Discussion paper: Review of options for future research and mitigation for New Zealand sea lion pup mortality

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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.

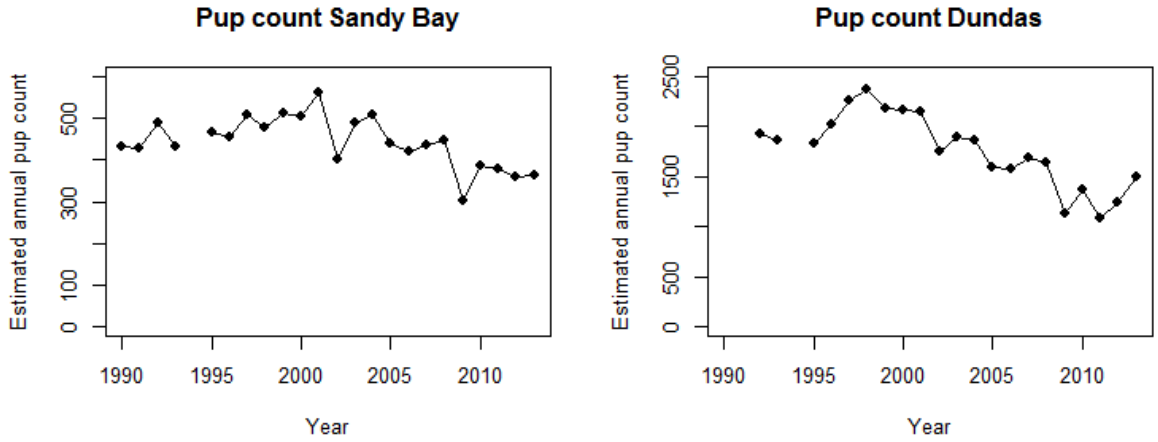

Figure 1. Estimated annual pup production at Sandy Bay and Dundas Island, the two largest breeding colonies of NZ sea lions at the Auckland Islands.

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.

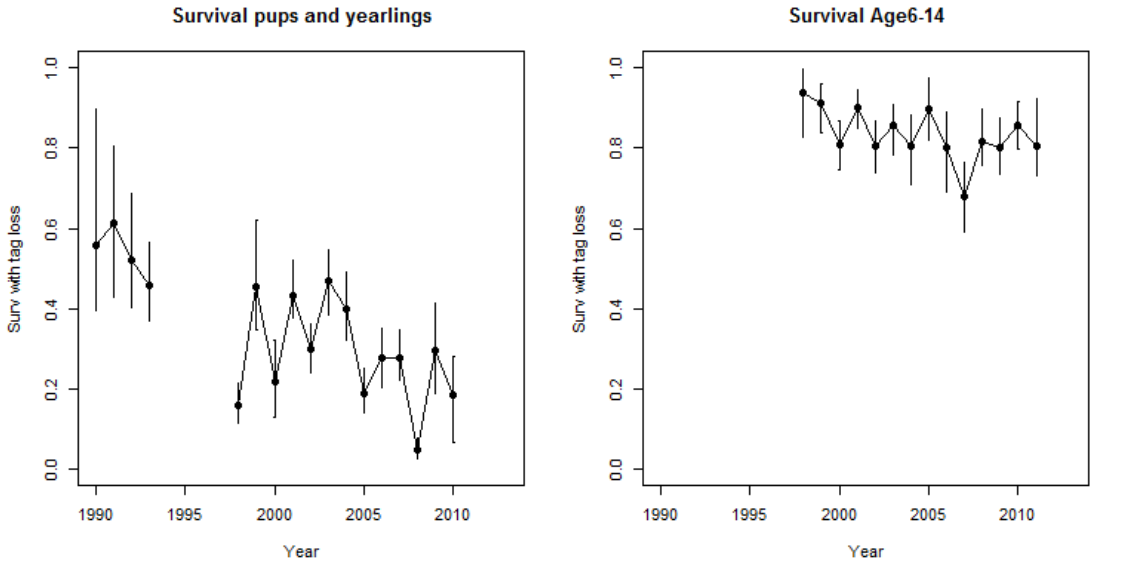

Figure 2. Model estimates of survival of pups/yearlings (cohort birth year) and adult females (age 6-14) at Sandy Bay, Auckland Islands. Bars are 95% confidence intervals, all estimates of survival confounded with tag loss rate. Source: Roberts et al. 2013

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.

This discussion paper follows on from a previous paper (Roe, Roberts & Childerhouse (2014) Discussion paper on New Zealand sea lion pup mortality: causes and mitigation) and a joint DOC/MPI workshop on pup mortality held in Wellington on 10 June 2014. The aim of this paper is to provide a review of options for future research and mitigation of pup mortality in NZSLs. This work builds on the previous paper and outcomes of the Wellington workshop.

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. Main knowledge gaps/areas requiring further research

Roe et al. (2014) identified the following knowledge gaps/areas requiring further research:

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.

3. Outcomes from the Wellington workshop on pup mortality

A Workshop was held in Wellington on 10 June 2014 that had a specific focus on the investigation of NZSL pup mortality including contributing and influencing factors, likely and possible causes and potential options for research and mitigation. Some of the general agreements of that workshop included (based on draft minutes of the workshop):

- That during the 2014/15 field season, mitigation action should be taken to address the issue of pups dying in holes;
- Research on *Klebsiella* should be a priority including aspects such as genotyping, development of PCR test for it, and implementation of a concurrent case control study to better understand it. The case controls study should be run over 2 seasons and should include concurrent elements including worming trials (e.g. Ivomec) and the investigation of effects of tagging studies;
- There is a wealth of existing data and samples already collected and available that has not been fully analysed. It would be useful to undertake analysis of existing material including research prior to the 2014/15 season;
- An extended field season should be considered to allow for a complete characterisation of pup mortality later (and also potentially earlier) in the season;
- That there should be an review of potential marking techniques for NZSL pups including an assessment of potential impacts from each methods; and

- That nutritional stress has been identified as a contributing factor to pup mortality and this should be investigated further.

We note the finalised minutes of that workshop were not available to use when developing this paper and so we have not been able to directly cite the general agreements of the workshop but believe that these agreements reflect what was discussed and agreed.

4. Options for research and mitigation

Based on the outcomes of the Wellington workshop, we review here options for future research and mitigation to further investigate and/or reduce pup mortality. We use the agreements from the workshop above to guide our consideration of options. We have endeavoured to provide some suggestions and potential indicative costings for each option wherever possible.

It is also important to note that the indicative costings provided are not mutually exclusive of each other and therefore some costs (e.g. salaries) would only be need to be covered once to deliver outputs against several different items. Furthermore, a more detailed costing of each project should be undertaken to establish the true costs of the project and the estimates provided here should be regarded as only indicative and provisional.

We have also made the assumption that for the 2014/15 season there will be a research programme funded by CSP similar to the programme that was funded in 2013/14 but note that the decision on the exact nature and extent of the field programme has yet to be confirmed. We make the following assumptions for the CSP programme for 2014/15:

- There will be a team of at least four researchers on based on Enderby Island from 10 January until 23 February 2014;
- All costs for this team during this time (including transport to and from the Island) will be covered by the CSP programme; and
- All the DOC NZSL field equipment normally available to the field team will be available.

We won't go into the details of the issues to be addressed as details of these can be found in our original paper and also in the notes from the Wellington workshop.

Table 1. Potential research and mitigation options for NZSL pup mortality

Issue	Item	Research/Mitigation options	Indicative additional resourcing	Indicative cost
Characterising pup mortality	1.1	Research – Enderby Island: There was good support for the continued characterisation of pup mortality during future field seasons. Additional personnel and/or skills would be required (e.g. vet) to undertake autopsies which would ideally be undertaken from the beginning of the breeding season into February or March requiring a longer field season (e.g. 8 weeks extra time)	Salaries	<$20k salaries <$5k field support **TOTAL <$25k**
	1.2	Research – Campbell Island: This was not specifically mentioned but relates closely to Item 1.1 (i.e. the characterisation of pup mortality during field seasons). The same process as for Enderby but would be quite a different and more expensive operation as teams would be have to in place early on in the breeding season and would require separate transport and salaries. Cost sharing options may be possible with other work programmes on Campbell and with Item 2.2. Likely to be 8 weeks field work for 3 people	Transport; salaries; field support (e.g. food, etc.)	<$50k return charter <$60k salary <$15k field support **TOTAL <$125k**
	1.3	Research – There was good support for the continued characterisation of pup mortality, specifically a reanalysis of previously collected data at the Workshop. This work would allow for the consistent characterisation of causes of pup mortality over time to investigate any changes and confirm the most significant causes. This could be undertaken at Massey on existing samples.	Lab costs, salaries	<$30k PhD stipend <$100k for lab testing of 10 years archived samples **TOTAL <$130k**
	1.4	Research - While not specifically mentioned as an outcome of the Wellington workshop, we believe that there is good support for 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.	Salaries	<$20k salaries **TOTAL <$20k**
Pups dying in holes	2.1	Mitigation – Enderby & Dundas Island: building ramps for pups to get out of pups. This has been trialled previously at Dundas and has been successful. Options are boardwalks (Dundas) or cutting steps or ramps (Sandy Bay). Would require team to put these in place prior to pups leaving the beach at Sandy Bay and Dundas but could be undertake alongside normal CSP work.	Materials for ramps (e.g. boardwalks, pegs); transport of materials to location	<$5k materials **TOTAL <$5k**
	2.2	Mitigation – Campbell Island: The same process as for Enderby and Dundas but would be quite a different and more expensive operation as teams would be have to in place prior to or early on in the breeding season (or it could be done during a winter trip) and would require separate transport and salaries. There is probably on a few days work on the Island if just building ramps is undertaken and nothing else. Cost sharing options may be possible with other work programmes on Campbell.	Materials for ramps (e.g. boardwalks, pegs); transport of materials & personnel to location; salaries; field support (e.g. food, etc.)	<$5k materials <$50k return charter <$5k salary <$5k field support **TOTAL <$65k**

Issue	Item	Research/Mitigation options	Indicative additional resourcing	Indicative cost
	2.3	Research – Monitoring of the effectiveness of mitigation is important. There are many technical ways that it could be done (e.g. Chip readers or cameras) but probably the best approach is just to undertake regular counts of the number of pups in holes. This is probably the best way to under simply and cheaply monitor.	None	Nil – concurrent with CSP programme
Klebsiella infection	3.1	Mitigation – Not really possible at this time given a lack of basic understanding of aetiology but standard practices should continue (e.g. quarantine between sites, equipment cleaned between individuals).	None	Nil – concurrent with CSP programme
	3.2	Research – Undertaking genotyping and development of PCR tests for presence. This will aid in further understanding the bacterium and hopefully lead to future mitigation	Lab costs, salaries	<$50k lab costs <$50k salaries **TOTAL <$100k**
	3.3	Research – Case Control Study: An experimental study undertaken on pups (and potentially their mothers) to investigate a range of issues including Klebsiella prevalence and aetiology and contributing factors. The study should be run over 2 seasons and could include concurrent elements including worming trials (e.g. Ivomec), the investigation of effects of tagging studies, and nutritional stress. Depending on the exact structure of such a programme, it would likely require additional personnel, skill sets and equipment (e.g. vet, vet sampling equipment, adult capture and handling experience & equipment for this). Extra person would be required for potentially a longer field season than the CSP programme and extra people to the standard CSP field team during that time. There would also be potentially significant cost and time involved in the analysis of samples that the field team bring back. See Appendix 1 for details.	Will depend on the exact nature of the study but likely to include: extra transport (e.g. extra early and later trips), salaries, field support (e.g. food, etc.), lab and analysis costs, field equipment (e.g. adult capture equipment)	<$5k field equipment <$40k return charter <$20k salary (field) <$10k salary (lab) <$10k field support <$10k lab costs **TOTAL <$105k**
Impacts of marking	4.1	Research – It would be useful to review potential marking methods (e.g. tagging, chipping, branding, photo-ID) including their advantages and disadvantages[4]. This would need to be undertaken once clear aims for an ongoing marking programme were confirmed and stated so the different techniques could be evaluated against them. This should also include an evaluation of minimum sample sizes required to deliver robust outcomes against those (e.g. estimate age specific survival rates with a CV of 0.2)	Salaries	<$10k salaries **TOTAL <$10k**

[4] For example see Beausoleil et al 2004. http://www.doc.govt.nz/Documents/science-and-technical/MarkingMethods.pdf

Issue	Item	Research/Mitigation options	Indicative additional resourcing	Indicative cost
	4.2	Research – it would be useful to undertake an evaluation of any impacts of the existing making programme (e.g. tagging, chipping). This could be done by the existing CSP team but would require supplemental skills (e.g. vet) to undertake autopsies. This would ideally form part of the case control study described in Item 3.3 rather than a stand alone project.	Salaries	<$5k salaries **TOTAL <$5k**
Nutritional stress	5.1	Research - This would ideally form part of the Case Control Study (e.g. Item 3.3) and would allow for the investigation of the effect of adult and pup nutrition on pup morality. Costs as per Item 3.3.	See 3.3	See 3.3
	5.2	Research - There is good support for detailed modelling of the influence of nutritional status on pup mortality. This project would include further modelling of existing data complemented by the addition of specific data collected on this issue from the 2014/15 season (e.g. collected as part of 3.3)	Salaries	<$50k salaries **TOTAL <$50k**
Other issues	6.1	Research & Mitigation - Hookworm treatment: This could be undertaken to following on from the work of Chilvers et al. (2009). This is proposed as part of the Case Control Study outlined in Item 3.3	See 3.3	See 3.3
	6.2	Research – Pup production estimate for Campbell Island: This was not a specific recommendation of the Wellington workshop but would complement the other work possibly proposed at Campbell Island (e.g. building ramps for holes 2.2, investigating pup mortality 1.2). This work would require much the same resourcing as identified into Item 1.2 but two options are available: (a) a single long season with a marking (e.g. tagging) of pups at breeding colonies and resighting of marked and unmarked pups as they disperse from the colonies or (b) two separate trips with an early (January) marking trip and a later (March) resighting trip. It would be useful to explore which is likely to be the more cost effective choice balancing increased salaries for (a) against increased charter costs for (b).	See 2.2	See 2.2 but an additional 1-2 transport trip may be necessary if the trip is split into two parts
	6.3	Research – Age structure of breeding females at Auckland Islands: This was also no a specific recommendation of the Wellington workshop but would complement other work proposed at Enderby and Dundas and the existing CSP programme. Reproductive females could be caught and/or resighted at Sandy and Dundas Island to develop an age structure of females that would be directly comparable with that undertaken in 1999 to 2001. The costs would be similar to Item 3.3 but it would likely require 2 additional personnel to undertake adult female captures and (if Dundas was to be included) regular access to Dundas Island by helicopter or boat. Some additional field equipment would also be required (e.g. anaesthetic machine, anaesthetic) and a vet	See 3.3 plus two additional personnel, 3 additional trips to Dundas Is, field equipment & supplies	See 3.3 plus <$15k salaries <$5k field equipment <$5k field supplies

5. Our recommendations

Based on a review our recommendations, the agreed outcomes of the Wellington Workshop and our expectation of the knowledge required for the NZSL Threat Management Plan, we would recommend the following approach to address the key research gaps and to immediately mitigate some of the NZSL pup mortality:

Auckland Islands

a. Implement a significantly expanded field season from the 'standard' CSP field programme by extending the field season to three months from mid-December to mid-March;
b. Team size of 3 from mid-December to mid-January, 6 from mid-January to mid-February, and 3 from mid-February to mid-March;
c. Undertake autopsies of pups through the whole season by an experienced vet;
d. Undertake Case Control Study at for pups and mothers from as early in the season to departure. This study would focus on (a) identifying cause of pup mortality and contributing factors, (b) effectiveness of worming treatment (c) impacts of marking and (d) influence of nutrition state on pup morality and reproductive rate;
e. Undertaken study if adult female age structure and Sandy Bay (and ideally Dundas as well) to complement the Case Control study; and
f. Undertake mitigation of pup mortality in holes by building ramps in appropriate places.

An indicative cost for this full project would be in the order of $160,000.

Campbell Island

a. Implement a field programme at Campbell Island;
b. Two field seasons: one month in January and one month in March with a team size of three (subject to a review of the cost effectiveness of the two options);
c. Undertake autopsies and sample collection of dead pups as per the Auckland Islands at the two main colonies and where ever else dead pups are found;
d. Undertake a mark-recapture estimate of abundance by marking pups in January and recapturing them in March; and
e. Undertake mitigation of pup mortality in holes by building ramps in appropriate places.

An indicative costs for this full project would be in the order of $125,000.

Targeted research

a. Undertaking genotyping and development of PCR tests for the presence of Klebsiella;
b. Analysis of all existing samples related to pup mortality to develop a definitive and comparable data set;
c. Modelling of the influence of pup mortality on long-term population trends and any benefits that may be achieved;
d. A review potential marking methods (e.g. tagging, chipping, branding, photo-ID) including their advantages and disadvantages; and
e. Modelling of the potential influence of nutritional status on pup mortality, reproductive rate and population growth.

An indicative cost for each of these projects is in the order of $5,000 to $40,000 each.

6. References

Chilvers BL, Duignan PJ, Robertson BC, Castinel A, Wilkinson IS (2009) Effects of hookworms (*Uncinaria* sp.) on the early growth and survival of New Zealand sea lion (*Phocarctos hookeri*) pups. Polar Biology 32: 295–302.

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[5] http://www.doc.govt.nz/Documents/conservation/marine-and-coastal/marine-conservation-services/pop-2012-02-sea-lion-demographic-model-selection.pdf

[6] http://www.doc.govt.nz/Documents/conservation/marine-and-coastal/marine-conservation-services/meetings/pop2012-02nzsealion-demographic-assessment-initial-results.pdf

7. Appendix 1: Preliminary outline of case control study for sea lion pup mortality

Sea-lion pup mortality epidemiological studies

The following is a preliminary design. Note that, depending on number of pup deaths and outcomes, more than one season of data may be required to generate meaningful results.

A concurrent case-control study with two nested randomised controlled trials will be used to evaluate risk factors for *Klebsiella* infection specifically, and for mortality more generally. Outcome variables are as follows:

Case-control study

- All cause mortality
- *Klebsiella*-associated mortality

Randomised controlled trials (RCTs)

- All cause mortality
- *Klebsiella*-associated mortality
- Growth rate?
- Faecal hookworm
- Blood parameters? (e.g. anaemia)

The risk factors considered (explanatory variables) could include age, gender, age/parity of mother, number of skin wounds, body condition score, location, date of death, ivomec status (from RCT1), tag method (from RCT2), plus any others identified as likely.

Case control study design

For each dead pup select at random three healthy pups from the live population at the time of post-mortem (note controls can become cases at a later date). Random selection can be done by a number of methods – e.g. randomly select direction of transect, then randomly select the number of pup encountered. Collect risk factor information and release.

Randomised controlled trial 1 (RCT1)

Recruit a dynamic cohort of pups (e.g. as they are born). Randomly allocate half to Ivomec treatment group, the other a placebo (or untreated). Blind the allocation if possible

Randomised controlled trial 2 (RCT2)

Randomly allocate using an alternative method to RCT1 (or another randomisation event) either:

1) Half of the young to receiving a single flipper tag vs two flipper tags; or

Dependent on whether PIT tag reading will be possible/possible sample sizes:

2) Half of the young one (two) flipper tag(s) and PIT tag and the other half a PIT tag only (Gauthier-Clerc et al. 2004).
3) Third of the young a single flipper tag, a third two flipper tags, and a third a microchip (PIT) tag only.