Estimation of Demographic Parameters for New Zealand Sea Lions Breeding on the Auckland Islands

Methodological Update

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Contents

Introduction

In this document the general methods that are intended to be used for the estimation of key demographic parameters are outlined. Details of the methods are not reproduced here (e.g., how to calculate the likelihood for a multi-state, mark-recapture model), but interested readers can easily obtain the details either from the literature cited or the internet. It is also too early to provide manner specifics of the analysis as we have not yet had the opportunity to discuss options with Louise Chilvers (DOC) as she has been in the field until recently. What is provided below is our expected plan for estimating the demographic parameters, however we may have to deviate from that once the analysis begins. Such is the nature of research.

Pup Production

Pup production is currently one of the key metrics for monitoring the NZ sea lion population on the Auckland Islands. As such it is vitally important that it is measured accurately and estimated appropriately. It is proposed to compare current methods for estimating pup production with a second approach based upon the estimated number of adult females and their reproductive output for the year. Broad agreement of the methods would indicate a certain level of robustness to the current approaches, while disagreement would necessitate an in-depth consideration of the potential factors that may cause such a discrepancy (e.g., violations of estimation method assumptions, discrepancies in the biological population being estimated, etc.).

Pup production is currently estimated using a combination of mark-recapture techniques (for larger colonies) and direct counts (for smaller colonies). Direct counting of individuals assumes that all pups at a location are counted by the observers, which may be feasible when the number of pups on a beach is small and the likelihood of an observer not counting a pup (e.g., due to obstructions on the beach) is remote. Therefore, there is the potential for the direct count to be an underestimate of the total number of pups at the location should either of these conditions not be meet. Direct counts also presume that each pup is counted only once, and while well designed field protocols minimize the chance of this occurring, it can sometimes be a possibility. On larger colonies, it is not feasible to obtain an accurate direct count of pups each year. Therefore, a mark-recapture procedure has been used in recent years to estimate the number of pups on a beach. A sample of pups are initially marked, then during the 'recapture' phase the number of marked and unmarked pups are recorded. Based upon the total number of pups marked and the number of unmarked/marked pups that are sighted/resighted in the second sample, the total number of pups at the colony at that time can be estimated (Gales and Fletcher 1999). This estimate does rely on a number of assumptions including that all pups have the same probability of being marked and sighted; and that the pups are sampled at random from the population. Failing to meet these assumptions may result in some bias to the estimates, however, given the historically high recapture rates, any bias is likely to be small.

Alternatively, given the number of adult females at a location (N), and the pupping rate (p) then an estimate of the total number of pups produced at that location (P) can be obtained by:

$$\hat{P} = \hat{N} \times \hat{p}$$

where ‘hats’ indicate estimated quantities. Details for how these quantities might be estimated are given below, and as the basic sources of information are independent, the resulting estimate of pup production will be independent of the current estimation methods.

It may also be possible to integrate the estimation of pup production from the direct counts and mark-recapture methods, with the estimation of the number of adult females and pupping rates into a single analytic framework. In order to do so, however, requires very careful consideration of the basic field protocols to ensure that integrating the analyses is reasonable and justified. The advantages and disadvantages of an integrated approach to the estimation will be considered as part of this project.

Total Population Size Estimate

Estimates of the population size for NZSL is extrapolated from the estimates of pup production based upon the method devised by Gales and Fletcher (1999). Essentially they used a population model, assuming a stable age distribution, to determine the likely population size given the observed number of pups produced. However, at the time of development there were no estimates of key demographic parameters for NZSL (e.g., female reproductive rate and juvenile survival probability), hence they assumed particular distributions for these parameters based upon expert knowledge and estimates from other otariid species. However, data is now available with which these parameters can be estimated. Hence in this project it is proposed to apply the Gales and Fletcher (1999) method, but with demographic parameter estimates that are specific to NZSL. The full time-series of population estimates dating from the mid-1990’s will be reanalysed using the revised model. As part of the reanalysis, the sensitivity of the general approach to some key assumptions used in the population model will also be evaluated, e.g., age of first reproduction.

Recent mean estimates of total population size for NZSL (Chilvers 2007) essentially mimic the trajectory of the estimate pup production numbers (mean total size is approximately 4.73 times the pup production estimates from 1997-2007; Table 1). This should not be unexpected given the current estimation methods. This reliance on the pup production estimates as the basis for estimating total population size has some undesirable features. Most notably is that for long-lived species with low fecundity, reproductive output is often one of the more variable, and elastic life history traits. As such, annual changes in pup production may be a poor indicator of changes in the size of the adult population.

Table 1: Estimated pup production numbers, mean total population size and ratio of the 2 quantities. Values reproduced from Chilvers (2007)

Season	Pup Production	Mean Total Population Size	Ratio
94/95	2640	12797	4.85
95/96	2807	13606	4.85
96/97	3097	14661	4.73
97/98	3143	14868	4.73
98/99	2989	14163	4.74
99/00	2978	14104	4.74
00/01	2980	14108	4.73
01/02	2404	11376	4.73
02/03	2902	13719	4.73
03/04	2899	13716	4.73
04/05	2533	11995	4.74
05/06	2474	11709	4.73
06/07	2609	12348	4.73

However, the manner in which the tag-resight data has been collected may provide an alternative approach to directly estimate adult population size. Each breeding season, beaches are surveyed on multiple days with a record being kept of which animal was seen on each day. As tags last for multiple seasons (tag loss excepted), then the tag-resight data is collected at two time scales; 1) annually, between which it is presumed additions and deletions to the adult population occur; and 2) within breeding seasons were additions and deletions are presumed negligible. This basic field methodology creates the type of tag-resight data that is commonly referred to (in mark-recapture literature) as Pollock's robust design where the breeding seasons are the primary sampling periods and daily surveys the secondary sampling periods (Pollock 1982, Williams et al. 2002). At present, the within season resights are not utilised, with the data bring aggregated to the level of seen/not seen each breeding season, which is then used to estimate annual survival rates. However, by considering the data at the finer resolution then it may be possible to estimate additional demographic parameters, including annual estimates of population size; possibly at the level of specific age-sex categories (e.g., adult females) to provide estimates of the size of desired sub-populations. Exactly how this could be done depends on the nuances of the field protocols, which still needs to be discussed with Louise Chilvers, DOC. Regardless, by exploiting the tag-resight at the finer scale it may be possible to simultaneously estimate population size and survival rates within a common framework.

Direct estimation of population size has the advantage of not relying upon the key assumptions used by Gales and Fletcher (1999; e.g., stable age distribution, age of first reproduction is 4) and provides an estimate of population size that is independent of the pup production estimates (and as indicated above, in combination with an estimate of pupping rate, provide a second estimate of pup production). An important assumption of Pollock's robust design is that within the period of daily resightings each breeding season the population is closed (no additions or deletions from the population), which could be violated by the late arrival of animals, or their early departure. However an approach has recently been developed by Kendall and Bjorkland (2001) for an analysis of sea-turtle mark-recapture data at nesting beaches that allows this assumption to be relaxed. Their method allows animals to arrive on the beaches after the daily surveys have begun, and permanently leave the nesting beach before the succession of the surveying. Such an approach may be applicable for the NZSL.

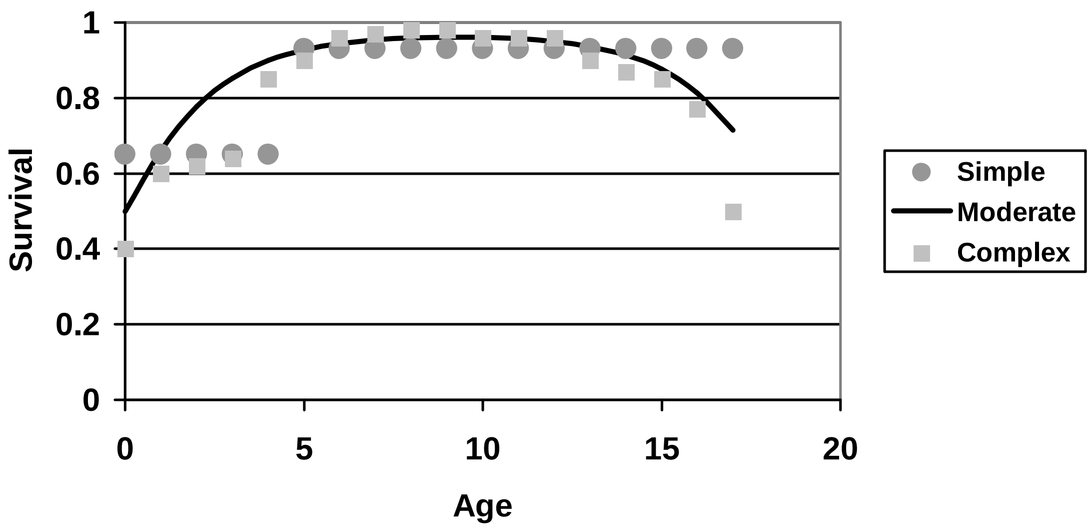
Survival of Previously Marked Individuals

Survival rate will be estimated from the tag-resight data using appropriate mark-recapture techniques. An important consideration however is the loss of flipper tags. Unaccounted for, tag loss will cause survival probabilities to be underestimated (Williams et al. 2002) as animals that loose both tags will no longer be identifiable unless they are branded or PIT tagged. Furthermore, animals with different combinations of flipper tags, PIT tags and brands are likely to have different resighting probabilities. This variation in resighting rates can cause further bias in estimated survival rates if unaccounted for. To accommodate for all of this, a multi-state mark-recapture analysis will be used (Arnason 1972, 1973; Nichols et al. 1992) where ‘state’ is defined by the number of tags remaining on the animal that year (which may obviously change). Using this approach all tagging cohorts from 1997/98 onwards will be analysed simultaneously. This general approach to the analysis of the tag-resight data has recently been used by MacKenzie and Chilvers (in prep) who estimated tag loss rates in excess of 13% per annum, which would result in survival being underestimated by 10%-15% if it was not possible to identify individuals by brands and PIT tags.

Using the multi-state mark-recapture framework with known-age individuals it is possible to allow survival rates to vary by age, and include annual variation. Age structure may be very simple (e.g., different rates for juveniles and adults), complex (e.g., age specific rates) or something in between (e.g., a non-linear relationship between survival and age; Figure 1). In consultation with Louise Chilvers (DOC) and other relevant experts, we shall comprise a list of 5 (or less) realistic age structures that will be included in the analysis and represented as different models which will be formally compared using Akiake’s Information Criterion (AIC) or similar metric. The intent of such metric is to find which models provide the most parsimonious description of the data; to avoid models that are too simplistic or over-parameterised. It should be noted however, that there is likely to be relatively few older individuals in the tag-resight data set which may be problematic for obtaining reliable survival rate estimates for older animals.

In addition to age structure, it is important that annual variation in survival is also considered. It may be essentially constant in all years over the period of the data collection, be different in particular years corresponding to suspected drivers (e.g., mass-mortality years), or vary each year. In combination with the 5 age-structure models, these 3 annual variation models combine to give 15 possible models associated with survival rates that will be ranked according to AIC.

Figure 1: Three hypothetical relationships between age and survival rates; different rates for juveniles and adults (simple), non-linear (moderate) and age-specific (complex).



Note that it is likely that the above survival rate analysis using the multi-state mark-recapture framework will be incorporated into the analysis for estimating population size to utilise the tag-resight data to its fullest extent.

Reproduction of Known Age Females

Reproductive output of females can also be estimated using the multi-state mark-recapture framework, where current breeding status is used to define the states (e.g., breeder/non breeder). As with the estimation of survival rates, there are likely to be a number of plausible functional relationships between age and breeding probabilities that could be fit to the tag-resight data and formally compared. In addition to age structure, annual variation and allowing the probability of the first breeding attempt to be different to the probability of rebreeding could also be considered as part of the model set. Clearly it is necessary to also account for survival rates in the analysis of reproductive output, and given the same general framework, it is likely to be advantageous to combine the estimation of these two demographic parameters into a single analysis.

An important consideration, however, is the potential for misidentifying breeding females as non breeders, particularly if the female is only resighted a couple of times during a breeding season (i.e., females that are seen more often during a year may be less likely to be misclassified as having not reproduced). A similar situation occurred during a study of a population of Florida manatees which provided the impetus for Kendall et al. (2003) to extend the multi-state model to account for potential misclassification of state by utilising the additional information from having data collected under Pollock's robust design. The basic rational behind the approach of Kendall et al. (2003) is that within a season a female manatee was either a breeder or a nonbreeder. In order to be classified as a breeder, the cow had to be observed in close proximity or nursing a calf on at least one survey occasion during the breeding season. However, even if the cow had a calf, on any given survey occasion when the cow was observed, there was a non-negligible probability that it would not be seen with the calf, thus it would appear to be a non-breeder. Over the course of a season, for those cows that had only been sighted a few times, there may still be a fair degree of residual uncertainty associated with whether or not she was truly a non-breeder, or a breeder that had never been observed with her calf. By utilising the additional information from the within season observations, Kendall et al. (2003) were able to show that it was possible to estimate the misidentification rate and thereby improve their estimates of breeding probability. After accounting for the potential misclassification of cows, the estimated breeding probability was twice the value estimated without accounting for misclassification. As the tag-resight data for NZSL has also been collected in a similar manner, with identification of 'breeders' dependent on observed behaviour with nearby pups, similar biases in breeding probabilities may result if the potential misclassification is not accounted for.

Recruitment to the Breeding Female Population

This can be estimated as part of the above analysis (as the probability of reproduction could vary with age), with an additional feature being that for females of the same age, the probability of first reproduction is different from the probability of subsequent reproduction. One output of this portion analysis would be to estimate the distribution for the age of first reproduction.

Summary

Clearly there is some degree of overlap in the proposed methods of analysis for estimating the different demographic parameters. The tag-resight data is potentially a rich source of information that is best utilised by analysing it within a multi-state mark-recapture framework. Theoretically, it should be possible to estimate survival and breeding rates while accounting for both tag loss and breeder misidentification, and possibly population size depending on exact field methods. Initial attempts at the analysis will focus on estimating all the relevant demographic parameters in the single framework.

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