed as a cause of pup mortality in 2001/02, and was the cause of mass mortality events in pups at Sandy Bay in 2001/02 and 2002/03. Its importance seemed to decline in the following few years, but between 2009 and 2014 this bacterium has been the diagnosed cause of death in approximately 55% of pups that were necropsied. It also appears that deaths due to *K. pneumoniae* now occur later in the season than they did in earlier years, and that deaths continue to occur after the science team leave the island (see Figure 4).

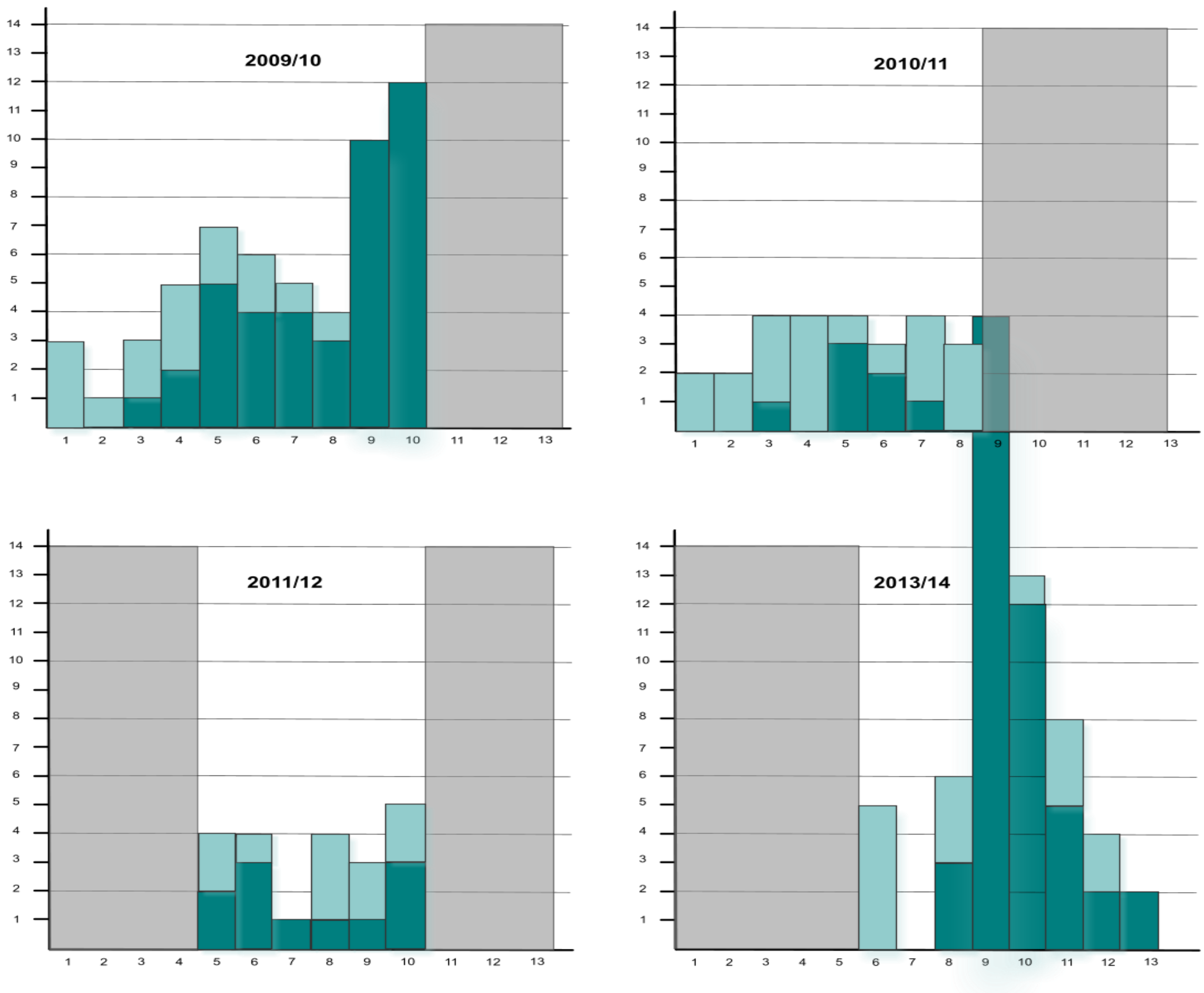

Figure 4. Distribution of total pup deaths (pale green bars) and Klebsiella pneumoniae pup deaths (darker green bars) over the breeding season. Weeks are shown on the horizontal axis, and pups affected on the vertical axis. The grey shaded areas indicate periods during which the science team was not present.

A potentially important cause of death, which was not previously identified by the gross necropsy work, is pups falling into and drowning in mud holes. During the late part of the 2013/14 season, approximately 70 pups were rescued from these holes.

3. What other contributing factors could be involved?

A number of factors may directly or indirectly affect changes to the rate of pup mortality though time. These include processes that may **directly** affect pup mortality, including:

- Periods of sub-optimal atmospheric climate and adverse physical environment;
- Introduction of pathogenic organisms;
- Implementation of excessively intrusive methods for field-based monitoring; and
- Others.

Up until approximately 10 months of age NZSL pups obtain the bulk of their nutritional requirements from their mother's milk. Variation in the quantity and quality of milk suckled will affect pup growth. In addition the largest pups of seal species will typically have an increased probability of survival - at the Auckland Islands this relationship was observed in cohorts born between 1997/98 to 2003/04. As such, the ultimate causes of pup mortality may not only be limited to processes that directly affect pups and could also include factors that may **indirectly** affect susceptibility to mortality, including:

- Changes in ocean climate and factors that affect the abundance of preferred prey species;
- Shifts in prey availability at maternal foraging grounds, maternal diet, foraging efficiency, milk quality/quantity supplied to the pup;
- Changes in the age structure of breeders; and
- Others.

In the short-term, management actions would most likely be limited to those that have an immediate positive affect on pup survival (relating to direct effects above) and on future pup production. However there are also multiple indicators of changing nutritional status of the Auckland Islands sub-population (including shifts in diet composition, variation in maternal condition/milk quality and low pupping rates; Riet-Sapriza et al. 2012; Roberts et al. 2013; Stewart-Sinclair 2013), which may affect susceptibility of pups to mortality. It may not be possible to address these with short–term management interventions.

As such, an integrated approach to management of pup mortality (e.g. management interventions to address the proximate causes of mortality in parallel with targeted research to better understand the ultimate causes of mortality) may be considered the most effective means of improving pup survival in both the short- and long-term.

4. What mitigation techniques could we put in place in the short term (specifically, next field season) that might make a difference?

Given what we know about the causes of pup mortality and the contributing factors, the next step is to explore options for ways in which we may be able to mitigate some of these factors. While there are a range of potential mitigation techniques, we have focused on ones that we believe could be implemented in the short term at the Auckland Islands and have only provided some high level suggestions to stimulate discussion. This list is not intended to be exhaustive and we would welcome input from others about other possible mitigation. Table 1 identifies issues related to pup mortality and potential mitigation techniques to address these.

Table 1. Issues related to NZSL pup mortality and potential short-term mitigation techniques to address these.

Issue	**Brief description**	**Effect size?**	**Potential mitigation options**
Pups falling into and dying in holes	This has been an ongoing issue for pups at Dundas Island, Sandy Bay and also Campbell Island. If pups are unable to escape from these holes, they are likely to either starve or drown. Some ramps allowing pups to escape were installed on Dundas Island in the late 1990s but none anywhere else. Anecdotal evidence from installing ramps into holes on Dundas Island suggests that pup mortality in holes is reduced when ramps are added. Last summer (2013/14) the research team removed 70 pups from holes around Sandy Bay before ramps were made to allow them to climb out (Hamer et al. 2014).	Medium – high	Possibilities include installing ramps made from boardwalks, rocks and/or lowering the edge of holes so pups (and juveniles) can get out. Could be undertaken by existing field team at all sites visited. DOC permits required.
Hookworm	Hookworm is a primary cause of mortality and a contributor to mortality from other causes (e.g. by weakening the pup making it susceptible to other issues). The prevalence of this varies considerably from year to year. Hookworm treatment trials have been undertaken at Sandy Bay and showed that hookworm infection had no significant effect on mortality rate except when overall mortality was high during epidemics caused by other pathogens (Chilvers et al. 2009). Analysis is presently ongoing to further investigate any longer term benefits of treatment (e.g. detectable, positive effects on survival to age 1 and recruitment)	Low	Hookworm treatment could be applied in an adaptive management framework with strict experimental design to investigate and confirm effectiveness. Previous protocol was three treatments for each pup but if a single treatment could be applied during the mark recapture no additional captures would be required. DOC and AEC permits required. An alternative could be a single treatment of mothers rather than pups but this would require some further investigation.
Klebsiella infection	*Klebsiella* is a bacterial infection and is perhaps the single biggest contributor to pup mortality. It is not clear whether this is a pathogen new to the Auckland Islands or if it has always been present as a source of mortality but has recently increased in prevalence.	Medium – high	There is no short-term mitigation option for *Klebsiella*. Longer term mitigation (e.g. 3-5 years) could potentially include the development of vaccination. Short-term focus on improving understanding the infection and transmission process.

Issue	Brief description	Effect size?	Potential mitigation options
Nutritional stress	Recent work (Roberts et al. 2014) has outlined the key demographic and biological mechanisms by which pup mortality may occur in response to nutritional stress. This is discussed in more detail in the section above. Nutritional stress primarily affects maternal condition and is driven by changes in prey availability and the relative efficiency of foraging. Nutritional stress will tend to increase susceptibility to some of the primate causes of mortality listed above.	Unknown?	Supplementary feeding of pups displaying symptoms of nutrition stress could be possible. Challenges would include determining which pups may benefit from this, developing suitable milk supplements, and providing treatments for times when the field team is not present. There would be no point in feeding abandoned pups abandoned for January-February only. Therefore feeding would either have to be just to 'top up' pups whose mother might be struggling to feed them over January-February or accept that feeding would have to occur until weaning, which represents a significant challenge.
General injuries	Every year we see pups with injuries or issues that could potentially be treated or reduced through direct veterinary intervention. These include dislocated limbs, dehydration, swollen abscesses, bites, etc. While some may lead to mortality, others may not but they are likely to impact on the pup as reduced fitness. Given that these are natural events, intervention for these kinds of issues has not been undertaken in the past.	Low	With appropriate veterinary advice, interventions could be undertaken but would need to be assessed using a cost benefit analysis to look at the long-term prognosis of the intervention, any impact to the pup and available resources (including skilled personnel)
Impacts of capturing and marking	There is increasing scrutiny regarding potential impacts of capturing, handling and marking wildlife including NZSLs. This could come about through increased stress to individuals through capture and handling, potential avenues for infection through injection sites for tags and microchips or disturbance of normal behaviour (e.g. separation of mothers and pups, disturbance of breeding behaviour).	Unknown?	Any impacts could be mitigated by either improving the way the existing work is done or reducing the number of pups impacted. The former could include improving tagging and microchipping (e.g. cleaning the injection site, cleaning the equipment between individuals). The latter through the careful determination of minimum sample sizes required to address clear objectives and using the fewest pups possible.

5. What are the main knowledge gaps/areas requiring further research?

There has been over 20 years of detailed investigation of NZSLs at the Auckland Islands and elsewhere with the overwhelming focus of this research on understanding the impacts of commercial fishing on the population. While this has been very important work, we believe that it is time to start broadening the scope of research to include more detailed research into other aspects of the decline, specifically with a view to identifying management actions that can lead to positive benefits to the population. This new research would naturally complement the existing work on fisheries interactions and hopefully contribute to halting and reversing the decline of this species.

With view to improving our understanding of pup mortality and developing effective mitigation solutions, the following knowledge gaps have been identified:

a. Improving our understanding of *Klebsiella* – specifically determining if it is endemic to NZSLs and its mechanism for transmission and infection;
b. Improved characterisation of pup mortality – this is important through the continuation of standardised autopsies including a review of over the length of the period that monitoring is important to correctly characterise the bulk of mortality;
c. Formal investigation into the feasibility of developing treatment for *Klebsiella* – this would include determining if a vaccine is feasible in both development and practical implementation for wide spread field application;
d. Detailed modelling of the influence of pup mortality on long-term survival – to investigate the potential benefit of any mitigation options and whether they are likely to be effective with respect to influencing population growth;
e. Carefully designed experimental approach to any adaptive management – any interventions that are undertaken need follow strict experimental designs (e.g. control vs. treatments) to ensure that any outcomes (either positive or negative) can be identified and quantified;
f. Nutritional stress – understanding the indirect effects of this on pup mortality is critical and the relationship between maternal nutritional status and pup mortality in particular; and
g. Reviewing impacts of research – it is important that informed decisions are made about research being undertaken on a nationally critical species and that any impacts are understood and weighed up against potential or expected benefits.

6. What about Campbell Island and other sites?

Pup mortality rates at Campbell Island are reported to be much higher than those at the Auckland Islands. Notwithstanding this, there is reasonable evidence that pup production has greatly increase over at least the last two to three decades. While much of the same research and mitigation issues discussed here for the Auckland Islands will be potentially relevant for pups at Campbell Island, it is important to better understand what specific mechanisms are occurring there to try and understand why there appears to be a difference in population trajectories between the two locations.

Other sites such as Otago and Stewart Island may also offer insights into pup mortality, however, it is likely these sites have different drivers and pressures to those in the Subantarctic. One potential advantage of having sea lions at Otago is that they may offer opportunities to trial mitigation and treatment options on readily accessible pups although sample sizes will obviously be limited and any potential impacts of trials would have to carefully weighed up against any negatives for a small and recovering population.

7. Concluding remarks

The aim of this discussion paper was not to necessarily provide an answer to the broad issue of pup mortality but to raise the profile of this issue and to stimulate discussion about potential options for mitigation that can contribute to population recovery in both the short and longer term. We would also reiterate that pup mortality is only one of a range of factors that are likely to be contributing to the decline of this species and addressing pup mortality alone is unlikely to lead to population recovery. Therefore we strongly support an integrated approach in reviewing all of the contributing factors including, but not only restricted to, issues affecting adult survival and reproductive rates. It is only through a broad package of active and targeted management that we are likely to halt the decline of this species and see some positive recovery. Finally, while undertaking further research is important, it should not necessarily be seen as a reason to delay careful, targeted management action. We believe that it is possible to achieve some active and positive intervention in the coming 2014/15 NZSL breeding season that will improve survival of sea lion pups and improve our understanding of this issue.

8. Acknowledgements

The development of this discussion paper would not have been possible without the helpful advice and insights provided by a wide variety of our colleagues. We appreciate their willingness to share their expertise and look forward to engaging them further in this discussion. We would also like to thank Massey University, NIWA and Blue Planet Marine for supporting us during the development of this paper.

9. References

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